World Journal of Zoology 4 (2): 63-69, 2009
ISSN 1817-3098

Seasonal Periodicity of Pill Millipedes (*Arthrosphaera*) and Earthworms of the Western Ghats, India

[1]B.S. Kadamannaya, [2]K.R. Sridhar and [3]S. Seena

[1]Department of Zoology, Field Marshal K.M. Cariappa Mangalore University College, Madikeri 571 201, Karnataka, India
[2]Microbiology and Biotechnology, Department of Biosciences, Mangalore University, Mangalagangotri, Mangalore 574 199, Karnataka, India
[3]Centre of Molecular and Environmental Biology (CBMA), Department of Biology, University of Minho, Campus de Gualtar, 4710-057 Braga, Portugal

Abstract: Seasonal periodicity of pill millipedes (*Arthrosphaera*) and earthworms in three habitats of the Western Ghats: Kadaba mixed plantation (mid-altitude), Kadaba semi-evergreen forest (mid-altitude) and Madikeri semi-evergreen to evergreen forest (high-altitude) have been surveyed at monthly intervals up to one year. Earthworms were found in all seasons, while pill millipedes confined to monsoon and post-monsoon seasons. The biomass and abundance of pill millipedes and earthworms were highest in mixed plantation than forests. In plantation and high-altitude forest between monsoon and post-monsoon, the biomass and abundance of pill millipedes and earthworms differed significantly, while only pill millipede biomass at the mid-altitude forest. In all habitats soil temperature and pH were significantly differed between monsoon and post-monsoon seasons. Organic farming practices (e.g. use of organic manure, moisture retention) at the mixed plantation of Western Ghats seem to support a variety of soil saprophagous fauna including colonization of pill millipedes.

Key words: *Arthrosphaera* · Earthworms · Soil edaphic factors · Pill millipedes · Seasons · Western Ghats

INTRODUCTION

Soil humification is an important process carried out by the saprophagous fauna in forests and plantations. Earthworms, millipedes, woodlice and land mollusks among saprophagous macrofauna are important in soil humification [1,2]. Human-induced environmental disturbances (e.g. use of chemicals, land use pattern) severely deteriorate the soil qualities and soil fertility and warrant practice of organic farming for sustainable agriculture. Organically managed mixed plantation of the southwest part of India resulted in high diversity and activity of many saprophagous fauna (e.g. earthworms, millipedes, mollusks) [3]. Accumulation of considerable amount of earthworm castings and millipede fecal pellets was seen mainly in the tree bases of mixed plantations. Among the pill millipedes *Arthrosphaera magna* Attems become abundant in organically managed mixed plantation [3]. Pill millipedes were never found or colonized the chemically managed plantations. However, they were common in semi-evergreen forests adjacent to mixed plantations. Although the Western Ghats of India and Sri Lanka endowed with a variety of pill millipedes belonging to the genus *Arthrosphaera* [4-8], studies on their occurrence and seasonal periodicity are meager [8,9]. Therefore, the major objective of the present study was to extend investigation on the seasonal occurrence of pill millipedes found in mixed plantation forests of the Western Ghats at different altitudinal range in relation to soil edaphic features. This study also compares the abundance and biomass of earthworms found in association with pill millipedes.

MATERIALS AND METHODS

Study Sites: Survey was carried out at monthly intervals (June 2005 to May 2006) at three habitats of the Western Ghats: mixed plantation (Kadaba plantation) at

Corresponding Author: K.R. Sridhar, Microbiology and Biotechnology, Department of Biosciences, Mangalore University, Mangalagangotri, Mangalore 574 199, Karnataka, India

