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DIVERSITY AND ECOLOGICAL ROLE OF SOIL MICROARTHROPODS IN CASHEW FOREST ECOSYSTEMS FROM RAMNAGAR, WEST BENGAL, INDIA

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Abstract. In agricultural environments such as cashew forests, soil microarthropods are crucial for the maintenance of ecosystem functionality and soil health. The widespread distribution of soil microarthropods and their varying degrees of adaptation render them effective indicators for evaluating soil ecosystem health. Soil samples were obtained from different depths in ten selected sites in the Ramnagar block, West Bengal, India, and assessed for microarthropod presence by utilising standard extraction techniques. This paper provides the first comprehensive study of the diversity, abundance, and ecological functions of soil microarthropods within cashew forest ecosystems from this region. During the one-year study period (February 2024 – January 2025), 24 taxa were documented. The seasonal and functional group-wise abundance of microarthropods in different layers of soil and their relationship with soil moisture, temperature, pH and organic carbon content were evaluated. The highest abundance of microarthropods was recorded from the 0–10 cm soil layer. Decomposers were the most abundant functional group, followed by predators and detritivores. Abundance peaked during the monsoon season (June–September). The ANOVA test indicated spatial heterogeneity with respect to diversity and abundance among the ten sampling sites. While soil moisture and organic carbon content showed a positive correlation with both abundance and diversity of microarthropods, pH had a negative impact. The study emphasises the need for maintaining soil biodiversity in agroforestry systems and offers baseline data for further studies on the management and preservation of soil ecosystems in cashew-producing areas.

INTRODUCTION

Soil is home to diverse and abundant living communities, providing them with food, shelter, anchoring, and concealment (Wallwork 1970). Exceptional diversity and ecological attributes of microarthropods have attracted the attention of researchers worldwide (Norton 1994; Bhattacharya and Chakraborty 1994). Soil microarthropods are vital to terrestrial ecosystems due to their significant influence on soil health, nitrogen cycle, and overall ecosystem functionality. These tiny but varied organisms, which include springtails (Collembola) and mites (Acari), as well as other tiny arthropods, flourish in the soil matrix and aid in the production of soil structure and organic matter turnover, as well as decomposition. Arthropods have multiple roles in soil, including pulverising, litter transforming, and ecosystem engineering (Bagyaraj et al. 2016). Soil fertility, which is critical for agricultural production and ecosystem resilience, is maintained by their activities, which increase microbial populations and facilitate the decomposition of organic materials.

Cashew (*Anacardium occidentale*) plantations create a distinctive ecological habitat characterised by complex and dynamic interactions between soil organisms and plant community. The cashew cultivation in this part of West Bengal gained popularity as it provides a profitable source of income to the rural people. The long-term sustainability of agroforestry systems is significantly dependent on soil health and biological diversity, especially the less apparent elements like microarthropods.

Currently, there is very little information available about the roles of soil microarthropods and their abundance in cashew forests. Developing sustainable farming methods that improve soil health and ecosystem services requires the understanding of the community structure and functional roles of soil microarthropods in these ecosystems. The current study seeks to investigate the diversity, distribution, and ecological functions of soil microarthropods within cashew forest ecosystems in the Ramnagar block of the Purba Medinipur district in West Bengal. This research aims to elucidate the community makeup and functional activities of these groups, thereby enhancing

the understanding of their contributions to soil fertility and sustainability in cashew farming, which will contribute to soil management and conservation strategies.

MATERIALS AND METHODS

Study site

The research was carried out in cashew forest ecosystems within the Ramnagar block of the Purba Medinipur district. The region has a tropical climate characterised by distinct wet and dry seasons, with cashew (*Anacardium occidentale*) being a significant crop grown in this area. The research location was chosen to exemplify standard cashew agroforestry systems characterised by different levels of soil moisture, temperature, pH and organic carbon. The present study was conducted from the 1st of February 2024 to the 31st of March 2025.

Sampling process, microarthropod extraction and identification

Soil samples were obtained from 10 randomly chosen plots within the cashew forest. Each area was 10 meters by 10 meters. From the study sites, soil samples were routinely collected at three depths: 0–10 cm, 10–20 cm, and 20–30 cm, once a month between 8:00 am 10:00 am. A 5 cm steel corer was used to collect the samples, which were then stored in separate sterile plastic bags for subsequent examination. To collect soil microarthropods, a modified Tullgren funnel equipment was utilised, along with a 25W electric lamp. After bringing the soil samples to the lab, they were carefully placed on the mesh above the funnel. Then, the collecting vial with preservation liquid was inserted beneath the funnel. The liquid composition was 2 parts 75% ethanol and 1 part glycerol. There was zero tolerance for vibration and outside interference throughout the whole extraction system. Soil microarthropods were extracted for a period of 72 hours. Microarthropods were stored in vials with preservation liquid and were identified using Julka's (2016) taxonomic keys under a stereoscopic binocular microscope (Brand-EISCO, Model- STR-TRI3). Based on their ecological roles, specimens were arranged into 3 functional groups – decomposers, predators, and detritivores.

Soil physicochemical analysis

The key physico-chemical characteristics, such as soil moisture content, organic carbon content, pH, and soil temperature were examined in a fraction of each soil sample in order to understand how microarthropod communities are distributed in relation to soil conditions. Soil temperature and pH were measured with the help of digital soil survey instrument (Brand- D2N, Model- 4 in 1 digital soil meter moisture, sunlight and temperature tester for plant use 3). Soil moisture was measured with a digital meter (HTC-01). Soil organic carbon was measured by following Walkley Black method.

Data analysis

A statistical analysis was performed to evaluate the diversity and abundance of soil microarthropods at various soil depths and locations. One-way analysis of variance (ANOVA) was employed to assess differences in microarthropod diversity and abundance across soil layers and sampling plots. Pearson's correlation was used to analyse the link between microarthropod diversity and soil physicochemical characteristics. For the creation of graphs, tables and statistical analysis like one-way ANOVA and Pearson's correlation, MS-WORD, MS-EXCEL and GraphPad prism8 software were used.

