



Millipede Species Enrich the Fertility of Soil in Alagar Hills Reserve Forest

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ABSTRACT

Soil biota can interact with litter decomposition and significantly change nutrients of soil through egestion of faecal pellets. In the present study, interactions between soil fertility and millipedes occurrence in Alagar hills Reserve forest. Millipedes as detritivores significantly affect nutrient cycling through the redistribution of organic material and consequently, the release of biochemical elements such as N, P, K and calcium and reduce the level of carbon content and C/N ratio of the soil. Our field microcosm study included population density and estimation biochemical compounds. Considering the data on the occurrence of millipedes, two sites were identified at study area as Site I (with millipede occurrence) and Site II (without millipedes). The soil samples from both sites were subjected for the analysis of biochemical compounds such as organic carbon, nitrogen, phosphorus, potassium and calcium. The site which is occupied by millipede (site I) showed remarkably high quantity of nitrogen (2.14%), phosphorus (23.10%), potassium (0.24%) and calcium (0.83%) than the site without millipedes (site II) during the month of November 2016. Similarly, an ideal C/N ratio (20.05) was observed in site I which favours the plant growth, in turn increases the quantity of leaf litter which supports the life of millipedes. Millipedes play an essential role in enhancing the fertility of soil and ecosystem functioning in this tropical dry deciduous forest of Alagar hill (Eastern Ghats), South India. In forest ecosystem, conservation of millipede is an essential step to improve the fertility of soil and maintaining the forest ecosystem.

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Authors' Contribution

BR did hypothesis framing, reviewing the literature, protocol framing and collection of species. RG performed review of literature, data analysis and processing. BR and RG conducted the lab work together.

Key words

Alagar hills, Millipedes, Density, Eastern ghats

INTRODUCTION

Forest floor varies in the quantity of plant debris and this variation is attributed to spatial heterogeneity of soil biota in forest ecosystem because plant debris provides them with food and shelter (David *et al.*, 2006). Soil fauna are the important component in forest ecosystem, due to their functional role in the acceleration of organic matter, decomposition and nutrient transformation (Muneto *et al.*, 2004; Bardgett *et al.*, 2001). In the forest ecosystem, macro-arthropods ingest and accelerate the plant debris and nutritionally enriched the soil fertility (Nevo and Dror, 2021). The soil invertebrates have been shown to perform a significant character in plant litter decomposition in tropical forest (Liu and Zou, 2002). Soil macro creatures make significant commitments to the reusing of dead plant

material across the globe (Griffiths *et al.*, 2020). Decomposition process of plant residues is also influenced by substrate quality, decomposer community and environmental factors (Smith and Bradford, 2003). Shaw and Harte (2001) reported that litter decay and nutrient release are controlled by the litter quality, including the nitrogen (N) concentration of the litter, the carbon to nitrogen (C/N) ratio as well as other chemical properties.

Plant litter decomposition rates are often connected with lower C/N ratios and high nitrogen concentration (Mekonnen, 2020). On the other hand, soil macro-fauna gives a vital contribution to soil fertility by promoting the stability and productivity of forest ecosystem, mainly due to their influence on soil processes such as litter decomposition and nutrient dynamics (Nevo and Dror, 2021; Griffiths *et al.*, 2020). According to Bird *et al.* (2000), established arthropod communities stabilize the availability of nutrients to plants and change the physical conditions of the soil, which become more suitable for root growth and plant water uptake. These conditions are important for maintaining productivity. Wolters (2000) reported that millipedes, woodlice, earthworms and slugs are the major soil macro fauna demonstrated to increase the nutrient leaching from dead-leaf litter and enhance the humification of the soil. Millipedes and earthworms are called "litter transformers and ecosystem engineers"

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(Kaneko and Ito, 2004). Moreover, the significant character of millipedes in decomposition is to alter the physical and chemical atmosphere of the litter. Millipedes nourish by shredding leaf litter with tooth-like structures on paired mandibles, and then crushing the shredded material between smooth molar plates (Sridhar and Ashwini, 2016). The nutrient content of the consumed plant resources also alters in the route through the millipede gut; pH, moisture and bacterial fungal counts are higher in faecal pellets than in the ingested litter (Tajovsky and Wytwe, 2009).

In forest ecosystem, the pill millipede species, *Glomeris marginata* increase the microbial diversity simultaneously stimulating the nitrogen mineralization and enlistment of cations such as potassium and sodium (Andrew *et al.*, 2006). Besides, faecal pellet formation results in an increase the availability of nutrients such as nitrogen and phosphorous to microorganisms (Scheu *et al.*, 2005). Millipedes as detritivores, apparently affect nutrient cycling through the redistribution of organic material and, consequently, the release of chemical elements such as nitrogen in the soil (Sridhar and Ashwini, 2016). Since nutrient cycling is one of the key processes governing ecosystem dynamics (Tilman *et al.*, 2014), millipedes may have profound influences on ecosystem. However, in forest habitats the millipede communities are influenced by the type of humus (Meyer and Singer, 1997), nitrogen (Stasiov, 2005) and carbon content (Stasiov, 2002), carbon-nitrogen ratio (Branquart *et al.*, 1995), and pH of the soil (Smith *et al.*, 2006). Even though, millipedes are the significant fauna in forest ecosystem, so far no adequate information is available on role of millipedes in soil fertility of forest ecosystem in India. Therefore, the major objective of the present study is to investigate the role of millipedes in soil fertility of Alagar Hill Reserve Forest, Madurai, Tamil Nadu.