mid-altitude (124 msl; 12°44´N, 75°29´E), semi-evergreen forest at the mid-altitude (Kadaba forest) (124 msl; 12°44´N, 75°29´E) and semi-evergreen to evergreen forest at the high-altitude (1147 msl; Madikeri forest) (12°25´N, 75°44´E). Thirty years-old Kadaba plantation spread over two hectares. Plantation crops cultivated include: areca (*Areca catechu*), cocoa (*Theobroma cacao*), banana (*Musa paradisiaca*) and coconut (*Cocos nucifera*) pepper (*Piper* spp.). During post-monsoon season (October), each tree base of receives cow dung, biogas plant spent slurry, green manure and mixed leaf litter. In addition, leaf litter generated from the plantation was heaped at the tree bases. Plantation receives sprinkler irrigation (December through May), which is equivalent to 2.5 cm rain/day. Four hectares of semi-evergreen Kadaba forest reserve is located adjacent to the Kadaba plantation. The major tree species of the forest include: *Acacia, Cinnamomum, Dalbergia, Entanda*, *Holigarna, Lagerstroemia, Mangifera, Mimusops, Piper*, *Sapium*, *Syzygium, Terminalia* and *Ziziphus.* The Madikeri forest consists of dense semi-evergreen to evergreen vegetation. Sunlight does not reach the ground due to the dense vegetation and the forest atmosphere is saturated with water vapour during major parts of the year. The main trees and shrubs in this forest consist of *Acrocarpus, Alstonia, Allophyllus, Anthocephalus, Aporusa, Arisaema, Asystasia Dipterocarpus, Ficus, Haldinina, Harpullia, Holigarna, Homalium, Ophiorrhiza, Spodyctes, Pittosporum* and *Spondias*.

Faunal Survey: In each habitat, four sampling points were identified at a stretch of 50 m distance along 200 m transect. Pill millipedes and earthworms were sampled in surface leaf litter (30×30 cm) in each sampling point. Subsequently, soil was excavated up to 10 cm depth and the available pill millipedes and earthworms were recovered. Pill millipedes and earthworms in 9000 cm^3 were enumerated and their biomass was determined on fresh weight basis (Mettler Toledo, Switzerland; Model PB 303DR) and expressed per m^{-3}. The animals were left in the same locaton after weighing and enumeration. For each month, different stretch of transects were used for assessment to avoid repeated samping in same site.

Soil Analysis: At each sampling point, soil temperature was measured using mercury thermometer at a depth of 10 cm. About 3 kg of composite soil samples were procured from each sampling point and brought to the laboratory in airtight polythene bags for analysis. Composite samples of soil was mixed with distilled water (1:2.5 w/v), shaken for 10 min and pH was detected on the sampling spot using portable pH meter (Systronics, India; Model 335). The soil solution prepared for pH determination was used to assess the conductivity (Systronics, India; Model 304). The soil texture was determined based on the percentage of clay, silt and sand as outlined in Chopra and Kanwar [10]. Soil moisture was estimated gravimetrically on drying the soil at 100°C until attaining constant weight. To quantify the soil organic carbon, Walkley and Black's rapid titration method was followed [11]. The total available phosphorus in soil was estimated spectrophtometrically (Systronics, India; Model 106) as per the method by Jackson [11]. Available potassium in soil was estimated by flame photometry (Systronics, India; MK1/MK3) [11]. Exchangeable calcium and magnesium in soil were evaluated by Versenate method [11].

Data Analysis: To determine the difference in soil edaphic features, biomass and abundance of pill millipedes and earthworms, the pooled data of monsoon (June-September), post-monsoon (October-January) of three habitats was assessed by *t* - test [12]. To evaluate the relationship between biomass of pill millipedes and earthworms vs. soil edaphic factors in different seasons and habitats, Pearson correlation was employed (GraphPad Prism version 4.0b for Macintosh, GraphPad Software, San Diego, California; parameters: *P* values, two tailed; confidence intervals, 95%) (www.graphpad.com)

RESULTS

Faunal Biomass and Abundance: In Kadaba plantation and Kadaba forest, single species dominance of pill millipede was seen (*Arthrosphaera dalyi* Pocock), so also in Madikeri forest (*Arthrosphaera fumosa* Pocock). Kadaba plantation showed the highest biomass of pill millipedes as well as earthworms than forests (Fig. 1). The biomass of pill millipedes is higher than earthworms and reached a peak during August in all habitats. Madikeri forest consists of pill millipede in June, while in Kadaba plantation and forest in July. The abundance of earthworms was higher than pill millipedes in all habitats and attained two peaks (June-August, December) (Fig. 2). Abundance of pill millipedes was highest in Kadaba plantation and peaked during August. Plantation and forest locations were devoid of pill millipedes during summer.

