__Original Research Article__

Soil biodiversity: influence of soil management systems

ABSTRACT

Aim: Soil represents one of the most diverse habitats found on our planet. Soil organisms play crucial roles within ecosystems by exerting influence over physical properties and processes, as well as contributing to carbon and energy fluxes and the cycling of nutrients. The activity and composition of soil organisms are significantly impacted by land use and land management practices. In this study, we examined the predominant functional groups present in soil two different soil management systems viz., organic and integrated nutrient management (INM).

Methods: We collected soil samples from coconut-based cropping systems under organic soil management and integrated nutrient management. Soil samples were characterised for soil macrofauna, mesofauna, microfauna and microflora.

Result: The presence of soil macrofauna, mesofauna, microfauna, and microflora was more pronounced under organic management. Furthermore, the PERMANOVA analysis indicated that while management practices did not significantly impact community dissimilarity in the study area, the depth of the soil did have a significant influence.

Conclusion: Although the PERMANOVA analysis within the light conditions examined, revealed that the influence of management practices on community dissimilarity was not statistically significant, it was noted that organic management led to an enhancement in soil biodiversity. The results of this study offer a comprehensive evaluation of the manner in which the organic management and INM practices influence the biodiversity of the soil.

Keywords: *Soil biodiversity, organic management, integrated nutrient management, soil macrofauna, mesofauna, microfauna, microflora*

1. INTRODUCTION

Soil constitutes one of the most ecologically diverse habitats on our planet, comprising a higher level of biodiversity per unit area compared to biodiversity found above the ground. Soil contains the majority of the biodiversity found in agricultural systems (Brussaard et al., 2007). These soil organisms engage in various interactions with each other as well as with plants and small animals, thereby creating a complex network of biological processes. The extent of soil biodiversity is highly variable across different regions of the world due to factors including but not limited to atmospheric conditions, temperature, acidity levels, moisture levels, nutrient composition, and the presence of organic matter. It is worth noting that soils serve as an extraordinary habitat, potentially harbouring more than ten thousand species per square meter (Orgiazzi*et al.,* 2016).

Soil biodiversity encompasses the diversity found among living beings, which includes a multitude of organisms that cannot be observed without the aid of visual aids, such as microorganisms like bacteria, fungi, protozoa, and nematodes, as well as mesofauna like acari and springtails. Additionally, it includes the more recognizable macrofauna, such as earthworms and termites.

Organic nutrient sources not only serve to supplement the nutrients of plants but also uphold a favourable soil environment of physical, chemical, and biological nature. The requirement for basal application of Farm Yard Manure (FYM) in order to sustain an optimum fertility status has been demonstrated by long-term experiments with fertilizers (Ranjan et al., 2020). The regular utilization of organic inputs in conjunction with a decreased amount of chemical fertilizer has the potential to enhance the chemical and biological traits of soil within the rice-wheat rotation. Specifically, the incorporation of fortified compost with a minimal quantity of chemical fertilizer resulted in an enhancement of soil enzyme activities, microbial biomass carbon, microbial population, and organic carbon concentration in the soil within this rotation (Nath et al., 2011).

Measuring soil biodiversity is of paramount importance as a greater species diversity is indicative of a healthy ecosystem. The presence of numerous, diverse, and active soil organisms serves as a pivotal indicator of a well-functioning soil. Despite the significance of comprehending soil biodiversity, this particular field of soil science has not been thoroughly explored. Investigating the interrelationships within this domain is crucial due to the substantial influence that soil biodiversity has on soil characteristics. Hence, a study was conducted in order to explore the biodiversity status of soil under organic and integrated nutrient management (INM) systems.

The proposed study area encompassed coconut-based cropping systems of AEU 8 (southern laterites) in Thiruvananthapuram district, Kerala, India,under both organic and integrated soil management practices. In this study, we measured the abundance of different groups of organisms including macrofauna (earthworms), mesofauna (acari and collembola), microfauna (nematode), microflora (bacteria, fungi and actinomycetes) and beneficial microorganism (*Azospirillum*) from both management practices. With these data, we aimed to estimate the prevailing functional groups in the soil.