RESULTS

The present study revealed various microarthropod taxa in the cashew forest ecosystem of the Ramnagar area, categorized into 3 functional groups – decomposers, detritivores, and predators with their individual and cumulative abundance recorded across months. Eleven taxa and 1516 individuals belonged to the decomposers category which was dominated by Acaridae (267), Collembola (234) and Oribatida (179). Detritivores comprised 7 taxa and 977 individuals, where Chilopoda (207), Diplopoda (180) and Isopoda (164) were dominant taxa. Predators were represented by 6 taxa and 1156 individuals, where Pseudoscorpiones (272), Thysanoptera (219) and Carabidae (179) were dominant taxa (Table 1). The decomposers (41.5% of the total abundance) dominated the community structure, followed by predators (31.7%) and detritivores (26.8%). Abundance increased steadily from January to September, peaking during the monsoon months (June–September).

The highest total abundance was recorded in the 0–10 cm soil layer (1670), followed by 10–20 cm (1067), and the lowest in 20–30 cm (912). Decomposers were dominant in the 0–10 cm layer (990), with a sharp decline in deeper layers (355 in 10–20 cm and 171 in 20–30 cm). The abundance of predators increased marginally as the depth increased, from 365 (0–10 cm) to 401 (20–30 cm). The distribution of detritivores across strata was relatively consistent, with a range of 315 (0–10 cm) to 340 (20–30 cm). The Shannon index demonstrated that the diversity of organisms was highest in the 10–20 cm soil layer (1.10), followed by 20–30 cm (1.04), and most minimal in the topsoil (0.96) (Figure 1).

The soil temperature decreased with depth, from 26°C in the topsoil to 24.6°C at 20–30 cm. The moisture content also decreased with depth, from 33.2% in the topsoil to

Table 1. Seasonal and group-wise abundance of soil microarthropod taxa in cashew forest ecosystem of Ramnagar area.

Functional groups	Taxa name	Abundance												Total
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Decomposers (11)	Oribatida	10	9	13	13	12	17	22	23	21	22	9	8	179
	Mesostigmata	7	6	11	11	13	15	17	19	17	20	7	6	149
	Prostigmata	7	6	10	9	13	18	17	20	18	19	5	5	147
	Collembola	12	13	15	19	21	24	24	27	27	28	13	11	234
	Hypogastruridae	5	3	6	6	8	11	15	17	19	19	4	4	117
	Entomobryidae	3	4	3	5	7	12	14	14	17	15	2	1	97
	Sminthuridae	4	4	7	8	11	11	12	14	15	15	3	3	107
	Acaridae	12	14	16	18	23	27	31	35	33	30	15	13	267
	Trombidiformes	2	3	3	4	4	6	9	12	13	12	1	1	70
	Tetranychidae	4	3	4	4	3	7	7	9	8	8	2	2	61
	Cryptostigmata	5	5	8	6	9	8	9	9	11	9	5	4	88
	Sub-total	71	70	96	103	124	156	177	199	199	197	66	58	1516
Detritivores (7)	Formicidae	3	4	7	14	15	15	17	17	18	16	7	3	136
	Trogidae	3	2	4	7	7	10	12	13	16	13	6	3	96
	Diplopoda	9	9	10	13	14	17	21	25	24	20	11	7	180
	Chilopoda	10	11	12	15	18	22	25	26	26	19	12	11	207
	Isopoda	7	7	10	11	14	15	18	21	22	20	10	9	164
	Symphyla	5	4	7	10	11	13	14	14	11	12	6	3	110
	Scarabaeidae	4	4	5	6	8	8	10	11	11	9	5	3	84
	Sub-total	41	41	55	76	87	100	117	127	128	109	57	39	977
Predators (6)	Lycosidae	3	7	10	16	19	19	21	23	24	19	9	2	172
	Carabidae	8	8	9	13	16	18	24	24	26	21	8	4	179
	Staphylinidae	5	7	8	11	12	15	19	21	25	19	9	4	155
	Pseudoscorpiones	10	12	15	19	24	29	33	34	34	32	21	9	272
	Linyphiidae	8	8	9	12	13	15	19	20	24	21	7	3	159
	Thysanoptera	10	11	14	14	17	18	25	29	29	27	18	7	219
	Sub-total	44	53	65	85	101	114	141	151	162	139	72	29	1156
		156	**164**	**216**	**264**	**312**	**370**	**435**	**477**	**489**	**445**	**195**	**126**	**3649**

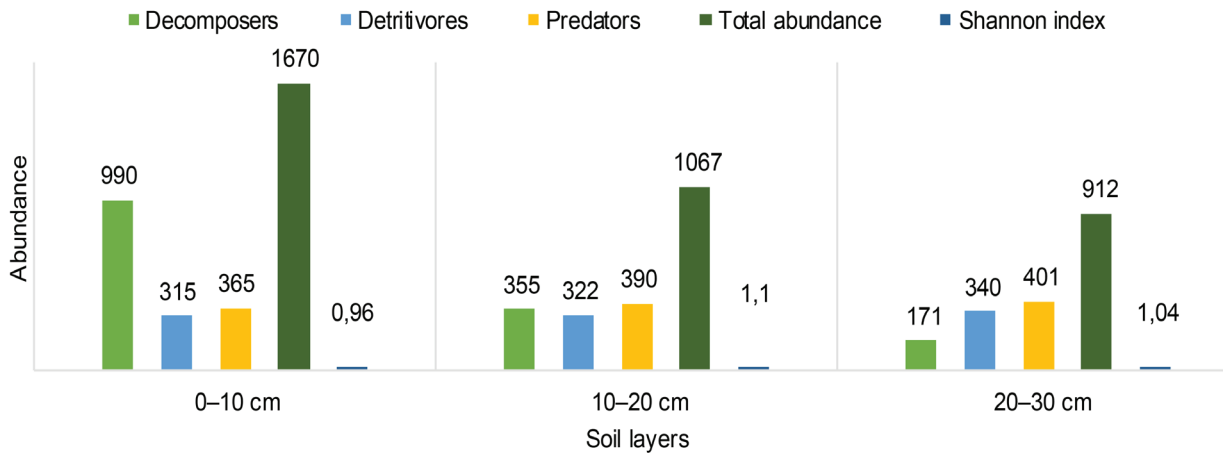

Figure 1. Abundance and diversity of three functional groups across different soil layers.