MATERIALS AND METHODS

Observation of field microcosm studies were conducted at Silambar valley of Alagar Hills Reserve Forest from June 2016 to May 2018. The study area, Algarmalai Hills is located in Madurai District, a part of the eastern plains of the Deccan plateau, has many minor discontinuous hill ranges and isolated iselbergs of the Eastern Ghats. The area surveyed (10°0'-10°30' and 75°55'-78°20'E) are 20 km north-east of Madurai city. Two sites were identified at a stretch of 100 m distance long and 100 m transect i.e. Site I (with millipede occurrence) and Site II (without millipedes). Soil samples were collected from 5 quadrats each with 1m × 1m size from site I and II. Soil with litter was excavated up to 10cm depth from each sampling point twice a month from

June 2016 to May 2018. For each study, different stretch of transects were used for assessment to avoid repeated sampling in the same site. The juvenile and adults of five millipede species, *Harpaphe haydeniana*, *Xenobolus carnifex*, *Arthrosphaera magna*, *Aulacobolus newtoni* and *Spinotarsus colosseus* were sampled in surface leaf litter.

The average number of individuals in the four quadrates of the study area was recorded. The mean of four such censuses collected in each month was considered the mean density of the population and expressed as number of individuals/m². The soil samples were brought to the laboratory in airtight polythene bags for analysis of biochemical composition of soil. Composite sample of soil was mixed with distilled water (1:2.5w/v) and then shaken for 10 minutes. The pH was measured on the sampling spot using potable pH Meter (Systronics model 335, India). To quantify the organic Carbon in the compost, Walkley and Black's rapid titration method was followed (Jackson, 1973). Total nitrogen was determined using MicroKjeldhal method (Umbreit *et al.*, 1974). Phosphorus was estimated by Vogel's technique (1963). Available potassium and calcium were detected using Flame Photometer (Elico; Model CL 378).

RESULTS

During the study period, maximum (34.2°C) and minimum (21.5°C) temperature were recorded in the month of May, 2017 and November, 2017, respectively. Whereas maximum (93%) and minimum (58%) humidity was recorded in November 2017 and May 2018, respectively. The highest rainfall (818.01mm) was observed in October 2017. The occurrence of millipede species was highest in November and it was found to decrease in the month of March to July. Density of five different millipede species was greater during 2016 – 2017 than 2017 – 2018 (Fig. 1). The meteorological parameters such as temperature and humidity significantly altered population density and biomass of millipedes. A critical comparison of rainfall with the data on population density and biomass did not provide any significant conclusion.

Data related to pH, organic carbon, nitrogen, phosphorus, potassium, calcium and C/N ratio in the study site I and II during the period June 2016 to May 2018 are presented in Tables I to II. The pH value is comparatively much higher in study site II (6.3 to 7.1) than the site I (5.4 to 6.3) from June 2016 to May 2018. In study site I, the percentage of organic carbon was greater (50.02%) in the month of July 2017 and was much less (43.87%) in November 2016. But in site II, it decreased from 48.32% to 36.18% during the month of May 2018 and December 2017, respectively. The site which is occupied by millipede

(site I) showed remarkably very high quantity of nitrogen (2.14%) during the month of November 2016. But in the site II i.e. site without millipedes showed only 1.03% during December 2017. The ratio carbon to nitrogen was at its peak (55.54) during May 2018 and it was very low (35.12) in the month of December 2017 in the site II, i.e. site without millipedes. The C/N ratio was higher (48.70) in May 2018 and quite less (20.05) in November 2016 in the site I.

calcium in study site I maximum (0.83%) and minimum (0.15%) values were obtained during the month of November 2016 and May 2018 respectively. In site II it was found to be maximum (0.45%) in November 2016 and minimum (0.08%) in May 2018. Two-way ANOVA indicates significant variations ($P < 0.05$) in sites with and without millipedes of Alagar hills reserve forest.

DISCUSSION

The soil fauna is a key component of forest ecosystem. They decompose the leaf litter and release the nutrient in the form of fecal pellet to the forest soil. The variation in the abundance for certain soil faunal groups and faunal diversity is often related to litter quantity and quality changes during succession and forest type (Wardle *et al.*, 2006; Milcu *et al.*, 2006). Diplopoda, the millipedes are one of the prominent soil fauna in forests. Their impact on decomposition processes and consequently soil element concentration may vary depending on the species. The quality of leaf litter in tropical region, influences the millipede population and, in turn, the rate of litter mineralization (Loranger *et al.*, 2003, 2008). The feeding activity of the millipedes is also important in the vertical redistribution of organic matter in an ecosystem. As the animal feeds and travels vertically through the soil system, the aeration of the soil influences the flow of nutrients and propagation of microbes (David *et al.*, 2001). Additionally, the fine particulate of the now comminuted litter has greater ability to move into the lower soil horizon by gravity. The combination of these modifications to the soil surface and litter allows for increased transfer on nutrients into the lower layers of the soil horizon through the flow of leachates.