2. MATERIALS AND METHODS

2.1 Location and soil sample collection

Soil samples were collected from coconut-based cropping systems under organic soil management in the Model Organic Farm, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani (Site 1) and also from coconut-based cropping systems under integrated nutrient management in the Instructional Farm, College of Agriculture, Vellayani (Site 2).

Soil samples were collected from each field using a soil core sampler with a diameter of 7 cm. From each site, 10 composite soil samples each was collected from 0-15cm, 15-30cm and 30-60 cm depth. The soil cores were hammered into the soil at the respective depths. The soil of the same depth was then pooled for the estimation of soil biodiversity from each site.

2.2Soil Biodiversity Estimation

For the estimation of earthworms from the soil, blocks of soil 20 x 20 cm, in three layers to depth of 60 cm was dug out (0-15cm, 15-30 cm, 30-60 cm). Earthworms were hand-sorted and preserved in 70% ethanol in the field. The number of earthworms were counted and recorded in terms of number m^{-2} (Buckerfield, 1992). All other macrofauna except earthworms was estimated by hand sorting from the pooled sample.

The soil mesofauna like acari and collembolawere extracted from the samples using modified Berlese-Tullgren funnel extractor (Macfadyen, 1961).Soil sample was taken and placed on a wire guaze over a steep sided funnel. Soil was heated gently using 40 watts bulb. Heating was continued for a day. The arthropods moved down in response to the temperature gradient created and eventually got collected in a collecting vial containing ethanol-water mixture kept at the tail of the funnel. The content of the collecting vial was directly transferred to a counting dish and their population counted under a stereo microscope.

Microfauna which includes nematodes were extracted from soil samples following the modified method of Cobb's decanting and sieving technique (Christie and Perry, 1951). The soil weighing 200 g was transferred to a plastic basin and mixed thoroughly in one litre water. Coarse particles and foreign materials wore allowed to settle for a few seconds. The suspension was then decanted through a twenty mesh sieve and the materials collected in the sieve and the sediments in the basin were discarded. The filtrate was allowed to stand for a few seconds and then passed through a hundred mesh sieve and the catch in the sieve was collected. The sediments in the basin after three washings were discarded. The filtrate was again allowed to stand for a few seconds and then decanted and passed through two hundred mesh sieve and then through three hundred and fifty mesh sieve. The fine silt and nematodes collected in these sieves were washed down into a beaker using minimum quantity of water.

The preserved suspension of nematodes was shaken well and one ml was taken and transferred to a counting slide by means of a pipette. Then the population of nematodes was counted and recorded.

For the estimation of microflora, the serial dilution agar plating method outlined by Timonin (1940) was adopted. For the isolation and enumeration of the microorganisms, the following media were used.

Bacteria - Nutrient agar

Fungi - Martins' Rose Bengal agar

Actinomycetes - Ken knight's agar

Azospirillum - Nitrogen free Bromothymol blue (NFB) agar

2.3 Statistical analysis

PERMANOVA (Permutational Multivariate Analysis of Variance) in conjunction with the Bray-Curtis dissimilarity index was employed to determine variation in functional group community composition among different sampling locations. Analysis was performed using the `adonis2` function in R. t- test was performed on soil biodiversity (macrofauna, mesofauna, microfauna and microflora) of the two sites. Correlation analysis between soil biodiversity and soil quality and plant nutrient availability was worked out.SIMPER (Similarity percentages-species contributions) was carried out. t-test and correlation analysis were performed using KAU GRAPES software tool (Gopinath *et al*., 2021).

3. RESULT

3.1 Soil biodiversity

Different types of organisms which fall under macrofauna, mesofauna, microfauna and microflora were observed from both organic and INM soil samples. A decrease in the count of each organism was found with increase in soil depth.

3.1.1 Soil macrofauna under organic management and INM

Among the macrofauna observed at a soil depth of 0-15 cm, it was found that annelids, hymenopterans, and dermapterans exhibited higher abundance in organic soil. Among these organisms, a significant difference in population was observed only for annelids and hymenopterans, with a p-value less than 0.05 (Table 1). Isopods, myriapods, and carabids were exclusively observed in organic soil. Annelids and myriapods were the only organisms observed at a soil depth of 15-30 cm in both organic management and integrated nutrient management (INM). Annelids were significantly more abundant in organic management compared to INM, while myriapods were found solely in organic soil. At a depth of 30-60 cm, only annelids were observed among the macrofauna, and their abundance was significantly higher in organic soil with a p-value less than 0.05 compared to INM.