Table 2. Variation in microarthropod diversity, abundance, soil temperature, moisture, pH and organic carbon values across different soil layers.

Soil depth	Abundance of microarthropods	Diversity of microarthropods (H′)	Mean soil temperature (^{0}C)	Mean soil moisture (%)	Mean soil pH	Mean organic carbon (%)
0–10 cm	1670	0.96	26	33.2	6.27	2.13
10–20 cm	1067	1.10	25.3	31.5	6.43	1.76
20–30 cm	912	1.04	24.6	30.2	6.53	1.22

Table 3. Correlation matrix showing relationship between soil parameters, microarthropod diversity and abundance across soil layers.

	Abundance of microarthropods	Diversity of microarthropods (H′)	Soil temperature (^{0}C)	Soil moisture (%)	Soil pH	Organic carbon (%)
Abundance of microarthropods	1	-0.804	0.946	0.968	-0.981	0.906
Diversity of microarthropods (H′)	-0.804	1	-0.569	-0.631	0.673	-0.478
Soil temperature (^{0}C)	0.946	-0.569	1	0.997	-0.991	0.994
Soil moisture (%)	0.968	-0.631	0.997	1	-0.998	0.983
Soil pH	-0.981	0.673	-0.991	-0.998	1	-0.971
Organic carbon (%)	0.906	-0.478	0.994	0.983	-0.971	1

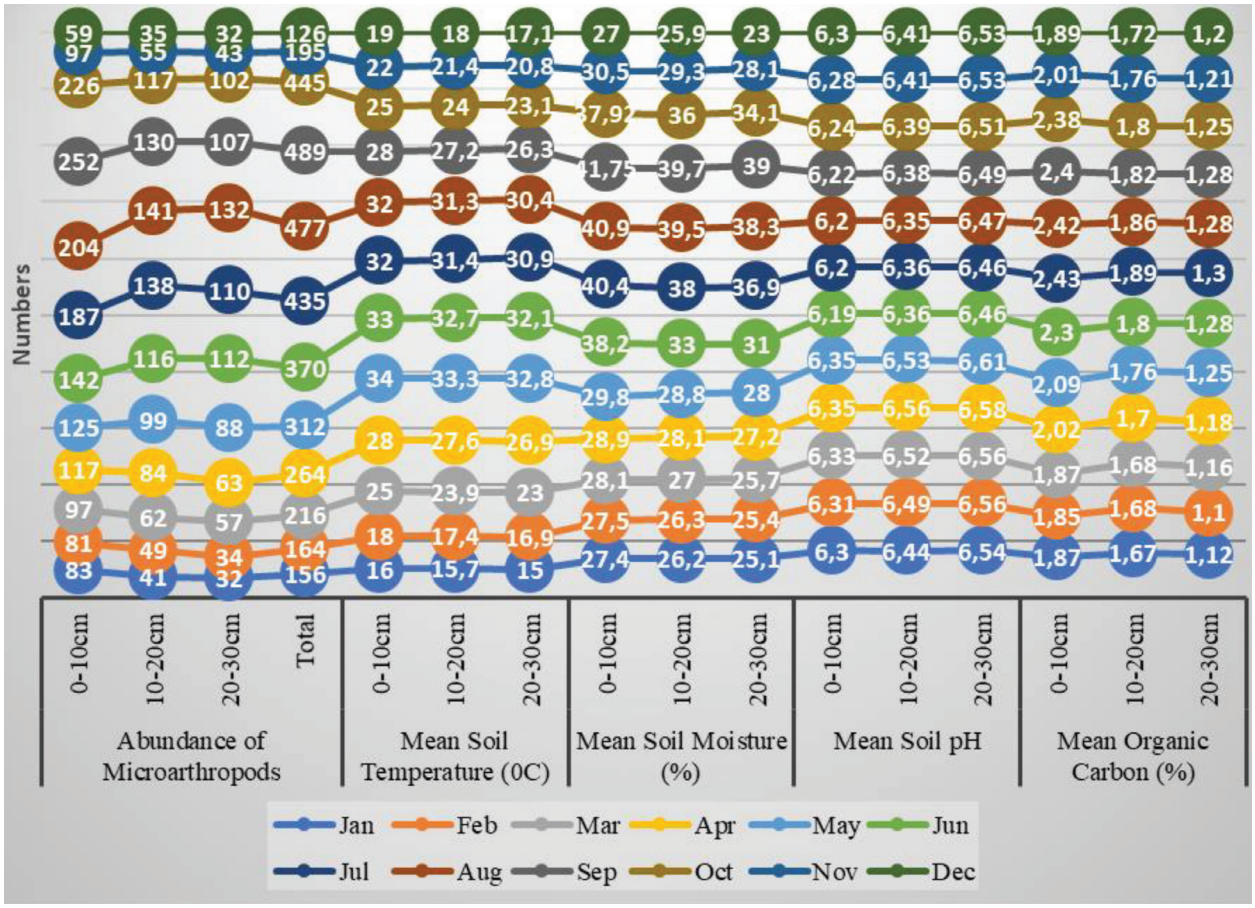

Figure 2. Seasonal variation in microarthropod abundance, soil temperature, moisture, pH and organic carbon across different soil layers.

30.2% at 20–30 cm. The soil pH became progressively less acidic with depth, ranging from 6.27 in the topsoil to 6.53 at 20–30 cm. With depth, the amount of organic carbon dropped dramatically, going from 2.13% in the 0–10 cm layer to 1.22% at 20–30 cm (Table 2).

Correlation analysis (Pearson correlation r) revealed that microarthropod abundance was strongly influenced by soil moisture, temperature, organic carbon (positively), and pH (negatively), but diversity exhibited an inverse relationship with abundance and was moderately affected by soil temperature, moisture, and pH (Table 3). Soil parameters were highly interdependent, particularly between temperature, moisture, and pH. Optimal conditions for microarthropod abundance seemed to align with high moisture, moderate temperature, slightly acidic pH, and rich organic carbon content.

