Tropical Ecology **42**(1): 51-58, 2001 ISSN 0564-3295

Efficiency of detritivore soil arthropods in mobilizing nutrients from leaf litter

R. PRAMANIK, K. SARKAR & V.C. JOY[1]

Soil Zoology Laboratory, Department of Zoology, Visva-Bharati University, Santiniketan - 731 235, West Bengal, India

Abstract: The feeding effect of detritivore soil arthropods namely *Porcellio laevis* (Isopoda: Crustacea) and *Anoplodesmus saussurei* (Polydesmida : Diplopoda) could mobilize important nutrients from decomposing leaf litter under microcosm conditions. Their feeding effect was compared against the nutrient status of soil and density of soil microarthropod fauna in three young monoculture plantations of *Acacia auriculiformis, Cassia siamea* and *Shorea robusta*. The arthropods extracted from seasonal field samples using 'Tullgren' funnels were identified up to major taxonomic categories. Microbial decomposition of litter was sufficient to release potassium into the sand bed of microcosms but significantly high rates of nitrates, calcium and organic carbon were released by the animal activity. Feeding interaction between the 2 species had synergistic effect in sequestering the nutrients particularly calcium and nitrates. Slow rate of feeding by the isopod produced gradual release of calcium and organic carbon but voracious feeding of the diplopod resulted into high rate of release of all the nutrients. In the afforested condition, a large population of microarthropods and higher amounts of all the above nutrients characterized the soil of *Cassia* plantation. On the contrary, soil of *Acacia* and *Shorea* stands contained less microarthropod density and low nutrient status. Acari predominated over Collembola in all the sites indicating rapid rate of litter decomposition. The soil under *Cassia* trees had uniformly high microarthropod population during all the seasons suggesting improved ecological conditions. Similarly, high nutrient content in the soil of *Cassia* plantation, particularly calcium could be attributed to the functional significance of a rich population of decomposer arthropods. Leaf litter of *Cassia* trees is a good organic source for improving the decomposer arthropod population and nutrient status in afforested soil.

Resumen: El efecto de la alimentación de los artrópodos detritívoros del suelo *Porcellio laevis* (Isopoda: Crustacea) y *Anoplodesmus saussurei* (Polydesmida: Diplopoda) podría movilizar nutrientes importantes del mantillo foliar en descomposición en condiciones de microcosmo. El efecto de la alimentación de estos organismos fue comparado con la situación nutricional del suelo y la densidad de la fauna de microartrópodos del suelo en tres plantaciones jóvenes en monocultivo de *Acacia auriculiformis, Cassia siamea* y *Shorea robusta*. Los artrópodos extraídos de muestras de campo estacionales usando embudos 'Tullgren' fueron identificados hasta categories taxonómicas mayors. La descomposición microbiana del mantillo fue suficiente para liberar potasio hacia la cama arenosa del microcosmo, pero solo la actividad animal fue capaz de liberar nitratos, calico y carbono orgánico a tasas significativamente altas. La interacción alimenticia entre las dos especies tuvo un efecto sinérgico en el secuestro de nutrientes, particularmente de calico y nitratos. La baja tasa alimenticia del isópodo produjo una liberación gradual de calico y carbono orgánico, pero la alimentación voraz del diplópodo resultó en un tasa alta de liberación de todos los nutrients. En condiciones de repoblamiento con árboles, una población grande de microartópodos y cantidades mayores de todos los nutrientes arriba mencionados caracterizaron el suelo de la plantación de *Cassia*. Por el contrario, los

[1]*Corresponding Author*

Suelos de los rodales de *Acacia* y *Shorea* contuvieron una densidad menor de microartrópodos y una condición nutricional más pobre. Los ácaros predominaron sobre los colémbolos en todos los sitios, hecho que indica una tasa rápida de descomposición del mantillo. El suelo bajo árboles de *Cassia* tuvo una población de microartrópodos uniformemente alta durante todas las estaciones, lo que sugiere un mejoramiento de las condiciones ecológicas. De manera similar, el contenido alto de nutrientes en el suelo de la plantación de *Cassia*, particularmente de calico, podría atribuirse al significado functional de una población rica en artrópodos descomponedores. El mantillo foliar de árboles de *Cassia* es una Buena fuente orgánica para el mejoramiento de la población de atropodos descomponedores y de la condición nutricional en suelos donde hay un Nuevo repoblamiento de árboles.

