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Microarthropod Diversity Associated with Vermicomposting Process and Vermicompost of Municipal Solid Wastes Processed by Three Earthworm Species

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ABSTRACT

The present investigation assessed, for the first time, the species diversity of microarthropods associated with the vermicompost (VC) and compost (C) of the organic fraction of three types of urban wastes – municipal solid waste (MSW), vegetable market waste (MW) and flower waste (FW) – processed by three earthworm species, *Eudrilus eugeniae*, *Eisenia fetida* and *Perionyx excavatus* during the vermicomposting process. The data showed the diversity and abundance of different taxa of microarthropods – Acarina (mites) such as Mesostigmata, Prostigmata and Cryptostigmata, and Collembola (springtails) such as Isotomidae, Entomobryidae and Sminthuridae and other miscellaneous microarthropod taxa. Microarthropods were extracted from the VCs, Cs and the substrate samples, MSW, MW and FW using a Tullgren funnel. Dry funnel extractions were examined microscopically, revealing a total of 16 species and morpho-species of Acarina, 19 species of Collembola and 12 species of miscellaneous microarthropods. Collembola was the dominant group followed by Acarina. Among Collembola, Isotomidae dominated while Mesostigmata was the dominant group of Acarina. Species belonging to Formicidae in Hymenoptera were also found in good numbers. The biodiversity of microarthropods was significantly higher in the VCs of all three substrates produced by *E. eugeniae* followed by that of *E. fetida* and *P. excavatus* and that of Cs ($P < 0.05$). Positive and significant co-relationships were found between microarthropod densities and nutrients – nitrogen, phosphorus, potassium, calcium and magnesium of VCs ($P < 0.05$). Prostigmata and Mesostigmata densities showed positive and significant co-relationship with each other and with the densities of Collembola – Isotomidae, Entomobryidae and Sminthuridae ($P < 0.05$). Interestingly, there was no relationship with the densities of Cryptostigmata and miscellaneous groups.

Keywords: Acarina, Collembola, flower waste, market waste, miscellaneous taxa, municipal solid waste

INTRODUCTION

Vermicomposting is the process of composting of any biodegradable organic matter using indigenous as well as exotic species of earthworms, the end product of the process being known as vermicompost (VC), a value-added product used as organic fertilizer (Domínguez *et al*. 2003; Pattnaik and Reddy 2009). The process has been adopted worldwide for promoting sustainable management of biodegradable solid waste (Edwards 1998). The organic material is pre-composted initially to stabilize the material and to reduce the temperature resulting from initial bacterial activity. During the pre-composting stage, the organic material is colonized by primary decomposers such as various microorganisms particularly bacteria initially and actinomycetes later and the secondary decomposers – microarthropods, which feed on the soft organic matter and break down to small pieces on which the microorganisms colonize; at the same time, the earthworms devour the soft precomposted material, grinding the devoured materials by the action of the their gizzard (Domínguez *et al.* 2003). Microarthropods generally prefer habitats that provide a continuous supply of organic matter (Curry 1994; Vreeken-Buijs *et al.* 1998). The role of microarthropods in comminuting organic matter during the decomposition process is well established (Reddy 1992; Seastedt 1995). Microarthropods represent a large diversity of small arthropods and are characterized by numerous species occupying a wide range of ecological niches in the detritus food web. The term ‘microarthropod’ is used to describe the arthropod taxa that are < 2 mm in size and may measure up to 10 mm in length (Wallwork 1976), and comprise mainly different species of Acarina and Collembola, and along with other taxa such as Diplura, Thysanura, Protura, Thysanoptera, Symphyla, Pauropoda, Isopoda, etc. Stork (1988) reported that the major soil microarthropod groups include about 48% Collembola, 18% Acari and 16% ants (Formicidae), followed by Psocoptera, Coleoptera, and Hemiptera, the former two being dominant.