One-way ANOVA indicated a considerable disparity in organism abundance among the three soil levels (0–10 cm, 10–20 cm, and 20–30 cm). The substantial F-statistic ($F = 5.823$, $P = 0.007$) demonstrated that the soil strata influenced the variance in abundance observed. The R^2 value of 0.261 indicated that roughly 26.1% of the overall variation in abundance was attributable to changes among the soil layers, whereas the remaining 73.9% was affected by within-group variability or other environmental factors (Table 4).

Table 4. One- Way ANOVA results showing differences in soil physicochemical and biological parameters across soil layers.

Parameters	Source of variation	SS	DF	MS	F	*P*-value	*P*-value summary	R^2	Significant difference among means ($P < 0.05$)?
Abundance	Treatment (between columns)	26728	2	13364	5.823	0.007	***	0.261	Yes
	Residual (within columns)	75737	33	2295					
	Total	102464	35						
Temperature (°C)	Treatment (between columns)	11.62	2	5.812	0.149	0.862	ns	0.009	No
	Residual (within columns)	1284	33	38.89					
	Total	1295	35						
Moisture content (%)	Treatment (between columns)	56.01	2	28.01	0.864	0.431	ns	0.049	No
	Residual (within columns)	1069	33	32.39					
	Total	1125	35						
pH	Treatment (between columns)	0.392	2	0.196	51.76	< 0.0001	****	0.758	Yes
	Residual (within columns)	0.125	33	0.004					
	Total	0.517	35						
Organic carbon (%)	Treatment (between columns)	5.032	2	2.516	111.2	< 0.0001	****	0.871	Yes
	Residual (within columns)	0.746	33	0.023					
	Total	5.778	35						

The ANOVA results indicated that the mean temperatures across the three layers (0–10 cm, 10–20 cm, and 20–30 cm) had no statistically significant differences [$F(2, 33) = 0.149$, $P = 0.862$]. This absence of substantial temperature variation indicated that the temperature was relatively consistent across the soil layers under investigation, which contributed marginally to the observed variations in microarthropod abundance. The low R^2 value (0.009) further confirmed that the preponderance of the variability was attributable to other factors, with less than 1% of the temperature variation being explained by differences among soil layers (Table 4). The non-significant *p*-value ($p = 0.431$) of the ANOVA results demonstrated that, in the investigated cashew forest, the soil moisture content (%) did not substantially vary between the soil layers (0–10 cm, 10–20 cm, and 20–30 cm) (Table 4). The ANOVA results also demonstrated substantial differences in soil pH among the three soil strata in the cashew fields ($F = 51.76$, $p < 0.0001$). In accordance with the high R^2 value of 0.7583, the soil strata' differences accounted for nearly 75.8% of the total variability in soil pH (Table 4). The ANOVA results indicated that the organic carbon content (%) of the soil strata in the cashew forest varied significantly ($F = 111.2$, $p < 0.0001$). The high R^2 value of 0.871 suggested that the differences between the soil strata were responsible for approximately 87.1% of the variability in organic carbon content (Table 4).

The diversity and species richness of three functional groups of soil microarthropods–decomposers, detritivores, and predators – are highlighted in Figure 3 through the use of diversity indices (Shannon diversity index, H′, and Margalef's index). Decomposers dominated both in diversity and species richness, followed by detritivores and predators.

Table 5 displays the abundance of diverse taxa throughout ten sampling sites (SS1–SS10) inside the cashew agroecosystem. The predominant taxon was Pseudoscorpiones (total abundance: 272), consistently observed in substantial quantities across all locations, with maximum counts at SS6 (33) and SS8 (30). The rareness and absence of Trombidiformes at SS10 set it apart as the least common taxon (total abundance: 70). Other prevalent taxa were Acaridae (267), Collembola (234), and Thysanoptera (219), all of which were widely spread and regularly seen in different locations. For many species, including Acaridae, Chilopoda, Pseudoscorpiones, and Thysanoptera, SS6 stands out as a site with the highest abundance. The taxa Formicidae, Diplopoda, and Lycosidae showed more consistent distributions across sites. There were notable differences across sites for taxa like Trombidiformes and Scarabaeidae. The abundance of microarthropods ranged from 246 (SS1) to 489 (SS6). The diversity index (H′) was consistent and relatively high across all sites, ranging from 3.02 to 3.13. The diversity index of SS6 was the highest at 3.13, while SS1 had the lowest at 3.02 (Figure 4).

Results from the analysis of variance indicated spatial heterogeneity in the distribution of taxa, as there was a significant difference in the abundance of taxa among the 10 cashew field sample sites ($F = 3.657$, $p = 0.0003$). Despite the statistical significance of the discrepancies, site-specific variables only accounted for 12.5% of the abundance variability ($R^2 = 0.125$) (Table 6).

Table 7 highlighted the variability in soil temperature,

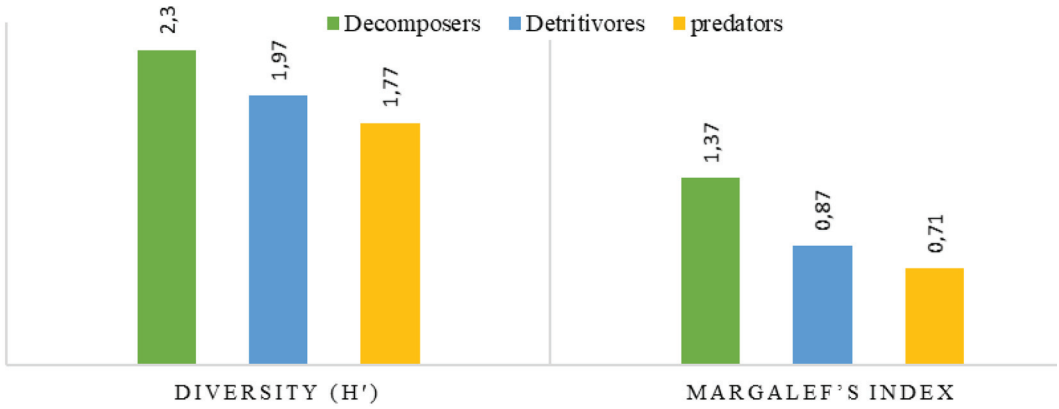

Figure 3. Functional groups and their Shanon and Margalef's index values.