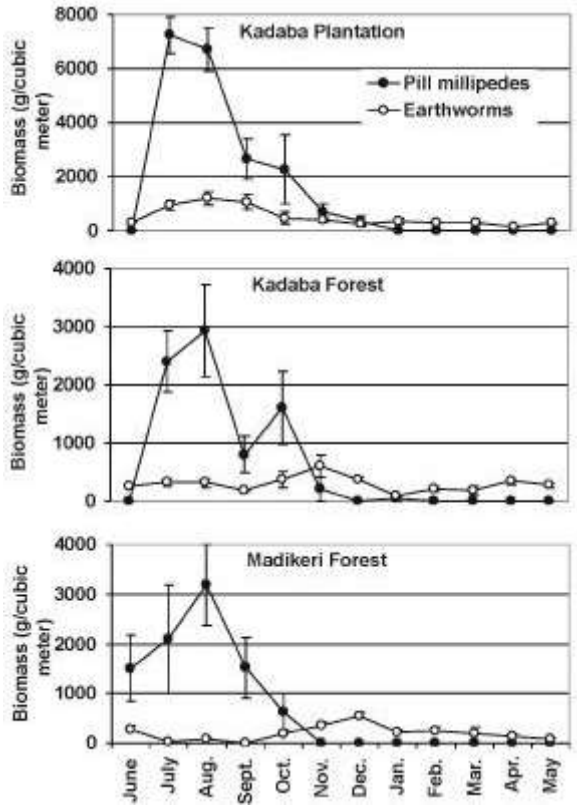

Fig. 1: Seasonal variation in biomass of pill millipedes and earthworms in Kadaba plantation, Kadaba forest and Madikeri forest (n = 4, mean ± SE).

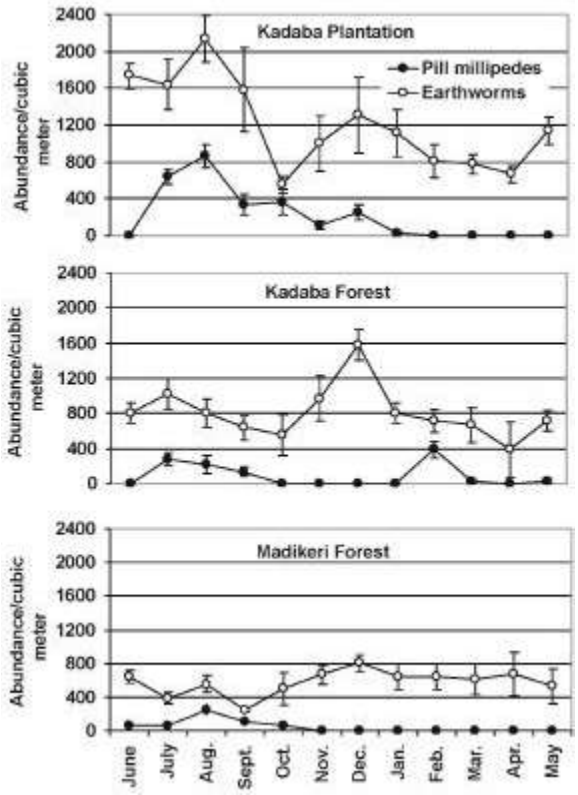

Fig. 2: Seasonal variation in abundance of pill millipedes and earthworms in Kadaba plantation, Kadaba forest and Madikeri forest (n = 4, mean ± SE).

In all habitats, from monsoon to summer, biomass and abundance of pill millipedes showed decreasing trend (Table 1). The earthworm biomass and abundance were decreased from monsoon to summer in Kadaba plantation. In Kadaba and Madikeri forests, earthworm biomass and abundance peaked at post-monsoon season. In Kadaba plantation, between monsoon and post-monsoon, significant difference was seen in pill millipede and earthworm biomass ($P < 0.01$) and pill millipede ($P < 0.05$) and earthworm ($P < 0.001$) abundance, while only pill millipede biomass was significantly differed ($P < 0.05$) in Kadaba forest. In Madikeri forest, pill millipede ($P < 0.001$) and earthworm ($P < 0.05$-0.01) abundance and biomass were significantly differed between monsoon and post-monsoon.