Smith *et al.* (2006) reported that, the pH values of the soil are the most important factors affecting the population density of millipedes in the urban parks and gardens of London. Influence of soil acidity on the communities of the millipedes was studied by Gonzalez *et al.* (2012) Soil fauna can enhance N concentration in litter by influencing N release and stimulation of microbial N mineralization (Gonzalez and Seastedt, 2001; Irmeler, 2000). Similarly, the significantly higher concentration of N in soil subjected to millipede activity suggests that millipedes may play an important role in the mobilization of N, especially considering that N is a restrictive element in maximum ecosystems (Hooper *et al.*, 2005). Warren and Zou (2002) observed a significant positive correlation between the density of millipedes and the nitrogen content of *Leucaena* plantation of Puerto Rico. *Parafontaria laminata* increased nitrogen mineralization with discharge excretion as soil aggregates (Okai *et al.*, 2008). Loranger *et al.* (2008) has

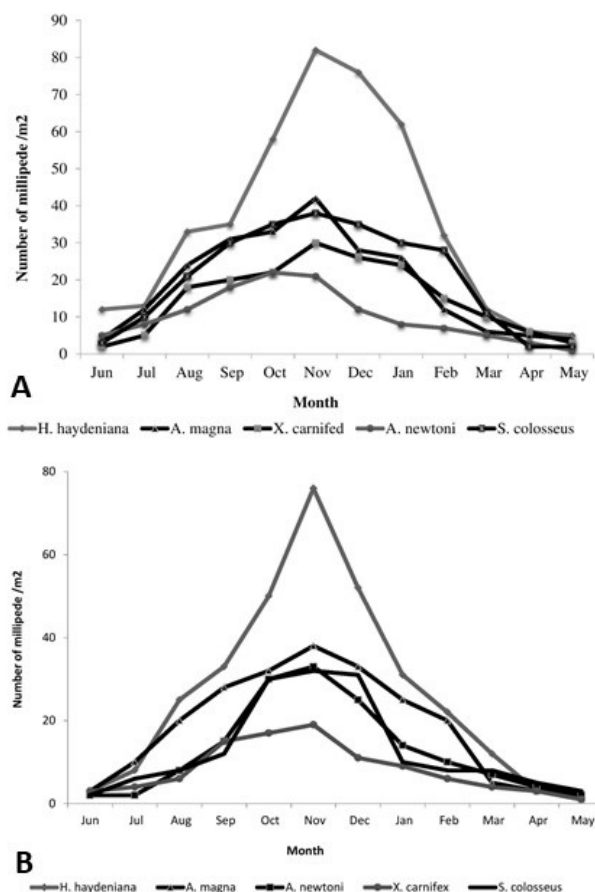


Fig. 1. Density of millipede species in the study area during June 2016- May 2017 (A), and June 2017-May 2018 (B).

The phosphorus content was maximum (23.10%) in the month of November 2016. But it was found to be less (4.89%) in the month of May 2018 in millipede occupying site (site I). In the site without millipedes (site II) phosphorus was found to be maximum (15.35%) in November 2017 and minimum (3.05%) in May 2018. The site I showed maximum amount of potassium content (0.24%) during the month of November 2016. But it was less (0.05%) in May 2017. In site II, maximum quantity of potassium (0.14%) was noticed in November 2016 and it was minimum (0.03%) in May 2018. With reference to

Table I. Nutrient composition (%) of soil in the study site I (with millipede) and site II (without millipedes) from June 2016 to May 2017. Each value represents the mean (X±SD) of five estimates.

Month	pH	C	N	P	K	Ca	C/N ratio
Site I (with millipede)							
Jun	6.1±0.48	47.10±3.76	1.10±0.08	7.16±0.57	0.07±0.004	0.27±0.021	42.81±3.42
Jul	5.9±0.47	48.56±3.88	1.28±0.10	12.36±0.98	0.07±0.004	0.32±0.025	37.50±3.00
Aug	5.7±0.45	49.11±3.92	1.44±0.11	16.45±1.31	0.10±0.008	0.53±0.042	34.11±2.72
Sep	5.5±0.44	47.14±3.77	1.66±0.13	18.02±1.44	0.13±0.010	0.68±0.054	28.39±2.27
Oct	5.6±0.44	45.31±3.62	2.02±0.16	20.18±1.61	0.17±0.013	0.75±0.060	22.43±1.79
Nov	5.4±0.43	43.87±3.50	2.14±0.17	23.10±1.84	0.24±0.019	0.83±0.066	20.05±1.60
Dec	5.5±0.44	44.96±3.59	2.00±0.16	18.72±1.49	0.19±0.015	0.65±0.052	22.48±1.79
Jan	5.7±0.45	45.71±3.65	1.96±0.15	16.35±1.30	0.15±0.012	0.58±0.046	23.32±1.86
Feb	5.7±0.45	46.12±3.68	1.71±0.13	13.21±1.05	0.14±0.011	0.47±0.037	26.97±2.15
Mar	5.9±0.47	48.14±3.85	1.70±0.13	10.25±0.82	0.11±0.008	0.33±0.026	28.31±2.26
Apr	6.0±0.48	49.72±3.97	1.53±0.12	8.32±0.66	0.10±0.008	0.28±0.022	32.49±2.59
May	6.1±0.48	49.90±3.99	1.42±0.11	6.58±0.52	0.08±0.006	0.25±0.020	35.14±2.81
Site II (Without Millipede)							
Jun	6.8±0.54	45.48±3.63	0.91±0.06	3.98±0.31	0.04±0.003	0.12±0.009	49.97±3.98
Jul	6.7±0.53	44.76±3.58	0.95±0.07	5.78±0.46	0.05±0.004	0.21±0.16	47.11±3.76
Aug	6.5±0.52	42.18±3.37	0.96±0.07	7.36±0.58	0.06±0.004	0.28±0.022	43.93±3.51
Sep	6.5±0.52	40.22±3.21	0.98±0.07	9.47±0.75	0.06±0.004	0.36±0.28	41.04±2.28
Oct	6.4±0.51	38.56±3.08	1.02±0.08	11.08±0.88	0.08±0.006	0.40±0.32	37.80±3.02
Nov	6.3±0.50	37.13±2.91	1.02±0.08	14.10±1.12	0.12±0.009	0.45±0.36	36.40±2.91
Dec	6.5±0.52	38.92±3.11	0.99±0.07	13.58±0.96	0.10±0.008	0.43±0.034	39.31±3.14
Jan	6.6±0.52	40.55±2.24	0.99±0.07	11.09±1.08	0.08±0.006	0.41±0.032	40.95±2.27
Feb	6.6±0.52	42.16±3.37	0.99±0.07	8.87±0.88	0.07±0.008	0.32±0.025	42.58±3.40
Mar	6.7±0.63	43.82±3.50	0.98±0.07	6.32±0.70	0.05±0.004	0.21±0.016	44.71±3.57
Apr	6.8±0.54	44.72±3.57	0.96±0.06	5.36±0.50	0.04±0.003	0.18±0.014	46.58±3.72
May	6.8±0.54	45.36±3.62	0.94±0.07	3.58±0.28	0.04±0.003	0.10±0.008	48.25±3.86