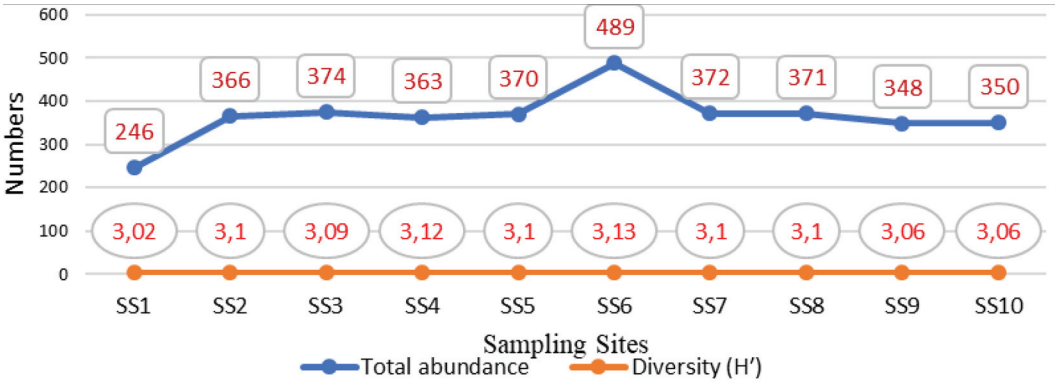

Figure 4. Total abundance and diversity of microarthropods across different sampling sites.

Table 5. Abundance of various taxa across different sampling sites in cashew forest.

Taxa name	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9	SS10
Oribatida	12	14	21	18	17	26	20	20	18	13
Mesostigmata	14	16	13	15	15	18	14	17	13	14
Prostigmata	11	17	15	11	15	18	16	17	15	12
Collembola	20	25	22	23	23	28	23	25	23	22
Hypogastruridae	9	13	10	12	11	15	13	11	12	11
Entomobryidae	7	11	8	10	9	13	10	12	9	8
Sminthuridae	7	10	12	13	10	14	11	10	8	12
Acaridae	20	29	26	24	26	33	27	29	25	28
Trombidiformes	4	6	9	6	7	13	6	7	12	0
Tetranychidae	0	6	4	8	6	14	6	10	0	7
Cryptostigmata	6	7	9	10	9	15	11	7	6	8
Formicidae	8	12	11	15	16	19	16	15	10	14
Trogidae	9	12	11	9	9	13	8	9	7	9
Diplopoda	11	19	20	18	18	23	17	16	20	18
Chilopoda	14	23	22	20	21	27	18	22	16	24
Isopoda	11	15	18	16	18	23	14	17	15	17
Symphyla	7	10	14	9	10	16	12	10	9	13
Scarabaeidae	0	10	7	11	9	12	8	9	11	7
Lycosidae	11	17	19	19	17	22	13	18	20	16
Carabidae	12	16	20	18	18	23	19	16	19	18
Staphylinidae	10	15	13	17	15	21	17	14	15	18
Pseudoscorpiones	19	27	28	25	27	33	30	27	29	27
Linyphiidae	10	14	18	16	19	22	19	13	16	12
Thysanoptera	14	22	24	20	25	28	24	20	20	22

Table 6. ANOVA results for abundance differences among sampling sites in cashew forest.

ANOVA table	SS	DF	MS	F	*P* value	*P* value summary	R^2	Significant diff. among means ($P < 0.05$)?
Treatment (between columns)	1260	9	140.0	F = 3.657	*P* = 0.0003	***	0.125	Yes
Residual (within columns)	8807	230	38.29					
Total	10067	239						

Table 7. Variation in soil temperature, moisture, pH and organic carbon across different sampling sites in cashew forest.

Sampling Sites	Mean soil temperature (^{0}C)	Mean soil moisture (%)	Mean soil pH	Mean organic carbon (%)
SS1	25	23	6.45	1.54
SS2	30	31	6.31	1.91
SS3	32	27	6.38	1.84
SS4	31	38	6.31	2.28
SS5	32	34	6.30	1.95
SS6	29	40	6.24	2.31
SS7	31	32	6.33	2.03
SS8	30	31	6.37	2.08
SS9	26	25	6.39	1.73
SS10	25	24	6.39	1.72

Table 8. Correlation between abundance, diversity and soil parameters across sampling sites in cashew forest.

	Mean soil temperature (^{0}C)	Mean soil moisture (%)	Mean soil pH	Mean organic carbon (%)	Abundance	Diversity (H′)
Mean soil temperature (^{0}C)	1	0.634	-0.585	0.623	0.448	0.766
Mean soil moisture (%)	0.634	1	-0.922	0.953	0.743	0.911
Mean soil pH	-0.585	-0.922	1	-0.847	-0.853	-0.904
Mean organic carbon (%)	0.623	0.953	-0.847	1	0.782	0.943
Abundance	0.448	0.743	-0.853	0.782	1	0.846
Diversity (H′)	0.766	0.911	-0.904	0.943	0.846	1

soil moisture, soil pH, organic carbon content at ten sampling sites (SS1–SS10). The mean temperature of the soil varied from 25°C to 32°C, with SS3 having the highest mean temperature at 32°C and SS1 and SS10 having the lowest at 25°C. The moisture content of the soil ranged from 23% to 40%, with SS6 having the maximum moisture content at 40% and SS1 having the lowest at 23%. The cashew forest's soil pH was comparatively consistent across sites, ranging from 6.24 to 6.45. The organic carbon content of the samples ranged from 1.54% to 2.31%, with SS6 exhibiting the highest value (2.31%) and SS1 the lowest (1.54%).

Table 8 displays the correlation matrix for soil characteristics (temperature, moisture, pH, and organic carbon) and their association with the abundance and diversity (H′) of microarthropods at the sampling sites inside the cashew forest. Soil moisture and organic carbon content were the primary factors positively related with microarthropod abundance and diversity. Soil pH was identified as a limiting factor, exhibiting negative associations with abundance and diversity. In comparison to soil moisture and organic carbon content, soil temperature had a milder impact.