The combined devouring activity of earthworms along with the comminuting activity of microarthropods results in decomposition and vermicomposting, bringing out a product known as VC. Microarthropods may regulate decomposition during the vermicomposting process by grazing on microflora. They break down organic matter by feeding on soft detritus during the process, and probably influence the processes through comminution, decomposition and mineralization (Reddy 1995; Seastedt 1995). In VC, biooxidation and stabilization of waste occur probably through complex interactions between earthworms, microorganisms and microarthropods (Domínguez *et al*. 2003). While both earthworms and microrganisms are central and essential to the vermicomposting process, the microarthropod community most probably plays a vital role simultaneously during the process in comminution of organic matter and through interactions with microorganisms. Although previous studies have investigated the functional significance of microbial-earthworm interactions during vermicomposting (Reddy 1995; Edwards 1998; Aira *et al.* 2006), inadequate detailed information is available on the association of microarthropod biodiversity and their densities during the vermicomposting process, although, in the last few decades, considerable work has been undertaken on soil and litter

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microarthropods in Asian countries, including India (Bhattacharya *et al.* 1982; Swarnalatha 2010). Though a few earlier researchers reported the simple association of various microarthropod taxa during vermicomposting (Domínguez *et al.* 2003; Aira *et al.* 2006), there have been no detailed studies on these groups associated with the vermicomposting process. Therefore, the present study attempted to assess and explore the structure of microarthropod biodiversity associated with the VCs and vermicomposting process of the biodegradable portion of three different urban wastes (municipal solid waste (MSW), vegetable market waste (MW) and flower waste (FW)), the relationships among different prey and predator species of microarthropods, and nutrients of VCs in the vermicomposting microcosm. This report is probably the first such report in the literature.

MATERIALS AND METHODS

Sample collection

Three types of urban waste *viz.*, MSW, MW and FW were chosen for the present study. MSW was collected from one of the major municipal garbage dumping sites of Puducherry, a small town, the erstwhile French colony on the east coast of India; the vegetable MW was collected from the main vegetable market, which comprised of different left-over vegetables such as cabbage, brinjal, tomato, potato, onion, carrot, turnip and leafy vegetables. The FW was obtained from *Peltophorum pterocarpum* (Caesalpinioideae, Fabaceae) – a widely-appreciated shade tree and a reclamation plant with a densely spread crown, planted along the road-sides of the Pondicherry Central University campus. Five samples of each waste were randomly collected and were then mixed to form composite samples before taking smaller sub-samples for analysis. These wastes were characterized and segregated into biodegradable and non-biodegradable components. The biodegradable component of MSW, MW and FW were separated and air-dried separately for 48 h and pre-composted for 3 weeks prior to vermicomposting and composting. During the pre-composting process, the temperature rose to about 60°C. As such a high temperature is lethal to earthworm survival, thermal stabilization was performed prior to introducing earthworms into all the substrates (Pattnaik and Reddy 2009).

Experimental design

Earthen pots were used for vermicomposting and composting; in each pot, 5 kg of the substrate was mixed with cow dung in a 3: 1 ratio. A total of four sets of earthen pots, each set containing six replicates, was used for each substrate material, of which three sets were used for vermicomposting, each set using one species of earthworm; the fourth set was used for composting without using any earthworms. Similarly, all the three substrate materials were used for vermicomposting and composting. Three species of earthworms, i.e., 50 adult individuals each of *Eudrilus eugeniae*, *Eisenia fetida* and *Perionyx excavatus*, were introduced on the top of the pre-composted substrate in each of the three sets of pots keeping the fourth set for composting without any earthworm species. The tops of all pots were covered by jute cloth and wire mesh to prevent and protect the earthworms from predators such as centipedes, moles and shrews. Small holes were drilled at the bottom of each pot, which was filled with small stones up to a height of 5 cm for air circulation and good drainage. Vermicomposting and composting were performed for a total of 60 days.

Extraction

Microarthropods were extracted from the samples using the Tullgren funnel extraction method (Goshie 2009). The instrument consisted of metal funnels fixed to a retort stand and sieves placed and fitted into each funnel. 50 g of the samples – each of the three types of wastes and their respective Cs and VCs were then transferred into the respective sieve of the funnel seperately. A collecting tube partially filled with 70% alcohol was then fitted to the lower end of the funnel. A 250 W electric bulb was then fixed about 25 cm above the sieve holding the sample. The heat and light emitted by the electric bulb falling on the sample drove the microarthropods of the sample down the funnel and were collected in small plastic bottle filled with 70% alcohol and glycerine that acted as a preservative (Kautz *et al.* 2006). The set up was left undisturbed for 48 h, after which the light was switched off and the tubes underneath were removed for microscopic analyses.