also demonstrated high feeding preference of nitrogen-rich leaf litter by three millipede species in semi-evergreen tropical forest of Guadeloupe. Krishna and Mohan (2017) showed that soil fauna significantly increased the release of N in microcosms that enriched coniferous forest floors.

Several workers have demonstrated the role of micro and macro arthropods in regulating C/N ratio during litter decomposition and humification processes. Yang and Chen (2009) stated that the soil fauna decrease carbon concentration and enhance nitrogen concentration in the rain forest leaf litter, where the initial high C/N ratio is substantially different from initial conditions in the broad leaf forest. Diplopoda (millipedes) as detritivores and macro fauna have been experimentally shown to have a significant effect on the mass loss of high C/N ratio of litter comparing to low C/N ratio litter (Hattenschwiler and

Gasser, 2005). For example, influence of high density of millipede on litter decomposition of mixed litter with high C/N ratio in forest site is seen in increasing N concentration and decreasing C/N ratio (Irmeler, 2000; Warren and Zou, 2002). Teuben and Verhoef (1992) reported that, the processing of litter by millipedes decreases the carbon-nitrogen ratio in the fecal pellets. This is mostly caused by the increase in nitrogen compounds with relatively little change taking place in the amount of Ca. From the present study it is evident that the drastic reduction of C/N ratio in site I may be due to the occurrence of millipedes and that favored the growth of plants.

The significant increase in K concentrations in the soil collected from site I may be due to high amount of faeces egested by millipedes that could increase the availability of K as reported by (Teuben and Verhoef, 1992). Ulrich (2000)

Table II. Nutrient composition (%) of soil in the study site I (with millipedes) and site II (without millipedes) from June 2017 to May 2018. Each value represents the mean (X±SD) of five estimates.

Month	PH	C	N	P	K	Ca	C/N ratio
Site I (with millipede)							
Jun	6.1±0.48	49.92±3.99	1.52±0.12	5.12±0.40	0.06±0.004	0.18±0.014	33.78±2.70
Jul	5.9±0.47	50.02±4.00	1.53±0.12	8.95±0.71	0.09±0.007	0.24±0.019	32.60±2.60
Aug	5.8±0.46	47.58±3.80	1.63±0.13	13.78±1.10	0.10±0.008	0.43±0.034	29.29±2.34
Sep	5.8±0.46	47.43±3.79	1.65±0.13	15.41±1.23	0.14±0.011	0.58±0.046	28.74±2.29
Oct	5.7±0.45	47.71±3.81	2.09±0.16	17.19±1.37	0.17±0.013	0.64±0.051	22.80±1.82
Nov	5.6±0.44	45.21±3.61	2.11±0.16	19.35±1.54	0.21±0.016	0.76±0.060	21.37±1.70
Dec	5.6±0.44	46.23±3.69	2.03±0.16	18.28±1.46	0.18±0.014	0.51±0.040	22.77±1.82
Jan	5.8±0.46	46.36±3.70	2.02±0.17	16.75±1.34	0.15±0.012	0.47±0.037	23.04±1.84
Feb	5.9±0.47	46.47±3.71	2.02±0.16	12.08±0.96	0.11±0.008	0.32±0.025	23.09±1.84
Mar	5.9±0.47	46.93±3.35	1.67±0.13	10.13±0.81	0.09±0.007	0.21±0.016	28.02±2.24
Apr	6.0±0.48	48.94±3.91	1.11±0.08	7.52±0.60	0.07±0.004	0.17±0.013	34.08±2.72
May	6.3±0.50	47.19±3.77	1.01±0.08	4.89±0.39	0.05±0.004	0.15±0.012	48.70±3.89
Site II (without millipedes)							
Jun	6.8±0.54	43.28±3.46	0.96±0.07	4.12±0.32	0.04±0.003	0.11±0.11	45.08±3.60
Jul	6.7±0.53	40.76±3.26	0.96±0.07	7.18±0.57	0.07±0.005	0.14±0.11	42.25±3.38
Aug	6.7±0.53	39.32±3.14	0.99±0.07	8.35±0.66	0.08±0.006	0.28±0.22	39.71±3.17
Sep	6.6±0.48	39.24±3.13	1.00±0.08	11.28±0.90	0.10±0.008	0.32±0.025	39.24±3.13
Oct	6.6±0.48	38.21±3.05	1.00±0.08	13.58±1.08	0.11±0.008	0.36±0.028	38.21±3.05
Nov	6.5±0.52	37.53±3.08	1.01±0.10	15.35±1.22	0.14±0.011	0.38±0.028	37.15±2.97
Dec	6.5±0.52	36.18±2.89	1.03±0.09	12.47±0.99	0.13±0.010	0.35±0.028	35.12±2.80
Jan	6.7±0.53	38.01±3.04	1.02±0.09	10.58±0.84	0.11±0.008	0.28±0.022	37.26±2.98
Feb	6.8±0.54	39.24±3.31	1.02±0.07	7.89±0.63	0.07±0.005	0.22±0.017	38.47±3.07
Mar	6.9±0.55	42.03±2.94	0.96±0.07	6.38±0.51	0.05±0.004	0.19±0.015	43.76±3.50
Apr	7.0±0.56	44.31±3.98	0.96±0.06	5.23±0.41	0.04±0.003	0.12±0.009	46.15±3.69
May	7.1±0.56	48.32±3.86	0.87±0.05	3.05±0.24	0.03±0.002	0.08±0.006	55.54±4.44