Soil Edaphic Features: The soil texture of three habitats was loamy sand. In all the habitats, soil temperature showed an increasing trend from monsoon to summer, while total phosphorus was peaked during post-monsoon. In Kadaba plantation, moisture, pH, potassium and magnesium showed a decreasing trend from monsoon to summer (Table 2). Between monsoon and post-monsoon, significant difference was seen in temperature and pH ($P < 0.05$). In Kadaba forest, moisture and pH were decreased from monsoon to summer. Moisture, temperature, potassium ($P < 0.001$), pH, conductivity, organic carbon, total phosphorus and magnesium ($P < 0.05$) differed significantly between monsoon and post-monsoon. In Madikeri forest, moisture and conductivity showed decreasing trend from monsoon to summer. Moisture, temperature, conductivity ($P < 0.001$), pH, potassium and magnesium ($P < 0.05$) were significantly differed between monsoon and post-monsoon.

Fauna Vs. Soil Edaphic Features: Biomass of pill millipedes of Kadaba plantation was positively correlated with moisture ($P < 0.001$; $r = 0.81$), while negatively with temperature ($P < 0.001$; $r = -0.87$) during monsoon. It was also positively correlated with calcium ($P < 0.01$; $r = 0.68$) as well as magnesium ($P < 0.01$; $r = 0.67$) in post-monsoon.

Table 1: Seasonal fluctuations of biomass and abundance of pill millipedes and earthworms in Kadaba plantation, Kadaba forest and Madikeri forest during monsoon, post-monsoon and summer seasons (n=16, mean±SE)

Biomass and abundance	Monsoon	Post-monsoon	Summer
Kadaba plantation			
Pill millipede biomass (g m^{-3})	4148±822^{a}	840±368^{b}**	0
Earthworm biomass (g m^{-3})	866±129^{a}	371±65^{b}**	246±19
Pill millipede abundance (individuals m^{-3})	458±94^{a}	187±52^{b}*	0
Earthworm abundance (individuals m^{-3})	1778±158^{a}	993±148^{b}***	847±76
Kadaba forest			
Pill millipede biomass (g m^{-3})	1533±378^{a}	464±226^{b}*	0
Earthworm biomass (g m^{-3})	275±30^{a}	361±71^{a}	248±31
Pill millipede abundance (individuals m^{-3})	160±41^{a}	111±48^{a}	0
Earthworm abundance (individuals m^{-3})	820±77^{a}	979±133^{a}	625±99
Madikeri forest			
Pill millipede biomass (g m^{-3})	2073±416^{a}	157±108^{b}***	0
Earthworm biomass (g m^{-3})	91±33^{a}	322±53^{b}**	160±42
Pill millipede abundance (individuals m^{-3})	118±30^{a}	14±10^{b}***	0
Earthworm abundance (individuals m^{-3})	458±53^{a}	653±70^{b}*	611±92

Figures across the second and third columns with different letters are significantly different (*, P < 0.05 ; **, P < 0.01 ; ***, P < 0.001)

Table 2: Seasonal fluctuations of soil edaphic features in Kadaba plantation, Kadaba forest and Madikeri forest during monsoon, post-monsoon and summer seasons (n=16, mean±SE)