Table 1. Effect of organic management and INM on macrofauna population (no. m^{-2} soil)

Depth	0-15 cm						15-30 cm		30-60 cm
Organi	Anneli	Hymenopt	Isopo	Dermapt	Myriapo	Carabid	Anneli	Myriapo	Anneli

sm	da	era	da	era	da	ae	da	da	da
Organic	40.00	6.00	1.33	17.33	17.33	8.67	26.67	8.67	16.67
INM	23.33	2.67	0.00	8.67	0.00	0.00	10.00	0.00	3.33
t-value	5.00	5.00	-	0.71	-	-	5.00	-	2.83
P-value	0.01**	0.01**	-	0.52	-	-	0.01**	-	0.05*

** indicates significance at 5% level*

*** indicates significance at 1% level*

3.1.2 Soil mesofauna under organic management and INM

The mesofauna group, including acari and collembola, displayed a greater presence in organic management and exhibited significant variation among the samples at a soil depth of 0-15 cm (p value < 0.05) (Table 2). Similarly, at a soil depth of 15-30 cm, the mesofauna followed a comparable pattern to that observed in the surface soil, wherein all of these organisms were significantly more abundant in organic soil (p value < 0.05). Among the mesofauna observed at a depth of 30-60 cm, acari were found only in organic management, while collembola were present in both organic management and INM, yet were noticeably more abundant in organic soil (p value < 0.05).

Table 2. Effect of organic management and INM on mesofauna population (no. m^{-2} soil)

Depth	0-15 cm		15-30 cm		30-60 cm	
Organism	Acari	Collembola	Acari	Collembola	Acari	Collembola
Organic	3983.33	4939.33	2656.00	3154.00	1453.33	1816.67
INM	2674.67	3146.67	1317.33	1811.33	0.00	346.67
t-value	5.84	5.04	5.73	5.74	-	2.93
P-value	0.00**	0.01**	0.01**	0.00**	-	0.04**

** indicates significance at 5% level*

*** indicates significance at 1% level*

3.1.3 Soil microfauna under organic management and INM

Among microfauna, nematodes were observed and was found to be significantly higher in organic than INM soil at all the three depths (p value < 0.05) (Table 3).

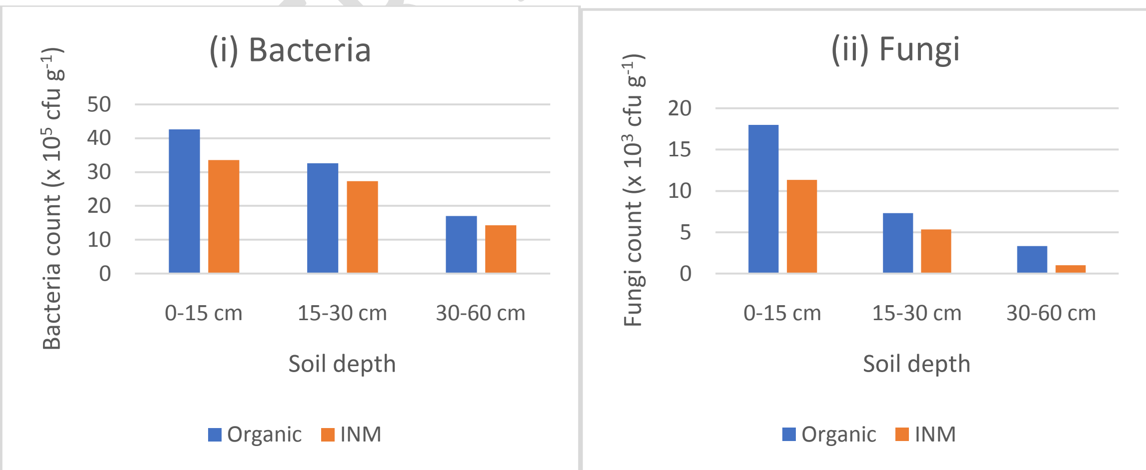
Table 3. Effect of organic management and INM on microfauna(nematode) population (no. m^{-2} soil)