noted that level of sodium and potassium concentration increased rapidly and easily in leaf litter due to the impact of faunal activity. Consumption of litter by soil saprophagous fauna replenishes the soil nutrients and prevents elemental leaching by rain (Gonzalez and Seastedt, 2001). Diplopod is important sinks for calcium and accumulates Ca and Mg up to fivefold higher than raw leaf litter (Gonzalez and Seastedt, 2001). The faecal pellets of millipede remain stable for long duration without any changes (Ambarish and Sridhar, 2013). Such stability has been connected to high Ca ions in soil (Sridhar and Kadamannaya, 2009). Furthermore, Kaneko (1999) found that digestion of litter and soil by *P. toniminea* also amplified soil respiration and leaching of Ca⁺, Mg⁺.

Ashwini and Sridhar (2006) detected a positive correlation in pill millipede richness and biomass to

soil calcium content in Western Ghats. The presence of millipedes positively changes concentrations of many nutrients, not just ammonia, phosphorus, calcium and magnesium (Smit and van Aarde, 2001). Leaching of Ca, Mg and nitrogen increased in proportion to the number of millipedes. An increase in nitrate leaching can be explained by animal-feeding activity. Yang and Chen (2009) have reported the importance of preserving soil fauna diversity in forest for the process of nutrient cycling.

The present study indicates that the biochemical constituents such as nitrogen, phosphorus, potassium and Calcium are increased and favourable C/N ratio was observed in millipede occurrence site compared to millipede absent site of Alagar hills reserve forest. Fujimaki *et al.* (2010) found that the soil surface in the habitat area of *P. laminate* contained high amounts of

organic matter than in soil without the millipede because the faecal cast is higher in organic matter. In conclusion, this study indicated that millipede species assemblage provided a significant contribution to improve the soil fertility of Alagar hills reserve forest. Our present study corroborates earlier reports that the quality of leaf litter is important in enhancing the growth and food conversion efficiency of millipedes that, in turn, leads to leaf litter mineralization and soil enrichment through faecal egestion (Seeber *et al.*, 2008). A similar study was observed by Topp *et al.* (2006) from millipedes collected from four primeval forests (including three oak-horbeam forest stands) of West Carpathians, Central Slovakia. They found that the gradient of the chemistry of the upper soil layer i.e. pH and nutrient content are strongly influenced by the millipede species. Similarly, the burrowing and other activities of millipede species can cause important physical modifications in the soil biochemical components in Alagar Hill reserve forest. It is evident from the present study that the increase in biochemical constituents like, N, P, K, Ca during the month of November is because of increase in the quantity of millipede faeces during rainy seasons as also reported by Ashwini and Sridhar (2006). It has confirmed the findings of Dangerfield and Telford (1996) that leaf litter ingestion and faecal production by millipedes occur mainly during two month of wet season in South Africa.

Millipede faeces consist of pulverized litter, minerals, and, high microbial load (Maraun *et al.*, 2003). The significant amount of organ minerals in millipede fecal pellets accelerate humification of litter strata (Loranger *et al.*, 2003). It has also been established that the faeces of *Glomeris* are a food source for certain earthworm species (Wolters, 2000). This proves that organominerals are re- ingested and mixed into the soil by earthworms, which cohabit at high biomasses with macroarthropods in mediterranean forests (Jordi *et al.*, 2004). Soil macro-fauna give an important contribution to soil fertility, by promoting the stability and productivity of forest ecosystem, mainly due to their influence on soil processes such as litter decomposition and nutrient dynamics (Irmeler, 2000; Hunter *et al.*, 2003; Griffiths *et al.*, 2020). The present study emphasizes the importance of preserving millipede diversity in forest for the process of nutrient cycling and soil enrichment.