Soil parameter	Monsoon	Post-monsoon	Summer
Kadaba plantation			
Moisture (%)	33.37±0.77^{a}	29.47±0.02^{a}	22.11±0.44
Temperature (°C)	25.16±0.09^{a}	25.91±0.08^{b}*	27.13±0.08
pH	4.93±0.03^{a}	4.55±0.03^{b}*	4.39±0.02
Conductivity (m mhos/cm)	0.32±0.01^{a}	0.38±0.004^{a}	0.28±0.004
Organic carbon (g kg^{-1})	29.3±0.20^{a}	33.2±0.60^{a}	26.3±0.30
Total phosphorus (µg g^{-1})	8.45±0.33^{a}	12.60±0.35^{a}	4.13±0.18
Potassium (µg g^{-1})	95.33±0.48^{a}	80.64±2.21^{a}	71.28±1.39
Calcium (mg g^{-1})	1.05±0.02^{a}	1.17±0.02^{a}	0.92±0.01
Magnesium (mg g^{-1})	0.42±0.01^{a}	0.39±0.01^{a}	0.38±0.004
Kadaba forest			
Moisture (%)	25.76±0.62^{a}	13.95±0.50^{b}**	7.56±0.16
Temperature (°C)	24.69±0.05^{a}	26.76±0.09^{b}**	27.19±0.06
pH	4.93±0.03^{a}	4.65±0.02^{b}*	4.56±0.02
Conductivity (m mhos/cm)	0.49±0.01^{a}	0.58±0.004^{b}*	0.31±0.01
Organic carbon (g kg^{-1})	25.6±0.60^{a}	30.6±0.20^{b}*	21.7±0.20
Total phosphorus (µg g^{-1})	12.57±0.33^{a}	18.30±0.42^{b}*	6.59±0.26
Potassium (µg g^{-1})	48.29±0.69^{a}	66.66±0.85^{b}**	54.56±1.38
Calcium (mg g^{-1})	0.72±0.01^{a}	0.90±0.03^{a}	0.60±0.01
Magnesium (mg g^{-1})	0.27±0.01^{a}	0.37±0.01^{b}*	0.21±0.01
Madikeri forest			
Moisture (%)	22.51±0.34^{a}	8.54±0.14^{b}**	7.47±0.13
Temperature (°C)	19.69±0.11^{a}	23.75±0.07^{b}**	24.75±0.05
pH	5.21±0.03^{a}	4.81±0.03^{b}*	4.89±0.02
Conductivity (m mhos/cm)	0.53±0.01^{a}	0.31±0.01^{b}**	0.25±0.01
Organic carbon (g kg^{-1})	40.3±0.70^{a}	38.0±0.40^{a}	43.6±0.70
Total phosphorus (µg g^{-1})	10.38±0.18^{a}	12.25±0.20^{a}	11.26±0.25
Potassium (µg g^{-1})	51.33±1.40^{a}	62.17±1.06^{b} *	59.21±0.82
Calcium (mg g^{-1})	0.72±0.01^{a}	0.74±0.01^{a}	0.86±0.01
Magnesium (mg g^{-1})	0.27±0.01^{a}	0.40±0.01^{b}*	0.29±0.01

Figures across the second and third columns with different letters are significantly different (*, P < 0.05 ; **, P < 0.01)

In Kadaba forest, the biomass of pill millipedes was positively correlated with moisture ($P < 0.001$; $r = 0.68$) and negatively with temperature ($P < 0.001$; $r = -0.65$) in monsoon, during post-monsoon it was positively correlated with temperature ($P < 0.01$; $r = 0.73$) and potassium ($P < 0.05$; r=0.58). In Madikeri forest, the pill millipede biomass of was negatively correlated with temperature ($P < 0.05$; $r = -0.52$), while positively with conductivity ($P < 0.05$; r = 0.52) in post-monsoon. In Kadaba plantation, the earthworm biomass was negatively correlated with temperature ($P < 0.01$; $r = -0.63$) in monsoon and summer, while positively with total phosphorus ($P < 0.05$; $r = 0.53$). In Madikeri forest, the earthworm biomass was positively correlated with temperature ($P < 0.01$; $r = 0.69$) only during monsoon.

DISCUSSION

The diversity and richness of saprophagous fauna are influenced by wide range of human activities (e.g. landuse pattern, agricultural practices, forestry, wildlife management) [13-16]. Changes in climate and litter chemistry are the major factors govern the rates of organic matter decomposition by saprophagous fauna at the continental and global scales [17, 18]. It is known that the richness of millipedes will be higher in natural heterogeneous woodlands than homogeneous plantations [19, 20] and woodlands with closed than open canopy [19, 21]. Although most of the ecological conditions are congenial, millipedes are sensitive to narrow range of factors (e.g. litter thickness, soil texture)

[22] and will be authentic indicators of soil qualities (perturbation or restoration). Physical disturbances (e.g. ploughing, tilling) and application of chemicals in plantations have both beneficial and adverse effects on soil fauna [23-26].