DISCUSSION

The seasonal and group-specific abundance (Table 1) of soil microarthropods in the cashew forest ecosystem of the Ramnagar region emphasised their functional roles, temporal fluctuations and ecological importance. The patterns of diversity and abundance across the seasons indicated environmental and ecological changes. The present study revealed that decomposers had the highest abundance. Baillie et al. (1990) also suggested their high abundance and vital role in nutrient recycling by breaking down organic matter. Behan-Pelletier (1999) indicated the dominance of taxa such as Oribatida and Acaridae in the nutrient-rich litter layer in the agroecosystem, which is in accordance with the current study. Seasonal peaks in abundance of microarthropods during the monsoon and post-monsoon months (June–October) could be attributed to increased organic matter availability and moisture content, which favour microbial activity and detritus decomposition. Lavelle and Spain (2001) also obtained similar results. Detritivores, with a total abundance of 977 individuals, contribute to litter fragmentation and enhance microbial activity (Brus-

saard 2021). The current study showed the abundance of taxa like Diplopoda and Chilopoda which may be due to their ability to adapt to varied soil microhabitats. Seasonal peaks during the monsoon period suggested that higher moisture levels improve their activity and reproduction. David (2014) obtained similar findings while researching the role of litter-feeding macroarthropods in decomposition processes. The current study highlighted the high abundance of predators, which is very significant as they regulate the population of other soil fauna and maintain ecological balance (Wardle et al. 2004). Taxa such as Pseudoscorpiones and Lycosidae exhibited higher abundance during late monsoon and post-monsoon seasons, most likely driven by the availability of prey. Their abundance reflected a healthy soil ecosystem with complex trophic interactions (Coleman et al. 2004). This study indicated a significant drop in abundance during the colder and drier months of January and December. Wardle (2002) suggested that reduced microbial activity and prey availability during this period may be responsible for such findings. The observed variety and abundance of the current study are consistent with findings from other tropical agroecosystems where soil microarthropods follow similar seasonal trends (Baillie et al. 1990).

Soil microarthropod diversity and abundance across three soil layers (0–10 cm, 10–20 cm, and 20–30 cm) showed unique ecological patterns influenced by functional group dynamics and habitat features. In the topsoil (0–10 cm), decomposers were most prevalent, with 990 individuals. However, the number of decomposers decreased significantly in the deeper strata. This trend is indicative of the fact that decomposers are more dependent on surface organic matter and litterfall, which are more abundant in the topsoil (Anderson and Ingram 1989). The current study revealed that the distribution of detritivores throughout the soil strata was comparatively uniform. Their capacity to use broken-up organic materials that seep through the soil profile may be the cause of this trend (Brussaard 2021). Predators exhibited heightened abundance with depth, reaching a maximum in the 20–30 cm stratum (401 individuals). This may be ascribed to the existence of prey species and microhabitats in deeper strata (Wardle 2002). The result of the present study revealed the 0–10 cm layer as the most abundant, followed by the 10–20 cm and 20–30 cm layers. This pattern highlighted the topsoil's biological significance as a hotspot for nutrient cycling and organic matter breakdown. Lower organic matter concentration and restricted oxygen availability may be the cause of decreased abundance in deeper strata (Lavelle et al. 2006). The calculated Shannon index revealed maximum diversity in the 10–20 cm layer (1.10), succeeded by the 20–30 cm layer (1.04) and the topsoil (0.96). In contrast to the topsoil, the mid-layer's greater diversity might be the result of a balanced distribution of functional groups and less interspecific competition (Behan-Pelletier 1999).

The relatively even Shannon index values across layers indicate a well-balanced soil ecosystem, as seen in the studies of other forest ecosystems (Baillie et al. 1990). As the depth increased, the soil temperature decreased from 26°C in the subsoil to 24.6°C at 20–30 cm. Wardle et al. (2004), while working on ecological linkages between above ground and below ground biota, suggested that the metabolic rates and activity levels of soil organisms are influenced by temperature. The study's findings indicated that the topsoil's maximum moisture content (33.2%) is conducive to the activity of microarthropods, particularly decomposers and detritivores. The activity and distribution of certain taxa may be restricted by the reduction of moisture at greater depths (Wall and Moore 1999). With depth, soil pH raised somewhat and became less acidic (6.27 at 0–10 cm to 6.53 at 20–30 cm). This slow transition reflects leaching processes and lowered organic acid accumulation in deeper layers, therefore affecting the makeup of soil microarthropod populations (Swift et al. 1979). Organic carbon content showed the steepest decline, from 2.13% in the topsoil to 1.22% in the 20–30 cm layer. Lavelle and Spain (2001) opined that the strong association between organic carbon and microarthropod abundance underscores the dependence of soil fauna on organic matter as a primary energy source. Substantial connections between the number and variety of microarthropods and critical soil factors, including soil temperature, moisture, pH and organic carbon were observed in the present study. These findings correspond with the comprehensive ecological concept of microarthropod habitats and their environmental requirements. Microarthropods prefer warm, humid environments, as evidenced by the abundance's significant positive association with soil temperature (r = 0.946) and moisture (r = 0.968). According to Lavelle et al. (2006), high soil moisture probably offers favourable microhabitats, sufficient food supplies, and protection against desiccation. The significant correlation with organic carbon (r = 0.906) suggests that soils abundant in organic matter serve as an essential resource for detritivores as well as other microarthropods. Briones et al. (1997), while researching the effect of climate change on soil fauna, obtained similar results. The pronounced negative correlation with soil pH (r = -0.981) indicates that slightly acidic soils may facilitate greater abundance, most likely owing to increased decomposition rates and nutrient availability in these environments (Zhu and Shen 2023). In the present study, microarthropod diversity (H′) exhibited moderate negative correlations with soil temperature (r = -0.569) and moisture (r = -0.631), which may indicate that extreme conditions favour the dominance

of specific taxa, thereby reducing evenness and overall diversity. Furthermore, the moderate positive correlation with soil pH ($r = 0.673$) implies that diversity may increase marginally in less acidic conditions, potentially expanding the niche range of multiple species (Gonzalez et al. 2010). However, in carbon-rich soils, where dominant species outcompete others, the slight negative association with organic carbon ($r = -0.478$) might indicate mechanisms of competitive exclusion. A closely connected relationship is indicated by the virtually perfect positive correlation ($r = 0.997$) between soil temperature and moisture and their high negative correlations ($r = -0.991$ and -0.998, respectively) with soil pH. Bardgett and van der Putten (2014) opined that warmer and wetter soils tend to be more acidic, which may have an impact on nitrogen cycling and, in turn, microarthropod populations. The robust association of soil organic carbon with temperature ($r = 0.994$) and moisture ($r = 0.983$) underscores its significance as a predictor of soil biota, since increased organic content augments microbial activity and offers a reliable food source for microarthropods (Behan-Pelletier 1999).