Resumo: O efeito da alimentação dos artrópodes detrívoros no solo, nomeadamente da *Porcellio laevis* (Isopoda: Crustacea) e de *Anoplodesmus saussurei* (Polydesmida: Diploda) pode mobilizar nutrientes importantes da folhada em decomposição sob condições micro-cósmicas. O seu efeito alimentar foi comparado em confronto com o status nutricional do solo e densidade da microfauna microartrópoda do solo em três plantações monoculturais jovens de *Acacia auriculiformis*, *Cassia siamea* e *Shorea robusta*. Os artrópodes extraídos de amostras estacionais de campo, usando funis de "Tullgren", foram identificados quanto às suas categorias taxonómicas principais. A decomposição da folhada era suficiente para a libertação do potássio no substrato de areia do micro cosmos se bem que a actividade animal tenha possibilitado uma taxa de libertação significativamente mais elevada em nitrato, cálcio e carbono orgânico. A interacção entre as duas espécies apresentavam um efeito sinergístico na captação de nutrientes particularmente do cálcio e dos nitratos. Uma taxa de alimentação dos isópodas produziram uma libertação gradual do cálcio e do carbono orgânico enquanto que uma alimentação voraz pelos diplodos implicaram uma elevada taxa de libertação de todos os nutrientes. Nas condições de florestação, uma elevada população de microartrópodes e elevados teores dos referidos nutrientes caracterizavam os solos das plantações de *Cassia*. Pelo contrário, o solo das parcelas de *Acacia* e *Shorea* continham menor densidade em microartrópodes e menor status nutricional. Os Acari predominavam sobre os Collembola em todas as estações indicando uma taxa de decomposição rápida da folhada. O solo sob árvores de *Cassia* tinha uma população de microartrópodes uniformemente mais elevada durante todas as estações, sugerindo melhores condições ecológicas. Similarmente, o mais elevado teor de nutrientes no solo das plantações de *Cassia*, particularmente de cálcio, pode ser atribuído ao significado funcional de uma população rica de artrópodes decompositores. A folhada das árvores de *Cassia* é uma boa fonte orgânica para melhorar a população de artrópodos decompositores e o estado nutricional dos solos florestados.

Key words: Afforestation, litter decomposition, microcosm, soil arthropods, soil nutrients.

Introduction

Organic matter decomposition in soil is performed by a dynamic system of microflora and invertebrate fauna and their synergistic interactions play a very important role in enhancing the nutrient release. Saprophagous soil animals are the "key" for mobilization of nutrients "locked" in microbial and higher plant tissues. Setala *et al.* (1998) while discussing the functional diversity in decomposer systems noted that when soil fauna, that is, consumers in detrital food webs, are removed from heterotrophic decomposition systems the activity of soil microbes may decrease dramatically, leading to reduced carbon and nitrogen mineralization. Decomposition thus represents an ecological service for the whole ecosystem, as 60-90% of terrestrial primary production is decomposed in the soil (Giller 1996). Studies on the role of soil fauna in ecosystem functioning require accurate characterization of the soil community food web, identifying the potentially important species and groups as well as the interactions among them (de Ruiter *et al.* 1997). Proper understanding on the contribution of different faunal groups to the ecosystem process are required for developing environmentally sound management practices and strategies to safeguard the biodiversity and soil fertility. The population density and metabolic rates of decomposer animals are comparatively high in tropical rain forests (Lee 1991) but very little information is available on their functional role in tropical and subtropical ecosystems. It is extremely difficult to isolate and quantify the role of even major species of soil arthropod decomposer fauna under field conditions. Their contribution to the ecosystem can be only indirectly assessed from performance criteria like density, succession and diversity with respect to input of organic matter and output of inorganic nutrients. However, the functional role of major decomposer species can be estimated under controlled laboratory conditions in microcosms for comparison with the above properties of detritus feeding guild under natural field conditions. In the present paper the feeding effect of two model species of detritivore soil arthropods on the rate of mobilization of important nutrients from decomposing leaf litter has been compared with the nutrient status of soil and density of major soil arthropod groups for evaluating the success of afforestation and suitability of different leaf litter types in enhancing biological activity and nutrient status of soil.