Organic farming practice over a decade showed enormous increase of pill millipede population (*Arthrosphaera magna*) in a mixed plantation Adyanadka at the foothill of the Western Ghats [3]. Significant difference was seen in total biomass of *A. magna* between the mixed plantation and adjacent semi-evergreen forest [9]. The population density of *A. magna* was highest at mixed plantation than forest reserve denotes the colonization of pill millipedes from the forest. As mixed plantation consistently receives water and organic manure, the population of *A. magna* might have been elevated. The organic matter used in Adyanadka plantation includes coffee husk, coconut husk and poultry manure, farmyard manure and green manure. In addition to input of organic manure, intermittent sprinkler irrigation during post-monsoon through summer resulted in long-term activities of *A. magna*.

The current study also reveals single species dominance of pill millipedes in plantation and forests. Biomass and abundance of pill millipedes and earthworms significantly differed between monsoon and post-monsoon in Kadaba plantation and Madikeri forest, while only pill millipede biomass in Kadaba forest. Higher biomass and abundance of pill millipedes and earthworms in Kadaba plantation than Kadaba forest and Madikeri forest indicates that the plantation practices at least partly fulfills the requirement for colonization of pill millipedes and earthworms. However, Kadaba plantation and forest locations were devoid of pill millipedes during summer due to hibernation, while earthworms were seen throughout the year in all habitats.

Among the nine soil edaphic features studied, only soil temperature and pH were significantly differed between monsoon and post-monsoon in Kadaba plantation denotes that most of the soil edaphic factors are congenial for pill millipedes and earthworms (Table 2). Except for calcium (Kadaba forest) and organic carbon, total phosphorus and calcium (Madikeri forest), rest of the soil edaphic factors differed significantly between monsoon and post-monsoon shows drastic alteration of edaphic features in forests than plantation. The biomass of pill millipedes was higher in Madikeri forest than Kadaba forest probably due to thick forest cover. The low biomass of pill millipedes in Kadaba and Madikeri forests than Kadaba plantation during post-monsoon might be related to decreased soil moisture and elevated soil temperature. In Kadaba plantation, moisture and temperature regimes were more or less uniform during monsoon and post-monsoon (see Table 2). But, the soil moisture dropped during summer in spite of sprinkler irrigation (29.5-33.4 vs. 22.1%) and soil temperature elevated (25.2-25.9 vs. 27.1°C). Such changes might influence millipedes supports the view that millipedes are sensitive to narrow changes in edaphic factors. Although such moisture and temperature differences ware seen in forests, the moisture differences were wider than plantation (see Table 2).

In Adyanadka plantation, the biomass of *A. magna* during post-monsoon, summer and monsoon seasons was significantly differed than the adjacent forest reserve [9] indicating positive influence of organic farming practices on pill millipedes. The farming practices followed in Kadaba plantation was slightly differs from Adyanadka plantation [2, 9]. Kadaba plantation receives forest leaf litter, areca leaf litter and spent cow dung slurry of biogas plant during post-monsoon along with sprinkler irrigation during post-monsoon through summer. In Adyanadka plantation, adult *A. magna* exhibits surface activity earlier than forests (early or late June and extend up to January), while in adjacent forest, activity of adults confined to only four months (July to November) possibly due to decreased soil moisture. In Kadaba plantation, pill millipede activities initiate during early July and extend up to January. In Kadaba forest, millipede activities confined from July to November, while in Madikeri forest from June to October. This clearly indicates the moisture is very important for the extended activities of pill millipedes. In the current study, biomass and abundance of pill millipedes and earthworms were highest in Kadaba plantation than Kadaba forest and Madkieri forest (Fig. 1, 2).