Depth	0-15 cm	15-30 cm	30-60 cm
Organic	231830.00	129895.00	51775.00
INM)	134913.30	79565.00	39866.67
t-value	32.86	10.55	6.63
P-value	0.00**	0.00**	0.00**

*** indicates significance at 1% level*

<u>3.1.4 Soil microflora under organic management and INM</u>

Microflora including bacteria, fungi, actinomycetes and *Azospirillum* were cultured and enumerated from both soil samples. All these organisms were found to be significantly higher in organic management (p value < 0.05) compared to INM in both surface and subsurface soil (Fig 1.). At 30-60 cm soil depth, bacteria and actinomycetes were significantly higher in organic soil (p value < 0.05). Fungi demonstrated a higher prevalence in the organic management, although there was no statistically significant variance observed among the soil specimens. *Azospirillum* was observed only in organic soil at this depth.



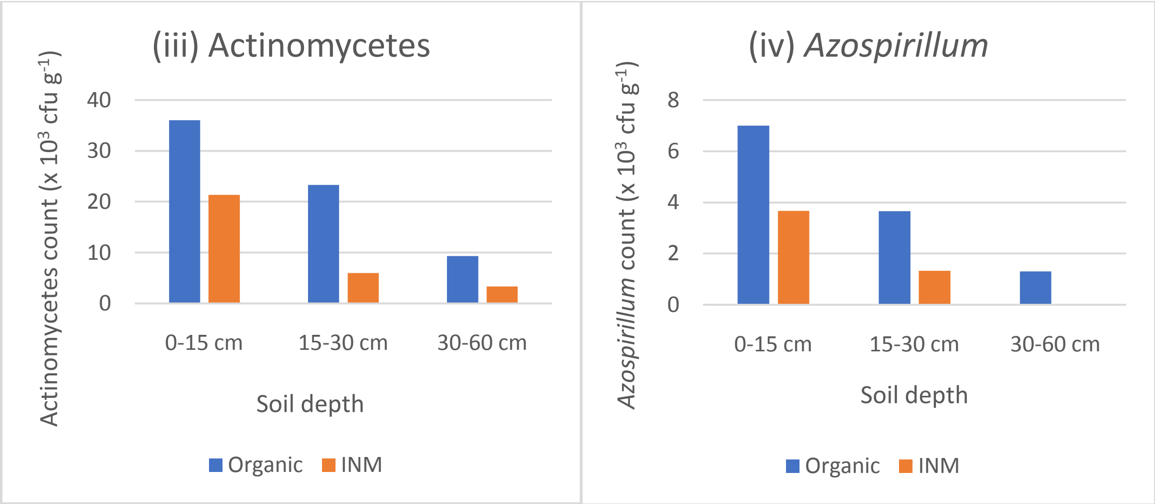


Fig 1. Effect of organic management and INM on microflora ((i) bacteria (ii) fungi (iii) actinomycetes (iv) *Azospirillum*) population

3.2 Statistical analysis

From the analysis of the Bray Curtis dissimilarity index, it can be observed that the average dissimilarity in biodiversity was recorded at 0.262 when comparing the surface soil under organic management and INM (Table 7). This observation indicates the presence of differences in species composition, albeit with some shared species or similarities to a certain extent. Furthermore, at a soil depth of 15-30 cm, the dissimilarity in biodiversity between the organically managed and INM soils was measured at 0.243, which then decreased to 0.156 at a depth of 30-60 cm.

Table 4. Bray Curtis dissimilarity indices between the biodiversity observed in organic management and INM at three soil depths

	S1D1	**S1D2**	**S1D3**	**S2D1**	**S2D2**
S1D2	0.279				
S1D3	0.628	0.423			
S2D1	0.262	0.018	0.438		
S2D2	0.489	0.243	0.203	0.260	
S2D3	0.714	0.543	0.156	0.556	0.346

S1- Organic (Site 1); S2- INM (Site 2); D1- 0-15 cm (Depth 1); D2- 15-30 cm (Depth 2); D3- 30 60 cm (Depth 3)

The PERMANOVA analysis showed that the factor "depth" had a substantial and statistically significant impact for dissimilarity in organism composition. This factor accounted for approximately 77.53% of the variation in organism composition, with an F-statistic of 25.771, and p-value of 0.011 (Table 5). On the other hand, the factor "management" did not make a significant contribution to community dissimilarity (The R2 value = 0.109, the F-statistic = 3.636, and the p-value = 0.147). Similarly, the interaction term "management × depth" did not have a significant role in explaining community dissimilarity (R2 value = 0.055, F-statistic = 1.834, and p-value = 0.236). In this context, "depth" was identified as a crucial factor influencing organism composition, whereas "management" and its interaction with "depth" were not found to be significant. This suggests that, within the examined light conditions, specific management practices did not exert a strong influence on the variation in organism composition.