Materials and methods

Laboratory study

Adult specimens of *Porcellio laevis* (Isopoda: Crustacea) and *Anoplodesmus saussurei* (Polydesmida: Diplopoda) were collected in large numbers from litter beds and maintained in the laboratory on decomposing leaf litter. The microcosms were prepared in polythene rearing vessels 250 cm^3) containing a bottom layer of 50 g washed and sterile river sand as substratum and 2 g leaf litter cuttings as food source. Known number of animals were introduced into the experimental vessels arranged into single species sets (*P. laevis*, 10; *A. saussurei*, 5) and combination sets (*P. laevis*, 10 + *A. saussurei*, 5) for comparison with control sets without animals. The vessels were maintained at controlled moisture (20% approximately), temperature (27 ± 1^{o}C) and photoperiod (16 hd + 8 hl) conditions in a B.O.D. incubator. Small quantity of distilled water was regularly added in the vessels to maintain the moisture. Dead specimens, if any, were also replaced during the routine check-ups. From each set three vessels were randomly sampled at fortnightly intervals for quantitative estimation of nutrients incorporated into the sand bed. All the litter fragments and specimens were discarded before processing the sand for analysis. Available nitrate nitrogen was estimated spectrophotometrically by phenol-di-sulphonic acid method and the optical density measured at 420 nm was compared against standard curve of pure potassium nitrate (Jackson 1962). Micronutrients namely calcium and potassium were estimated using a digital flame photometer calibrated against pure potassium chloride and calcium carbonate solution respectively. Organic carbon content was estimated by Walkley and Black's rapid titration method in which the amount of potassium dichromate utilized during chromic acid digestion of the sample was used for calculating the percentage of oxidisable organic carbon content (Jackson 1962). The results were statistically analyzed using 'tw' test, a modified version of 't' test (Snedecor & Cochran 1967).

Field study

Three different monoculture plantations (approximately 5 years old) of *Acacia auriculiformis, Shorea robusta* and *Cassia siamea* in the Ballavpur reserve forest near Santiniketan were selected for the field studies. These trees are extensively used in this area for afforestation and restoration of lost edaphic characteristics. Random soil samples of the size 5 x 5 x 5 cm were collected from the sites at seasonal intervals during the period from October 1996 to May 1998 to compare the arthropod fauna and nutrient status of soil. The arthropods extracted from the samples using modified 'Tullgren' funnels were identified up to major taxonomic categories. The soil samples were then processed for estimation of nitrate nitrogen, calcium, potassium and organic carbon as mentioned above.

Results

In the laboratory microcosms the average amounts of nitrate nitrogen, calcium, potassium and organic carbon in the sand medium of different sets (Fig. 1) and statistical validity of differences between sets (Table 1) clearly demonstrated that feeding by detritivore arthropods could enhance the release of nutrients from leaf litter. The amount of free nitrates and calcium were significantly low in the SL set without animals. Feeding by *P. laevis* could not mobilize the amount of available nitrates whereas it increased to a very high level in the set of *A. saussurei*. Both species could enhance the release of calcium but here also the role of the diplopod was greater than that of the isopod. Microbial decomposition of leaf litter was sufficient to release potassium into the sand medium ($P<0.01$) but the feeding activity by *A. saussurei* could further enhance the amount of potassium ($P<0.01$). On the other hand, both microbial and faunal actions were able to increase the level of organic carbon to statistically significant levels. Table 1 also shows that feeding interaction between *P. laevis* and *A. saussurei* had synergistic effect on the release of all nutrients particularly calcium and nitrates. Earlier studies have showed that *P. laevis* feeds at a steady low rate but *A. saussurei* feeds voraciously on leaf litter after certain degree of decomposition. Table 2 incorporates the rate of nutrient release from decomposing leaf litter estimated at fortnightly intervals. Noteworthy features are the uniformly low profile of nutrients in the SL set except for potassium. Regarding faunal impact, the steady rate of feeding by *P. laevis* was instrumental in gradually enhancing the level of calcium and organic carbon. The contribution of *A. saussurei* was remarkable in all the cases, but a close comparison of the multitude of nutrient release undoubtedly shows its ability to sequester nitrates at very high rates. The mobilization of calcium and organic carbon in SLP set also indicated steady rate of feeding by *P. laevis* on leaf litter. Whereas the high values of all the nutrients in SLA and SLAP sets towards the last part of experiment suggested voracious feeding habit of the diplopod only after certain degree of decomposition of leaf litter.