Biomass of pill millipedes showed more or less one peak during monsoon, while earthworm during monsoon in Kadaba plantation and during post-monsoon in forests. The abundance of pill millipedes and earthworms showed two peaks during monsoon and post-monsoon in Kadaba plantation and Kadaba forest. In Madikeri forest, pill millipede abundance peaked in monsoon, while earthworm showed decreased abundance in monsoon and more or less constant elevation during post-monsoon and summer seasons. Millipedes were influenced by litter chemistry at narrow spatial scales (meters to decameters), while earthworms at higher order of soil physical conditions

[27]. Pill millipedes dominated in mixed plantation, while earthworms in forest reserve and such decrease has been predicted due to the limited moisture availability in forest especially during post-monsoon and summer [9]. In Kadaba plantation, biomass and abundance of pill millipedes and earthworms were higher than forests probably due to higher moisture regimes. The cuticular structures of millipedes are heavily encrusted with calcium or magnesium carbonates and millipedes enrich and help the cycling of calcium and magnesium in soil [28, 29]. In our study, the biomass of pill millipedes in post-monsoon significantly positively correlated with calcium and magnesium only in Kadaba plantation but not in forest locations. Calcium and magnesium in Kadaba plantation soils are relatively more than forest locations. Further investigations are necessary on the calcium and magnesium concentration of soils, leaf litter and fecal pellets of pill millipedes to understand the role of pill millipedes in recycling pattern in different habitats.

The major objective of the sustainable farming is to achieve long-term benefits with least adverse effects on the environment. Forest fragmentation and monoculture plantations are the major threats, which severely affect of the biodiversity and conservation of wildlife. Mixed plantation devoid of fragmentation and exclusive organic farming practices would support soil saprophagous fauna. It is interesting to study the precise nature of plantation practices necessary in Western Ghats for colonization of pill millipedes. Increased pill millipede population in Adyanadka (*A. magna*) and Kadaba (*A. dalyi*) plantations reveals the importance of organic farming practices to support the pill millipede population and activities for sustainable agriculture. Earlier studies [8, 9] and the current study clearly indicate the intra-site heterogeneity in organic matter is very important for survival and extended activities of pill millipedes in Western Ghats.

ACKNOWLEDGEMENTS

Authors are grateful to Mangalore University for permission to carry out studies on pill millipedes. This study constitutes part of Ph.D. thesis of BSK conducted during the tenure of Faculty Improvement Programme (University Grants Commission, New Delhi). BSK is thankful to the Principal, FMKMC College (Mangalore University), Madikeri for support. We appreciate technical assistance rendered by Dr. K.M. Ashwini, Varanashi Research Farms, Adyanadka, Karnataka.

REFERENCES

1. Anderson, J.M., P. Ineson and S.A. Huish, 1983. Nitrogen and cation mobilization by soil fauna feeding on leaf litter and soil organic matter from deciduous woodlands. Soil Biol. Biochem., 15: 463-467.
2. Morgan, C.R., S.C. Schindler and M.J. Mitchell, 1989. The effects of feeding by *Oniscus osellus* (Isopoda) on nutrient cycling in an incubated hardwood forest soil. Biol. Fert. Soils., 7: 239-246.
3. Ashwini, K.M. and K.R. Sridhar, 2002. Towards organic farming with millipede - *Arthrosphaera magna*. Current Science, 82: 20-22.
4. Achar, K.P., 1986. Analysis of male meiosis in seven species of Indian pill-millipede (Diplopoda: Myriapoda). Caryologia, 39: 89-101.
5. Achar, K.P., 1987. Chromosomal evolution in Diplopoda (Myriapoda: Arthropoda). Caryologia, 40: 145-155.
6. Attems, C., 1936. Diplopods of India. Mem. Indian Mus., 11: 133-167.
7. Pocock, R.I., 1899. A monograph of the pill-millipedes (Zephroniidae) inhabiting India, Cylon and Burma. J. Bombay Nat. Hist. Soc., 12: 269-285.
8. Ashwini, K.M. and K.R. Sridhar, 2008. Distribution of pill millipedes (*Arthrosphaera*) (Family; Sphaerotheriidae) and associated soil fauna in the Western Ghats and west coast of India. Pedosphere, 18: 749-757.
9. Ashwini, K.M. and K.R. Sridhar, 2006. Seasonal abundance and activity of pill millipedes (*Arthrosphaera magna*) in plantation and semi-evergreen forest of Southern India. Acta Oecologica, 29: 27-32.
10. Chopra, S.L. and J.S. Kanwar, 1982. Analytical agricultural chemistry. Kalyani publishers, New Delhi, India.
11. Jackson, M.L., 1973. Soil Chemical Analysis. Prentice Hall International, New Delhi, India.
12. StatSoft, Inc. 1995. STATISTICA for Windows. Tulsa, OK, USA.
13. Curry, J.P., 1994. Grassland invertebrates: Ecology, Influence on soil Fertility and Effects on Plant Growth. Chapman and Hall, London.
14. Didham, R.K., J. Ghazoul, N.E. Stork and A.J. Davis, 1996. Insects in fragmented forests. TREE. 11: 255-260.