CONCLUSION

In forest ecosystem, soil macrofauna play an essential role in decomposition of litter, acceleration of organic matter and nutrient transformation. Among the litter arthropods, millipede is a significant fauna to alter

the physical and chemical atmosphere of the litter. The site which is occupied by millipede contain remarkably high nitrogen, phosphorus, potassium and calcium. The minimum level of carbon observed in millipede presence site when compare the without millipede site which is make to ideal C/N ratio in forest ecosystem. Hence, the present study instructed that the preserving of millipede diversity in forest ecosystem is an essential step for the process of nutrient cycling and soil enrichment. It is significant to proliferate the awareness of ecologists about the importance of millipede diversity in forest ecosystem.

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Statement of conflict of interest

The authors have declared no conflict of interest.

REFERENCES

- Ambarish, C.N., and Sridhar, K.R., 2013. Production and quality of pill-millipede manure: A microcosm study. *Agric. Res.*, **2**: 258–264. <https://doi.org/10.1007/s40003-013-0075-5>
- Andrew, J.R., Ian, D.B., Natacha, P., Philip, I., and Richard, P.E., 2006. The biochemical transformation of oak (*Quercus robur*) leaf litter consumed by the pill millipede (*Glomeris marginata*). *Soil Biol. Biochem.*, **38**: 1063–1076. <https://doi.org/10.1016/j.soilbio.2005.09.005>
- Ashwini, K.M., and Sridhar, K.R., 2006. Seasonal abundance and activity of pill millipedes (*Arthrosphaera magna*) in mixed plantation and semi-evergreen forest of southern India. *Acta Oecol.*, **29**: 27-32. <https://doi.org/10.1016/j.actao.2005.07.005>
- Bardgett, R.D., Anderson, J.M., Behan, P.V., Brussaard, L., Coleman, D.C., Ettema, C., Moldenke, A., Schimel, J.P. and Wall, D.H., 2004. The influence of soil biodiversity on hydrological paquatic ecosystem. Thways and the transfer of materials between terrestrial and aquatic ecosystem. *Ecosystem*, **4**: 421-429. <https://doi.org/10.1007/s10021-001-0020-5>
- Bird, S., Coulson, D.A., and Crossley, J., 2000. Impacts of silvicultural practices on soil and litter arthropod diversity in a Taxes pine plantation. *For. Ecol. Manage.*, **131**: 65-80. [https://doi.org/10.1016/S0378-1127\(99\)00201-7](https://doi.org/10.1016/S0378-1127(99)00201-7)