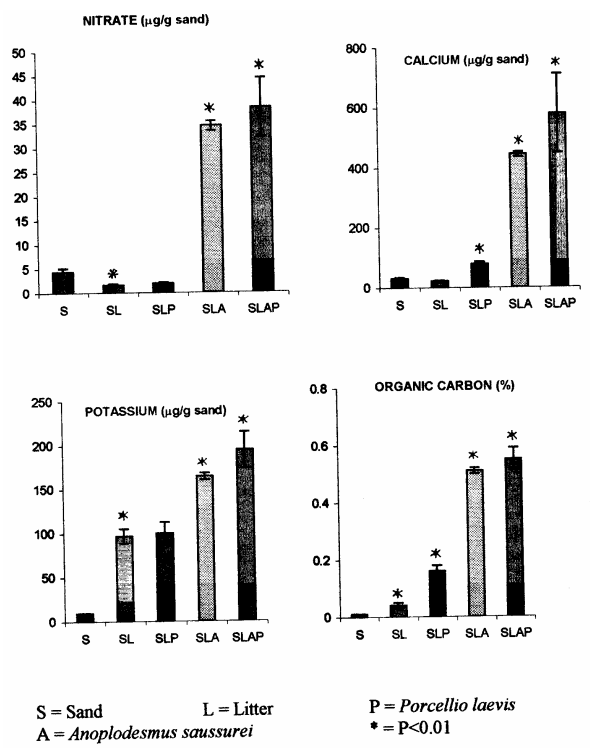

Fig. 1. Effect of microbial and faunal activity in mobilizing nutrients from decomposing leaf litter in different microcosm sets. (* = $P<0.01$)

Noteworthy features of the community struc-

Table 1. Statistical validity of the differences in the amount of nutrients mobilized from leaf litter in different microcosm sets.

Nutrients	Combinations		Deviation	tw	P
Nitrate nitrogen	S	SL	-2.69	1.08	<0.01
	SL	SLP	+0.52	0.29	n.s
	SL	SLA	+19.08	0.49	<0.05
	SL	SLPA	+36.71	0.70	<0.01
	SLP	SLA	+18.56	0.46	<0.05
Calcium	S	SL	-8.38	0.53	<0.02
	SL	SLP	+51.15	1.78	<0.01
	SL	SLA	+351.58	1.06	<0.01
	SL	SLPA	+557.01	1.08	<0.01
	SLP	SLA	+300.43	0.88	<0.01
Potassium	S	SL	+87.84	3.44	<0.01
	SL	SLP	-4.32	0.07	n.s
	SL	SLA	+53.54	0.75	<0.01
	SL	SLPA	+97.38	1.24	<0.01
	SLP	SLA	+57.86	0.71	<0.01
Organic carbon	S	SL	+0.035	1.75	<0.01
	SL	SLP	+0.092	0.71	<0.01
	SL	SLA	+0.12	0.52	<0.02
	SL	SLPA	+0.51	1.76	<0.01
	SLP	SLA	+0.33	1.03	<0.01

S = pure sand, L = leaf litter, P = *Porcellio laevis*, A = *Anoplodesmus saussurei*

Table 2. Rate of nutrient mobilization from decomposing leaf litter in different microcosm sets.