The ANOVA table (Table 4) shows a lack of considerable temperature change across soil layers, which corresponds with results from analogous research in tropical and subtropical areas, where temperature gradients in superficial soil layers are frequently negligible (Molnar 2022; Zhang et al. 2024). Davidson and Janssens (2006) opined that the combined effects of soil temperature and moisture on enzymatic activity and microbial biomass further underscore the importance of considering these parameters together rather than in isolation. Abiotic and biotic variables such as soil texture, organic matter content, root density, and evapotranspiration rates affect soil moisture. Cashew trees' root systems often penetrate many soil layers, which could uniformise the moisture content at multiple layers (Kühnhammer et al. 2023). Hasselquist et al. (2018) and Demo and Bogale (2024) opined that canopy cover, surface mulching techniques, and rainfall patterns can all contribute to the uniform distribution of moisture across soil strata, as demonstrated in analogous agroforestry systems. It is evident that the fluctuation in moisture content may be more significantly influenced by other factors than soil depth, as evidenced by the low R^2 value of 4.98%. The soil's texture, comprising the ratios of sand, silt, and clay, influences both water retention capacity and percolation rate (Hillel 2003). In cashew-growing regions, sand-rich soils may facilitate faster water infiltration, leading to less moisture fluctuation across strata (Abu-Zreig et al. 2020). The distribution of organic matter, the discharge of minerals and the presence of root exudates can cause fluctuation in soil pH with depth. As organic acids are produced during decomposition, the topsoil (0–10 cm) usually has a higher amount of organic matter, which lowers pH (Weil and Brady 2016). The present study is also in agreement with this. Due to lower concentrations of organic acid and a greater leaching of acidic ions like hydrogen (H^+) and aluminium (Al^{3+}), subsurface layers (10–20 cm and 20–30 cm) frequently have higher pH values (Jiang et al. 2018; Dvořáčková et al. 2022). The influence of root activity may also be reflected in the observed pH stratification. Deep-rooted cashew trees absorb nutrients and emit root exudates, therefore changing the pH in deeper soil layers (Sun et al. 2024).

ANOVA results for organic carbon revealed decreasing values with increasing soil depth. Weil and Brady (2016) claimed that reduced organic matter inputs and higher rates of decomposition in deeper layers cause organic carbon content to generally drop with depth. Plant debris, root exudates, and microbial activity all contribute to the topsoil's high organic carbon levels. Litterfall from the tree canopy is frequently observed in cashew plantations, which contributes to the enrichment of the topsoil with organic matter (Pankaj et al. 2023). Ota et al. (2013) suggested that lower soil organic carbon contents are the result of limited organic matter deposition in the subsurface strata (10–20 cm and 20–30 cm). These findings are in agreement with the present study. Tian et al. (2022) claimed that the diminished organic carbon concentration in deeper strata correlates with decreased root activity, as the majority of fine roots are focused in the topsoil, leading to localised carbon enrichment. The observed trend of decreasing diversity and species richness from decomposers to predators is consistent with ecological theories of resource partitioning and trophic dynamics (Pollierer et al. 2021). The present study highlighted high species richness (Margalef's index = 1.37), as well as diversity ($H' = 2.3$) of decomposers, which may be due to their ability in decomposing organic matter and nutrient cycling (Lavelle and Spain 2001). The species richness (Margalef's index = 0.87) and diversity ($H' = 1.97$) of detritivores were moderate. According to Brussaard (1997), this group is essential for breaking down organic materials and promoting microbial decomposition. Their limited functional role and increased reliance on particular resources, such as partially decomposed litter, may be the cause of their lower values when compared to decomposers (David 2014). The lowest species richness (Margalef's index = 0.71) and diversity ($H' = 1.77$) were displayed by predators. As groups at higher trophic levels, their populations are inherently limited by the availability of prey and the inefficiencies of energy transfer within the food web (Wardle et al. 2004). In this group, taxa like Pseudoscorpiones and Lycosidae are usually dominant, and their lower richness is a reflection of ecological restrictions such as prey competition and habitat structure dependence (Coleman et al. 2004). Temperate and

tropical soils have reportedly shown similar trends of decreased variety and richness with rising trophic levels (Coleman et al. 2004).

Table 5 highlights variations in distribution and overall representation of various taxa across 10 sampling sites in the cashew agroecosystem. As predators, pseudoscorpiones aid in controlling the numbers of smaller arthropods, while Acaridae and Collembola are vital decomposers that support soil health and nutrient cycling (Wardle and Yeates 1993; Thakur and Geisen 2019). The current study aligned with these findings, as they were found in sufficient numbers. Tetranychidae and Trombidiformes were the least prevalent taxa, which may have been due to their sensitivity to environmental factors or particular habitat needs (Hillel 2003). The abundances of various of taxa, such as decomposers (Acaridae, Diplopoda) as well as predators (Pseudoscorpiones, Lycosidae), were consistently higher in SS6 and SS8. Studies by Kooijman et al. (2020), Kotroczó et al. (2023), and Wang and Kuzyakov (2024) suggested that increased organic matter content, improved moisture retention, or appropriate pH levels may be the reason for a high abundance of decomposers and predators.

The one-way ANOVA results (Table 6) demonstrated a substantial disparity in species abundance across the studied sites within cashew fields [$F(9, 230) = 3.657$, $P = 0.0003$]. Spatial heterogeneity in species distribution is supported by the low P-value (< 0.05), which indicated that at least one site had significantly different abundance from the others. While the remaining variance is probably attributable to other environmental or biological factors, the R^2 value of 0.125 indicates that 12.5% of the variance in abundance may be related to variations among sampling sites (Quinn and Keough 2002). The findings of the present study pointed out a possible impact of site-specific factors, including microclimate, soil composition, and anthropogenic activities, on abundance of taxa in cashew forests (Tilman et al. 1997; De Frenne et al. 2021).