Table 5. PERMANOVA results showing variation in functional group community composition among different sampling locations and soil depths

	Df	SS	R2	F	Pr(>F)
Management	1	0.047	0.109	3.636	0.147
Depth	1	0.333	0.775	25.771	0.011
Management: depth	1	0.024	0.055	1.834	0.236
Residual	2	0.026	0.060	NA	NA
Total	5	0.429	1	NA	NA

SIMPER analysis plays a crucial role in identifying key species responsible for the observed dissimilarities in community composition. From the Bray Curtis dissimilarity index, SIMPER analysis is performed over different pairs of depth to identify contributions from individual species, ranking them by their influence on the observed differences or similarities. As the average contribution is highest for nematode in results of SIMPER analysis, it can be concluded that nematode is the species that contributes the largest amount of the difference between 0-15 cm and 15-30 cm soil depths (Table 6)and also between 15-30 cm and 30-60 cm soil depths(Table 7).

Table 6. SIMPER analysis between 0-15 cm and 15-30 cm soil depth

	Average contribution	SD	Ratio	avA	avB	cumsum	p
Nematode	0.252	0.185	1.36	183371.7	104730	0.963	0.89
Collembola	0.005	0.004	1.282	4043	2482.665	0.982	0.935

Acari	0.004	0.004	1.274	3329	1986.665	0.999	0.912
Annelida	0.001	0.0006	1.448	31.665	18.335	1	0.868
Dermaptera	0.001	0.0002	4.451	13	0	1	0.112
Myriapoda	0.001	0.0008	1.219	8.665	4.335	1	0.512
Hymenoptera	0.001	0.0002	3.524	4.335	0	1	0.112
Carabidae	0.001	0.0011	0.861	4.335	0	1	0.468
Isopoda	0.001	0.0011	0.861	0.665	0	1	0.468
Actinomycetes	0.002	0.0009	1.12	4.445	4.07	1	0.912
Azospirillum	0.001	0.0008	1.17	3.7	3.33	1	0.912
Fungi	0.002	0.0007	2.889	4.15	3.795	1	0.935
Bacteria	0.003	0.0013	1.481	6.58	6.5	1	0.979

Table 7. SIMPER analysis between 15-30 cm and 30-60 cm soil depth

	Average contribution	SD	Ratio	avA	avB	cumsum	p
Nematode	0.361	0.131	2.749	104730	45820.84	0.955	0.512
Collembola	0.009	0.007	1.274	2482.665	1081.67	0.978	0.579
Acari	0.008	0.006	1.37	1986.665	726.665	1	0.535
Annelida	0.004	0.0022	1.774	18.335	10	1	0.601
Dermaptera	0.001	0.0011	0.865	4.335	0	1	0.668
Myriapoda	0.001	0.001	0.947	3.33	1.55	1	0.29
Hymenoptera	0.002	0.0017	1.123	3.795	2.81	1	0.224
Carabidae	0.002	0.0012	1.702	4.07	3.74	1	0.401
Isopoda	0.002	0.0006	3.156	6.5	6.22	1	0.001
Actinomycetes	0.005	0	NA	0	0	1	0.935
Azospirillum	0.004	0	NA	0	0	1	0.668
Fungi	0.006	0	NA	0	0	1	0.935
Bacteria	0.007	0	NA	0	0	1	0.668

4. DISCUSSION

Soil macrofauna was observed to be greater in fields managed organically as compared to those managed using integrated nutrient management (INM). The notable increase in the population of earthworms in organic fields is primarily associated with the quantity of organic matter provided, which, as reported by Hendrix et al. (1992), exhibits a positive correlation with earthworm abundance. According to Kiss et al. (2021), the enhanced abundance of earthworms can be attributed to the higher content of soil organic matter and lower bulk density, which in turn creates soil conditions more conducive to the proliferation of earthworms. Soil isopods and millipedes exemplify a substantial degree of effectiveness in the decomposition of organic material and further exhibit the capability to partake in excavating activities within the layer of litter. The outcomes of this investigation were in line with preceding inquiries, substantiating the claim that the abundance and composition of soil organisms exhibited a significant correlation with the concentration of organic material in the soil, and were also interconnected with soil structure, particularly the volume of pores (Walmsley & Cerda, 2017).