Experimental sets	Amount of nutrients (mean ± S.D.) at fortnightly intervals					
	2 weeks	4 weeks	6 weeks	2 weeks	4 weeks	6 weeks
	Nitrate nitrogen (μg g^{-1})			Calcium (μg g^{-1})		
S	4.3 ± 0.3	3.6 ± 0.9	5.1 ± 1.2	25.3 ± 2.4	32.7 ± 3.1	34.6 ± 3.3
SL	1.2 ± 0.2	1.1 ± 0	2.6 ± 0.5	17.5 ± 1.2	28.0 ± 4.7	21.8 ± 1.3
SLP	2.7 ± 0.1	2.0 ± 0.3	1.1 ± 0.2	61.3 ± 9.3	79.7 ± 12.7	92.0 ± 4.6
SLA	4.4 ± 0.1	16.3 ± 1.3	83.2 ± 1.6	52.0 ± 3.5	590.0 ± 10.0	691.7 ± 12.3
SLPA	3.9 ± 0.1	18.3 ± 4.4	92.9 ± 13.8	38.9 ± 7.9	719.4 ± 266.7	980.0 ± 121.3
	Potassium (μg g^{-1})			Organic carbon (%)		
S	9.3 ± 0	8.8 ± 0	9.5 ± 1.2	0.01 ± 0	-	-
SL	77.8 ± 6.9	101.5 ± 6.2	111.8 ± 11.2	0.02 ± 0.01	0.02 ± 0.01	0.07 ± 0.01
SLP	77.7 ± 17.9	96.3 ± 9.1	127.0 ± 10.6	0.07 ± 0.03	0.15 ± 0.01	0.27 ± 0.02
SLA	125.0 ± 5.0	155.0 ± 5.0	214.0 ± 1.0	0.28 ± 0.01	0.56 ± 0.01	0.68 ± 0.02
SLPA	150.4 ± 9.3	199.6 ± 37.2	233.3 ± 14.9	0.30 ± 0.07	0.59 ± 0	0.76 ± 0.06

S = pure sand, L = leaf litter, P = *Porcellio laevis*, A = *Anoplodesmus saussurei*

ture of soil arthropod fauna are depicted in Table 3. Their average density (Number m^{-2}) was highest in the soil of *Cassia* plantation. Similarly the population of major groups like Acari and Collembola were more in *Cassia* when compared to the other sites. Predominance of Acari over Collembola could be noticed in all the cases indicating rapid rate of decomposition of leaf litter. Table 3 also shows the seasonal pattern of distribution of soil arthropod fauna in the afforested study sites. The influence of climatic parameters on soil arthropod fauna was evident in *Acacia* plantation with higher density during post monsoon season when compared to low population during winter. On the other hand, more or less uniformly high population in the soil of *Cassia* plantation during all the 3 seasons was indicative of improved ecological conditions. Similarly, low density of arthropods in the soil of *Shorea* plantation suggested the absence of proper resources in any of the 3 seasons under consideration.

Fig. 2 represents the summary of findings on the average amounts of important nutrients in the soil of 3 afforested sites. The importance of litter decomposition in enhancing soil fertility was clearly evident in the *Cassia* plantation from higher values for all the nutrients. On the contrary, all the nutrients registered low values in the soil under *Shorea* trees. The amount of nitrate nitrogen, organic carbon and potassium were moderate in all the sites but the amount of calcium was very high in the soil of *Cassia* when compared

Table 3. Density (number m^{-2}) of soil arthropod fauna in the afforested study sites.

Soil arthropod density (No m^{-2})	Soil arthropod groups					
	Afforested sites	Acari	Collembola	Insects other than Collembola	Arthropods other than Acari and Collembola	Total
Group wise density	*Acacia*	3819	790	524	10	5143
	Cassia	12067	2190	1267	48	15571
	Shorea	3010	467	295	38	3810
		Post monsoon	Winter		Summer	Total
Overall seasonal density	*Acacia*	3076	1200		867	5143
	Cassia	5657	4381		5533	15571
	Shorea	1039	1343		1428	3810