Table 7 illustrates significant variation in soil temperature, moisture, pH and organic carbon content among the 10 sampling sites within the cashew forest. Elevated soil temperatures typically augment microbial activity, hence facilitating nutrient cycling and sustaining a higher number of microarthropods (Stres et al. 2008; Lindo 2015). In this work, the relationship between temperature and microarthropod abundance validates the results of other studies showing that moderate temperatures (around 30°C) encourage optimal microbial and arthropod activity (Pietikäinen et al. 2004; Ghiglieno et al. 2021). SS6 displayed the highest soil moisture content (40%), together with the greatest microarthropod abundance and diversity (489 individuals and $H' = 3.13$). This conclusion implies that increasing moisture levels produce more suitable conditions for decomposers and predators in the soil, therefore sustaining bigger and more varied populations of microarthropods (Hillel 2003). Heděnec et al. (2022) have also recorded similar results, noting that higher soil moisture improves the breakdown of organic materials, thereby supplying a consistent food source for soil fauna. In contrast, SS1, which had the lowest soil moisture (23%), contained the lowest diversity and number of microarthropods (3.02 and 246), most likely as a result of drier conditions that restrict the growth of microorganisms and the breakdown of organic matter. With a 2.31% organic carbon concentration, SS6 matched the large number and variety of microarthropods. Elevated organic carbon concentrations enhance microbial activity, subsequently sustaining a more substantial population of soil organisms (Zhou et al. 2023; Liu et al. 2023). From 6.24 to 6.45, the pH of soil was rather constant throughout all sampling sites, indicating a near-neutral pH fit for a broad spectrum of soil life. Based on past research, most microarthropod taxa indicate that neutral to slightly acidic soils are ideal since they offer a balanced habitat for both microbial populations and microarthropods (Hillel 2003). According to Dewangan et al. (2023), a pH range of 6.0 to 7.0 sustains significant biodiversity in agroecosystems. The constant pH values in this study indicated that soil pH may not be a limiting factor for microarthropod diversity. According to Shannon diversity index (H'), microarthropod diversity was lowest at SS1 ($H' = 3.02$) and highest at SS6 ($H' = 3.13$). Sites with greater nutrient availability and moisture content are likely to support more diverse and plentiful microarthropod populations, as indicated by the positive correlation found between organic carbon, soil moisture, and diversity (Wasserstrom et al. 2016; Ge et al. 2023). With more resources available for a broader range of taxa, the results aligned with the concept that higher degrees of organic carbon and moisture favour more complex food webs (Billings et al. 2021; Almela et al. 2023).

Table 8 presents the correlation between soil parameters and microarthropod diversity and abundance. The abundance and diversity of microarthropods were substantially influenced by soil moisture, as evidenced by the high positive relationships between these variables (0.743 and 0.911, respectively). Previous research repeatedly demonstrated that higher moisture levels promote greater diversity and richness of soil fauna (Aupic-Samain et al. 2020). Crucially important for decomposers like Collembola and Acaridae, the positive association between soil moisture and organic carbon (0.953) also supported the theory that moisture helps to maintain organic matter. Microarthropod diversity (0.943) and abundance (0.782) were highly positively correlated with organic carbon content, suggesting

that nutrient-rich soils with greater amounts of organic carbon sustain both bigger and more varied populations of soil fauna. A more stable and fruitful environment for soil fauna is produced by increased organic carbon, which also encourages soil aggregation and microbial activity (Xiao et al. 2017; Zhao et al. 2023). The results are consistent with findings of Neher and Barbercheck (2019) and Ge et al. (2023), who found that organic carbon has a significant role in determining soil biodiversity by affecting the availability of food as well as habitat for microarthropods. Microarthropod diversity (-0.904) and abundance (-0.853) showed strong negative correlation with the soil pH, which indicates that lower pH levels may suppress microarthropod populations. The observed patterns in this study may be explained by research by Rousseau et al. (2024) and Xiong et al. (2024), which showed that extreme pH values (either too acidic or too alkaline) are less conducive to a diversified and plentiful soil fauna population. Hillel (2003) asserted that acidic soils are typically less favourable for various soil species, as they may affect nutrient availability and microbial activity, leading to reduced ecological activity. Both abundance (0.448) and diversity (0.766) exhibited moderate correlations with soil temperature. According to Mondal (2021), soil organisms' metabolic rates are strongly influenced by temperature; mild temperatures, in general, encourage greater activity and fertility rates.

The need for integrated soil management for sustaining microarthropod populations is highlighted by the correlations identified among several soil characteristics, especially the strong associations between soil moisture and organic carbon. Sun et al. (2021) and Rossi et al. (2024) suggested that microarthropod diversity and organic carbon storage can both be improved by techniques that increase moisture retention, such as mulching or lessening soil compaction. Additionally, soil structure, microbial habitat, and biodiversity can all be improved by soil management techniques that maximise organic carbon content, such as lowering tillage or adding organic amendments (Frøslev et al. 2021; Hu and Pan 2023).

CONCLUSION

The abundance and microarthropod community structure in the cashew forest ecosystem of Ramnagar represent varied soil conditions, with 24 taxa being documented. As a functional group, decomposers were most dominant. The topsoil exhibited the highest abundance. Seasonal variations and soil physicochemical properties significantly influenced their distribution and abundance, indicating their sensitivity to environmental changes. Soil moisture along with organic carbon content improved their diversity and abundance; temperature had less of an impact, whereas soil pH hurt them. Their significance as bioindicators of soil quality and ecosystem stability is emphasised by the extensive diversity of soil microarthropods that have been observed in these cashew plantations. We should encourage sustainable farming techniques such as organic farming and reduced chemical inputs to maintain soil biodiversity and enhance ecosystem services. Future studies focusing on long-term monitoring and functional analysis of these microarthropods will further elucidate their ecological roles and contributions to soil fertility.

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