15. Edwards, C.A. and P.J. Bohlen, 1995. Biology of Earthworms. Chapman and Hall, New York.
16. Wardle, D.A., 1995. Impact of disturbance on detritus food webs in agro-ecosystems of contrasting tillage and weed management practices. Adv. Ecol. Res., 26: 105-185.
17. Aerts, R., 1997. Climate, leaf litter chemistry and leaf litter decomposition in terrestrial ecosystems: a triangular relationship. Oikos, 79: 439-449.
18. Meentenmeyer, V., 1978. Macroclimate and lignin control of litter decomposition rates. Ecology, 59: 465-472.
19. Dangerfield, J.M., 1990. Abundance, biomass and diversity of soil macrofauna in savanna woodland and associated managed habitats. Pedobiologia, 34: 141-150.
20. Dangerfield, J.M. and S.R. Telford, 1992. Species diversity of Julid millipedes: Between habitat comparisons within the seasonal tropics. Pedobiologia, 36: 321-329.
21. David, J.F., S. Devernay, G. Loucougarry and E. Le Floc'h, 1999. Belowground biodiversity in a Mediterranean landscape: relationships between saprophagous macroarthrorpod communities and vegetation structure. Biodiver. Conser., 8: 753-767.
22. Kime, R.D. and S.I. Golovatch, 2000. Trends in the ecological strategies and evolution of millipedes (Diplopoda). Biol. J. Linn. Soc., 69: 333-349.
23. Raw, F., 1967. Arthropods (except Acari and Collembola). In: Soil Biology, Burges, N. and J. Raw, (ed.), Academic Press, London, pp: 323-362.
24. Edwards, C.A. and J.R. Lofty, 1969. The influence of agricultural practice on soil macroarthropod populations. In: The Soil Ecosystem, Sheals, J.G. (ed.), Systematic Association, London, pp: 237-247.
25. Cook, A.G., B.R. Critchley, V. Critchley, T.J. Perfect, A. Russell-Smith and R. Yendon, 1979. The effects of soil treatment with D DT on the biology of a cultivated forest soil in the sub-humid tropics. Pedobiologia, 19: 279-292.
26. Perfect, T.J., A.G. Cook, B.R. Critchley and A. Russell-Smith, 1981. The effect of crop protection with DDT on the macroarthropod population of a cultivated forest soil in the sub-humid tropics. Pedobiologia, 21: 7-18.
27. Warren, M.W. and X. Zou, 2002. Soil macrofauna and litter nutrients in three tropical tree plantations on a disturbed site in Puerto Rico. Forest Ecol. Manage., 170: 161-171.
28. Crossley, D.A. Jr., 1996. Macroinvertebrates and their relationship to coarse woody debris: with special reference to land snails. In: Biodiversity and Coarse Woody Debris in Southern Forests, Caldwell, R.S. and J.W. McMinn (ed.), Cumberland Mountain Research Center, Lincoln Memorial University, Harrogate, USA, pp: 49-54.
29. Enghoff, H., 1990. The ground-plan of chilognathan millipedes (external morphology). In: Proceedings of the 7th International Congress of Myriapodology, Minelli, A. (ed.), E.J. Brill, Leiden, Netherlands, pp: 1-21.