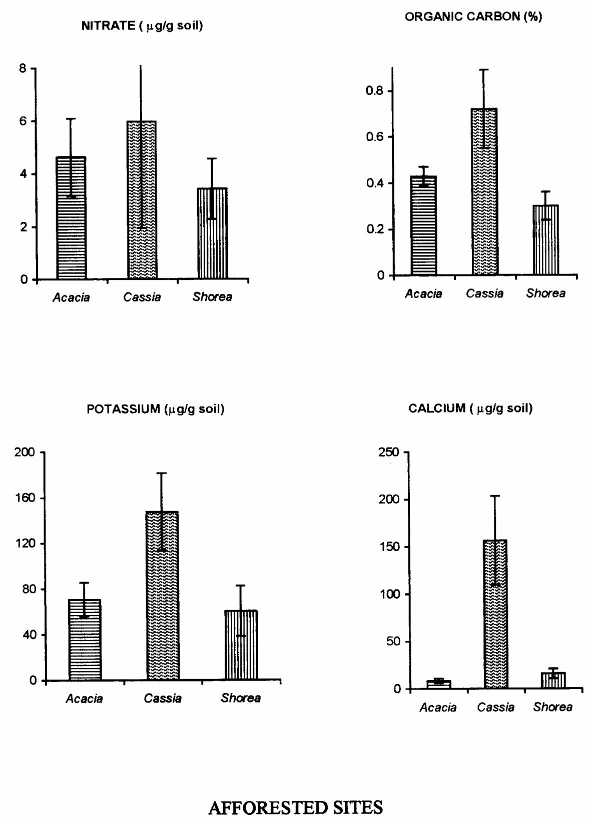

Fig. 2. Average amounts of nutrients in the soil of afforested study sites.

to negligible amount in *Acacia* and *Shorea* plantations. This is in full agreement with the laboratory findings on the role of 2 model decomposer arthropod species in nutrient mobilization. It was demonstrated that microbial decomposition of litter is sufficient to leach out the loosely bound potassium whereas calcium is undoubtedly mobilized by the feeding activity of detritivores. The present field study suggests that decomposing leaf litter of *Cassia* trees is a good source for improving decomposer arthropod population in soil thereby enabling effective mobilization of essential nutrients.

Discussion

The impact of decomposer arthropods in enhancing nutrient availability in soil could be established from the present microcosm findings. It is known that incorporation of organic matter in soil results in profuse growth of saprotrophic organisms. Wolters & Ekschmitt (1997) have described the saprophagous microarthropods as 'direct decomposer' which ingest the comminuted litter and rework on relatively undecomposed organic matter. According to Ananthakrishnan (1996) the complexity of bacterial, fungal and faunal community structure, their interaction and function in organic matter decomposition and nutrient cycles are essential aspects of litter studies, particularly in tropical forests. The relative importance of 2 species of arthropods was clearly evident from the present laboratory results. Addition of leaf litter enhanced microbial action and heterotrophic utilization of nutrients as evident from very low level of free mineral nitrogen in the SL set. The role of *P. laevis* in mobilizing the nutrients was less evident when compared to the feeding impact of *A. saussurei*. Several workers have demonstrated the role of micro- and macroarthropods (Bano & Krishnamoorty 1981; Guru & Panda 1991) in regulating C/N ratio during litter decomposition and humification processes. In the present microcosm experiment the functional role of decomposer arthropod fauna was assessed from a different angle to measure the rate of nutrients released into the medium. Soil invertebrates can enhance the rate of decomposition and microfloral activity through a number of mechanisms including comminution, removal of senescent colonies, enrichment of nitrogenous energy materials and elimination of bacteriostasis and mycostasis. Ambasht & Srivastava (1995) noted that physical and chemical changes occurring during litter decomposition are governed by chemical composition of litter, range of decomposer organisms and the environmental regimes under which the decomposition occurs. Anderson *et al.* (1983) found that sodium and potassium leached rapidly and easily from litter so that faunal impact on their cycling is minimum. On the other hand, feeding by decomposer fauna was important in releasing biologically bound calcium and nitrogen. This was in full agreement with the present findings that feeding by detritivore arthropods on leaf litter could enhance the rate of mobilization and enrichment of nutrients in the environment readily available for the uptake by plant roots.