The population of both acari and collembola exhibited a notably greater magnitude in organically managed environments when compared to those managed with integrated nutrient management (INM), in both surface and subsurface soils. This observation aligns with the findings of Krogh (1994), who similarly reported a higher prevalence of microarthropods, specifically springtails and mites, in organic farming systems as compared to integrated and conventional farming systems. The elevated abundance of mesofauna in organic management can be ascribed to the lower application of chemicals and pesticides in organic farming, as indicated by Hansen et al. (2001). Furthermore, the existence of soil organic matter (SOM) has the potential to promote the presence of predator communities by directly enhancing the complexity of structural habitats and the microclimate present at the soil surface, thereby attracting and conserving predators (Aldebron et al., 2020). Several studies involving altered animal densities have demonstrated that the actions of collembolans have a notable impact on the turnover of carbon and nitrogen in the soil, as well as on respiration and the growth of plants. Furthermore, these activities are subject to the influence of environmental conditions and frequently exhibit a mitigating effect (Filser, 2002).

Soil microfauna, specifically nematodes, exhibited significantly higher levels in organic management as compared to INM across all soil depths. According to Yeates (1979), nematodes are known for their prevalence, diversity, and ubiquity within the soil ecosystem. The population of nematodes is influenced by the quantity of litter biomass (Dash and Pradhan 1984), which provides a wider range of food sources, a greater amount of organic matter, and a larger fungal biomass (Behera and Dash 1980), as well as bacterial biomass. The presence of organic matter plays a significant role in the ecology of nematodes (Norton 1978), and there is a noteworthy positive correlation between soil nematodes and the percentage of soil organic carbon (Yeates 1979).

The count of microflora, including bacteria, fungi, and actinomycetes, exhibited a higher value in the soil managed with organic methods compared to that managed under integrated nutrient management. The outcomes of this study align with the findings of Mahanta et al. (2013), which indicated a greater microbial population in plots treated with farmyard manure (FYM) as opposed to plots treated with nitrogen, phosphorus, and potassium (NPK) fertilizers. The amplified microbial population observed in the organic field can potentially be attributed to the presence of organic manures, which act as sources of organic carbon, facilitating the accumulation of microbial populations. Additionally, another plausible explanation could be the advantageous secretions originating from root, such as carbohydrates, amino acids, organic acids, and various substances fostering growth. These secretions serve as nourishing substrates for microorganisms (Choudhary et al., 2022).

Azospirillum have the ability to fix atmospheric nitrogen and also mineralize nutrients from the soil, sequester iron, withstand harsh environmental conditions, and promote beneficial associations between mycorrhizal fungi and plants. Moreover, *Azospirillum* plays a role in mitigating the adverse impacts of abiotic stresses on plants (Saikia et al, 2012). The presence of *Azospirillum* population was observed to be notably greater in the organically managed field in both surface and subsurface soils. In general, the utilization of organic inputs stimulated the development of beneficial microorganisms and intensified the overall activity of the soil. This increase in population may likely be attributed to the improved availability of organic substrates essential for the proliferation of microbial communities (Bunemann et al., 2006).

CONCLUSION

The agricultural management practices have a direct influence on the activity and composition of soil organisms. Despite the finding from the PERMANOVA analysis that community dissimilarity was not significantly affected by INM and organic management practices, it was noted that the organic management approach led to an improvement in soil biodiversity. Hence, the observationspresented in this study provide valuable insights into the ecological mechanisms that operate within the designated research region. Moreover, they underscore the significance of taking into account various factors, such as soil management practices and depth, when evaluating the makeup of organisms in this context. As the substantial contribution of soil organisms in the functioning of the soil ecosystem is undeniable, efforts should be undertaken to safeguard the vitality harboured within the soil.

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