- Branquart, E., Kime, R.D., Dufrene, M., Tavernier, J., and Wauhty, G., 1995. Macroarthropod habitat relationships in oak forest in South Belgium. 1. *Environ. Commun. Pedobiol.*, **39**: 243-263.
- Dangerfield, J.M., and Milner, A.E., 1996. Millipede faecal pellet production in selected natural and managed habitats of southern Africa: Implications for litter dynamics. *Biotropica*, **28**: 113–120.
- David, A.W., Gregor, W.Y., Gary, M.B., and Karen, I.B., 2006. The influence of plant litter diversity on decomposer abundance and diversity. *Soil Biol. Biochem.*, **38**: 1052–1062. <https://doi.org/10.1016/j.soilbio.2005.09.003>
- David, S.P., Penny, R.H., and Philip, C.B., 2001. The role of soil microorganisms in soil organic matter conservation in the tropics. *Nutr. Cycl. Agroecosyst.*, **61**: 41-51. https://doi.org/10.1007/978-94-017-2172-1_5
- Fujimaki, R., Sato, Y., Okai, N., and Kaneko, N., 2010. The train millipede (*Parafontaria laminata*) mediates soil aggregation and N dynamics in a Japanese larch forest. *Geoderma*, **159**: 216-220. <https://doi.org/10.1016/j.geoderma.2010.07.014>
- Gonzalez, G., and Seastedt, T.R., 2001. Soil fauna and plant litter decomposition in tropical and subalpine forest. *Ecology*, **82**: 955-964. [https://doi.org/10.1890/0012-9658\(2001\)082\[0955:SFAPLD\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2001)082[0955:SFAPLD]2.0.CO;2)
- Gonzalez, G., Christina, M., Murphy, and Juliana, B., 2012. Direct and indirect effects of millipedes on the decay of litter of varying lignin content. *Trop. For.*, **388**. <https://doi.org/10.5772/32816>
- Griffiths, M., Louise, A., Catherine, L., and Paul, E., 2020. The impact of invertebrate decomposers on plants and soil. *New Phytol.*, **231**: 2142–2149. <https://doi.org/10.1111/nph.17553>
- Hattenschwiler, S., and Gasser, P., 2005. Soil animals alter plant litter diversity effects on decomposition. *Proc. natl. Acad. Sci. U.S.A.*, **102**: 1519-1524. <https://doi.org/10.1073/pnas.0404977102>
- Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A.H. and Inchausti, P.I., 2005. Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecol. Monogr.*, **75**: 3-35. <https://doi.org/10.1890/04-0922>
- Hunter, M.D., Adl, S., Pringle, C.M., and Coleman, D.C., 2003. Relative effects of macroinvertebrates and habitat on the chemistry of litter decomposition in two deciduous forests. *Pedobiologia*, **44**: 105-118. [https://doi.org/10.1078/S0031-4056\(04\)70032-3](https://doi.org/10.1078/S0031-4056(04)70032-3)
- Irmler, U., 2000. Changes in the fauna and its contribution to mass loss and N release during leaf litter decomposition in two deciduous forests. *Pedobiologia*, **44**: 105-118.
- Jackson, M.L., 1973. *Soil chemical analysis*. Prentice Hall of Indian Pvt. Ltd. New Delhi.
- Jordi, G.P., Pere, C., and Romanya, J., 2004. Litter decomposition and faunal activity in Mediterranean forest soils: Effects of N content and the moss layer. *Soil Biol. Biochem.*, **36**: 989–997. <https://doi.org/10.1016/j.soilbio.2004.02.016>
- Kaneko, N., 1999. Effect of millipede *Parafontaria tonominea* (Attems), (Diplopoda: Xystomidae) adult on soil biological activities: Microcosm experiment. *Ecol. Res.*, **14**: 271-279. <https://doi.org/10.1046/j.1440-1703.1999.143302.x>
- Kaneko, N., and Ito, M.T., 2004. Biodiversity and ecosystem function of soil animals. *Jpn. J. Ecol.*, **54**: 201-207.
- Krishna, M.P., and Mahesh, M., 2017. Litter decomposition in forest ecosystems: A review. *Energy Ecol. Environ.*, **2**: 236–249. <https://doi.org/10.1007/s40974-017-0064-9>
- Liu, Z.G., and Zou, X.M., 2002. Exotic earthworm accelerated plant litter decomposition in a tropical pasture and a wet forest of Puerto Rico. *Appl. Ecol.*, **12**: 1406-1417. [https://doi.org/10.1890/1051-0761\(2002\)012\[1406:EEAPLD\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2002)012[1406:EEAPLD]2.0.CO;2)
- Loranger, G., Imbert, D., Bernhard-Reversat, F., Ponge, J.F., and Levelle, P., 2007. Soil fauna abundance and diversity in a secondary evergreen forest in Guadeloupe (Lesser Antilles): Influence of soil type and dominant tree species. *Biol. Fertil. Soil*, **44**: 269-276. <https://doi.org/10.1007/s00374-007-0199-5>
- Loranger, G., Imbert, D., Bernhard-Reversat, F., Ponge, J.F., and Levelle, P., 2008. Litter N-content soil millipede abundance, species richness and feeding preference in a semi-evergreen dry forest of Guadeloupe (Lesser Antilles). *Biol. Fertil. Soil*, **45**: 93-98. <https://doi.org/10.1007/s00374-008-0321-3>
- Loranger, G., Ponge, J.F., and Lavelle, P., 2003. Humus forms in two secondary semi-evergreen tropical forests. *Eur. J. Soil Sci.*, **54**: 17-24. <https://doi.org/10.1046/j.1365-2389.2003.00500.x>
- Maraun, M., Martens, H., Migge, S., Theenhaus, A., and Scheu, S., 2003. Adding to ‘the enigma of soil animal diversity’; fungal feeders and saprophagous soil invertebrates prefer similar food substrates. *Eur. J. Soil Biol.*, **39**: 85–95.
- Mekonnen, G., 2020. Role of litter production and its decomposition and factors affecting the processes in a tropical forest ecosystem: A review. *J. Ecol. Environ.*, **44**: 11. <https://doi.org/10.1186/s41610->