Afforestation helps in the improvement of edaphic characteristics and the ecological gains, though occur at a slow pace are very significant for soil conservation with increase in nutrient status and stability and diversity of decomposer community. In general, the decomposer fauna acts as catalysts of microbial activity and hence can boost the progress of litter decomposition. The relative role of different groups and trophic levels in nutrient release vary with respect to their density, biomass and longevity. As these organisms ingest and digest both energy and nutrients are released from the organic matter, divided and spread throughout the biota and into the environment (Dindal 1978). Predominance of Acari and Collembola among soil and litter inhabiting arthropods has been demonstrated under temperate and tropical climatic conditions. The relative importance varies with respect to the volume of litter and rate of decomposition on the forest floor. Greater abundance of soil Acari was recorded by Singh (1977) in the floor of a Shal forest at Varanasi, whereas Prabhoo (1976) showed highest number of Collembola among soil arthropod fauna in the Western Ghat forests of Kerala. Joy *et al.* (1986) compared the density and diversity of soil microarthropods in six monoculture plantations at Santiniketan and found predominance of Acari over Collembola in all the sites. The relative role of these microarthropods in decomposition and nutrient release are controlled by the availability of nutrients, moisture content and organic matter in soil. While comparing the biomass of quantitatively principal functional groups of microarthropods with the organic matter and pore space distribution in soil, Vreeken-Buijs *et al.* (1998) noticed positive correlation of saprovorous cryptostigmatid mites with lighter organic matter fraction and small pore sizes whereas non-cryptostigmatid mites and omnivorous Collembola were correlated with heavy organic matter fraction and largest pore spaces of soil. Similarly, their population is controlled by the cumulative action of different climatic factors. Singh (1977) recorded maximum number of Acari and Collembola during July-August but minimum in November. Pillai & Singh (1980) recorded definite pattern of population fluctuation with peak during rainy season followed by winter and in the hot and dry summer months soil arthropod population was very low. Similarly, Reddy (1995) collected very few or no arthropods in the leaf litter of *Tectona* and Bamboo during the dry season, while larger densities of arthropods occurred during the wet season in tropical deciduous forest. However, we could find site-specific differences in their seasonal distribution with more or less uniform high population during all the seasons in *Cassia* plantation. Therefore, comparison of the density and diversity of arthropod fauna inhabiting forest soil and other diverse habitats with respect to edaphic and climatic parameters shall indicate stability of the system and impact of abiotic parameters in regulating the biological functioning and faunal activities.

Conclusions

Feeding by 2 model detritivore species of soil arthropods could enhance the mobilization of important nutrients from decomposing leaf litter under microcosm conditions. Microbial action on litter was sufficient to release potassium into the sand bed whereas feeding by the animals facilitated release of calcium, nitrates and organic carbon. Feeding interaction between the two species had synergistic effect in sequestering the nutrients particularly calcium and nitrates. The steady rate of feeding by the isopod produced gradual release of calcium and organic carbon but voracious feeding habit of the diplopod after certain degree of litter decomposition resulted in high rate of release of all the nutrients. In the afforested field, a large population of microarthropods and higher amounts of nutrients characterized the soil of *Cassia* plantation. On the contrary, the soil of *Acacia* and *Shorea* stands contained less microarthropod density and low nutrient status. Acari predominated over Collembola in all the sites indicating rapid rate of litter decomposition. The soil under *Cassia* trees had uniformly high microarthropod population during all the seasons suggesting improved ecological conditions. Similarly, high nutrient content in the soil of *Cassia* plantation, particularly calcium could be attributed to the functional significance of a rich population of decomposer arthropods as evidenced from the role of model detritivore species in microcosms.

Acknowledgements

The authors are grateful to the Head, Department of Zoology (DSA, UGC), Visva-Bharati University, for providing laboratory and other facilities. They are also thankful to the Ministry of Environment and Forests, New Delhi, for financial support in the form of a major research project (14/18/94-MAB/RE).

References

Ambasht, R.S. & K. Srivastava. 1995. Tropical litter decomposition : A holistic approach. pp. 225-247. *In*: M.V. Reddy (ed.) *Soil Organisms and Litter Decomposition in Tropics*. Oxford & IBH Publ. Co. Ltd., New Delhi.

Ananthakrishnan, T.N. 1996. *Forest Litter Insect Communities - Biology and Chemical Ecology*. Oxford & IBH Publ. Co. Ltd., New Delhi.

Anderson, J.N., P. Ineson & S.A. Huish. 1983. Nitrogen and cation mobilization by soil fauna feeding on leaf litter and soil organic matter from deciduous woodland. *Soil Biology & Biochemistry* **15**: 463-467.

Bano, K. & R.V. Krishnamoorty. 1981. Relative rates of litter decomposition and humification of various soils by the millipede, *Jonespeltis splendidus*. pp. 87-92. *In*: G.K. Veeresh (ed.) *Progress in Soil Biology & Ecology in India*. UAS Tech. Series No. 37, Bangalore.

de Ruiter, P.C., A.M. Neutel & J.C. Moore. 1997. Soil food web interactions and modeling. pp. 363-386. *In*: G. Benckiser (ed.) *Fauna in Soil Ecosystems*. Marcel Dekker Inc., New York.

Dindal, D.L. 1978. Soil organisms and stabilizing wastes. Compost science/land utilization. *Journal of Waste Recycling* **19**: 8-11.

Giller, P.S. 1996. The diversity of soil communities, the "poor man's tropical rainforest". *Biodiversity Conservations* **5**: 135-168.

Guru, B.C. & S. Panda. 1991. The role of *Cryptopygus thermophilus* (Collembola) in regulating C/N ratio. pp. 75-89 *In*: G.K. Veeresh, D. Rajagopal & C.A. Viraktamath (eds.) *Advances in Management and Conservation of Soil Fauna*. Oxford & IBH Publ. Co. Pvt. Ltd., New Delhi.

Jackson, M.L. 1962. *Soil Chemical Analysis*. Asia Publishing House, New Delhi.

Joy, V.C., N. Roy & J. Bhattacharya. 1986. Phytogenic composition of litter and soil inhabiting microarthropods in an artificial forest at Santiniketan. *In*: N.R. Prabhoo (ed.) *Proceedings of III Oriental Entomology Symposium*, Trivandrum.

Lee, K.E. 1991. The role of soil fauna in nutrient cycling. pp. 465-472. *In*: G.K. Veeresh, D. Rajagopal & C.A. Viraktamath (eds.) *Advances in Management and Conservation of Soil Fauna*. Oxford & IBH Publ. Co. Pvt. Ltd., New Delhi.

Pillai, K.S. & J. Singh. 1980. The composition of soil microarthropods in a grassland ecosystem of upper Gangetic plain. pp. 24-34. *In* N.R. Prabhoo (ed.) *Proceedings of Symposium on Environmental Biology*, Trivandrum.

Prabhoo, N.R. 1976. Soil microarthropods of a virgin forest and adjoining tea fields in the Western Ghats in Kerala - a brief ecological study. *Oriental Insects* **10**: 435-442.

Reddy, M.V. 1995. Liter arthropods. pp. 113-140. *In*: M.V. Reddy (ed.) *Soil Organisms and Litter Decomposition in the Tropics*. Oxford & IBH Publ. Co. Pvt. Ltd., New Delhi.

Setala, H., J. Laakso, J. Mikola & V. Huhta. 1998. Functional diversity of decomposer organisms in relation to primary production. *In*: C.A. Edwards & J.P. Curry (eds.). *Applied Soil Ecology; Special issue XII International Colloquium on Soil Zoology* **9**: 25-31.

Singh, U.R. 1977. Relationship between the population density of soil microarthropods and mycoflora associated with litter and total litter respiration on the floor of a Sal forest in Varanasi, India. *Ecological Bulletin (Stockholm)* **25**: 463-470.

Snedecor, G.W. & W.G. Cochran. 1967. *Statistical Methods.* 6th Edition. Oxford & IBH Publ. Co. Pvt. Ltd., Calcutta.

Vreeken-Buijs, M.J., J. Hassink & L. Brussaard. 1998. Relationships of soil microarthropod biomass with organic matter and pore size distribution in soils under different land use. *Soil Biology & Biochemistry* **30**: 97-106.

Wolters, V. & K. Ekschmitt. 1997. Gastropods, Isopods, Diplopods & Chilopods; Neglected groups of the decomposer food web. pp. 265-306. *In*: G. Benckiser (ed.) *Fauna in Soil Ecosystems*. Marcel Dekker Inc., New York.