- 020-0151-2
- Meyer, E., and Singer, A., 1997. Verteilung, Aktivität und Besiedlungsdichte von Diplopoden in Waldern Vorarlbergs (Österreich). *Berlin Natl. Med.*, **84**: 287-306.
- Milcu, A., Partsch, S.I., and Scheu, S., 2006. The response of decomposition (Earthworm, springtails and microorganisms) to variation in species and functional group diversity of plants. *Oikos*, **112**: 513-524. <https://doi.org/10.1111/j.0030-1299.2006.14292.x>
- Muneto, H., John, S., Balram, K.B., and Hiroshi, T., 2004. Leaf-litter decomposition of 15 tree species in a lowland tropical rain forest in Sarawak: dynamics of carbon, nutrients, organic constituents. *J. For. Res.*, **9**: 347-354. <https://doi.org/10.1007/s10310-004-0088-9>
- Nevo, S. and Dror, H., 2021. Arthropods as the engine of nutrient cycling in arid ecosystems. *Insects*, **12**: 726. <https://doi.org/10.3390/insects12080726>
- Okai, N., Fujimaki, R., Saito, Y., and Kaneko, N., 2008. Influence of feeding of larvae train millipede Parafontaria laminate on acceleration of nitrogen mineralization. Proceeding of the 31th annual meeting of the Japanese Society of Soil Zoology. pp. 16.
- Scheu, S., Ruess, L., and Bonkowski, M., 2005. Microorganisms in soils: Roles in genesis and functions. *Soil Biol.*, **3**: 254-278.
- Seeber, J., Seeber, H., Langel, R., Scheu, S., and Meyer, E., 2008. The effect of macro-invertebrates and plant litter of different quality on the release of N from litter to plant on alpine pastureland. *Biol. Fertil. Soils*, **43**: 333-340. <https://doi.org/10.1007/s00374-008-0282-6>
- Shaw, M.R., and Harte, J., 2001. Control of litter decomposition in a subalpine meadow-sagebrush ecotone under climate change. *Ecol. Appl.*, **11**: 1206-1223. <https://doi.org/10.2307/3061022>
- Smith, V.C., and Bradford, M.A., 2003. Litter quality impacts on grassland litter decomposition are differently dependent on soil fauna across time. *Appl. Soil Ecol.*, **24**: 197-203. [https://doi.org/10.1016/S0929-1393\(03\)00094-5](https://doi.org/10.1016/S0929-1393(03)00094-5)
- Smit, A., and Van-Aarde, R.J., 2001. The influence of millipedes on selected soil elements: A microcosm study on three species occurring on coastal sand dunes. *Funct. Ecol.*, **15**: 51-59. <https://doi.org/10.1046/j.1365-2435.2001.00493.x>
- Smith, J., Chapman, A., and Eggleton, P., 2006. Baseline biodiversity surveys of the soil macrofauna of London's green spaces. *Urban Ecosyst. Springer*, **9**: 337-349. <https://doi.org/10.1007/s11252-006-0001-8>
- Sridhar, K.R., and Ashwini, K.M., 2016. Diversity, restoration and conservation of millipedes. In: *Biodiversity in India* (ed. T. Pullaiah). Volume 5, Chapter 1, pp. 1-38. Regency Publ. New Delhi. <http://doi.10.13140/RG.2.1.3683.2889>
- Sridhar, K.R., and Kadamannaya, B., 2009. *Pill millipedes an overview*. In: *Organic farming: Methods, economics and structure* (eds. M. Nelson and I. Artamova). ISBN 978-1-60692-864-6. Nova Science Publishers, Inc.
- Stasiov, S., 2002. *Vybrane skupiny epigeickej makrofauny (Opilionida, Diplopoda a Chilopoda) ako indikatory stavu vrchnej podnej vrstvy v podhorskej bučine (selected groups of epigeic macrofauna (Opilionida, Diplopoda a Chilopoda) as indicators of the status of the top soil layer in submontane beech forest*. Scientific Studies, Technical University in Zvolen, Zvolen, pp. 88.
- Stasiov, S., 2005. Millipede communities (Diplopods) of oak-hornbeam ecosystems (the Male Karpaty Mts, Trnavska Pahorkatina Hills, SW Slovakia). *Ekologia (Bratislava)*, **24**: 143-151. <https://doi.org/10.1007/BF00335798>
- Tajovsky, K. and Wytwe, J., 2009. Millipedes and centipedes in wetland alder stands in North-Eastern Poland. *Soil Organ.*, **81**: 761-772.
- Teuben, A., and Verhoef, H.A., 1992. Direct contribution by soil arthropods to nutrient availability through body and faecal nutrient content. *Biol. Fertil. Soils*, **9**: 145-151.
- Tilman, D., Isbell, F., and Cowles, J.M., 2014. Biodiversity and ecosystem functioning. *Annu. Rev. Ecol. Evol. Syst.*, **45**: 471-493. <https://doi.org/10.1146/annurev-ecolsys-120213-091917>
- Topp, W., Kappes, H., Kulfan, J., and Zach, P., 2006. Distribution of pattern of woodlice (Isopoda) and millipede (Diplopoda) in four primeval forests of the western Carpathians (Central Slovakia). *Soil Biol. Biochem.*, **38**: 43-50. <https://doi.org/10.1016/j.soilbio.2005.04.012>
- Ulrich, I., 2000. Changes in the fauna and its contribution to mass loss and N release during leaf litter decomposition in two deciduous forests. *Pedobiologia*, **44**: 105-118. [https://doi.org/10.1078/S0031-4056\(04\)70032-3](https://doi.org/10.1078/S0031-4056(04)70032-3)
- Umbreit, W.W., Burris, R.H., and Stauffer, J.F., 1974. *Manometric and biochemical techniques (5th Eds.)*. Burges Publication. Co. Minnesota. pp. 259.
- Vogel, A.I., 1963. *A textbook of quantitative inorganic analysis including elementary instrumental*

- Analysis (3rd Eds.)*. The English Language Book Society and Longman.
- Wardle, D.A., Yeates, G.W., Barker, G.M., and Bonner, K.I., 2006. The influence of plant litter diversity on decomposer abundance and diversity. *Soil Biol. Biochem.*, **38**: 052-1062. <https://doi.org/10.1016/j.soilbio.2005.09.003>
- Warren, M.W., and Zou, X., 2002. Soil macrofauna and litter nutrients in three tropical tree plantations on a disturbed site in Puerto Rico. *Ecol. Manage.*, **170**: 161-171. [https://doi.org/10.1016/S0378-1127\(01\)00770-8](https://doi.org/10.1016/S0378-1127(01)00770-8)
- Wolters, V., 2000. Invertebrate control of soil organic matter stability. *Biol. Fertil. Soils*, **31**: 1–19. <https://doi.org/10.1007/s003740050618>
- Yang, X., and Chen, J., 2009. Plant litter quality influences the contribution of soil fauna to litter decomposition in humid tropical forest, Southwestern China. *Soil Biol. Biochem.*, **41**: 910-918. <https://doi.org/10.1016/j.soilbio.2008.12.028>