Identification of taxa

Extracts collected from the Tullgren-funnel were emptied into Petri dishes, which were examined mainly for different microarthropod taxa with the help of a stereoscopic binocular zoom microscope (Leica MZ 7.5) at 40-60X magnification. Specimens were identified to the family and genus level only and, within each genus, they were sorted to temporary morpho-species. In general, the evidence suggests that careful use of morpho-species allows for reliable assessment of arthropod species diversity (Odum 1971; Anderson and Ashe 2000).

Data analyses

Test of significance of densities of microarthropods of 50 g of different samples was computed using two-way ANOVA ($P < 0.05$). Regression analyses carried out between densities of different species of microarthropods, showed significant correlations ($P < 0.05$). Correlations between nutrients (N, P, K, Ca and Mg) and densities of microarthropod populations were computed using regression analyses ($P < 0.05$). Effects of predatory mites i.e., Prostigmata and Mesostigmata on the other microarthropods in the vermicomposting units were also calculated using the regression analysis ($P < 0.05$).

RESULTS AND DISCUSSION

Analysis of microarthropod diversity

The microarthropods in the present investigation were categorised into three major groups – Acarina (mites), Collembola (springtails) and miscellaneous taxa (**Fig. 1A**). Acarina, Collembola and Miscellaneous taxa constituted 40.0, 43.3 and 16.7% respectively, in the sole MSW; and 48.8, 47.0 and 4.2% at 15 days and 48.3, 50.8 and 0.9% at 60 days of MSW – 45.5, 46.8 and 7.7% in VC at 15 days processed by *E. eugeniae*, and 46.7, 51.5 and 1.8% of MSW – vermicomposted at 60 days produceed by *E. fetida*, 43.0, 45.5 and 11.6% of its VC at 15 days and 46.3, 51.5 and 2.2% at 60 days of MSW – vermicomposted by *P. excavatus*, and 38.5, 42.3 and 19.2% at 15 days of VC of MSW and 45.5, 50.3 and 4.2% at 60 days of MSW – compost; while 42.0, 34.9 and 23.1% in sole MW, 51.0, 41.1 and 7.9% at 15 days and 51.3, 47.7 and 1.0% at 60 days of MW – VC processed by *E. eugeniae*, 46.5, 40.2 and 13.4% at 15 days and 50.4, 47.7 and 1.9% at 60 days of MW – VC produced by *E. fetida*, 43.0, 37.4 and 19.6% at 15 days and 50.2, 46.6 and 3.2% at 60 days of MW – VC by *P. excavatus*, and 36.0, 36.0 and 27.9% at 15 days and 48.9, 44.1 and 7.0% at 60 days of MW – compost, 44.0, 29.0 and 27.0% in sole FW, 50.7, 35.6 and 13.7% at 15 days and 53.4, 45.6 and 1.0% at 60 days of FW – VC processed by *E. eugeniae*, 48.4, 34.4 and 17.2 % at 15 days and 53.3, 43.9 and 2.7% at 60 days of FW – VC produced by *E. fetida*, 43.9 30.6 and 25.5% at 15 days and 51.7, 44.0 and 4.3% at 60 days of FW – VC produced by *P. excavatus*, and 33.8, 26.3 and 40.0% at 15 days and 48.2, 42.1 and 9.8% at 60 days of FW compost.

The proportion of groups in Acarina, Collembola and Miscellaneous taxa respectively were presented in **Fig. 1B, 1C** and **1D**, respectively. Of the total Acarina, it was found that Prostigmata, Mesostigmata and Cryptostigmata comprised respectively, 40.5, 59.5 and 0.0% in MSW; 35.4, 56.1 and 8.5% at 15 days and 39.9, 48.7 and 11.4% at 60 days in MSW – VC produced by *E. eugeniae*, 36.9, 56.9 and 6.2% at 15 days and 39.8, 51.6 and 8.6 % at 60 days in MSW – VC processed by *E. fetida*, 36.5, 59.6 and 3.8% at 15 days and 39.6, 54.7 and 5.7% at 60 days of MSW – VC produced by *P. excavatus*, and 35.0, 65.0 and 0.0% at 15 days and

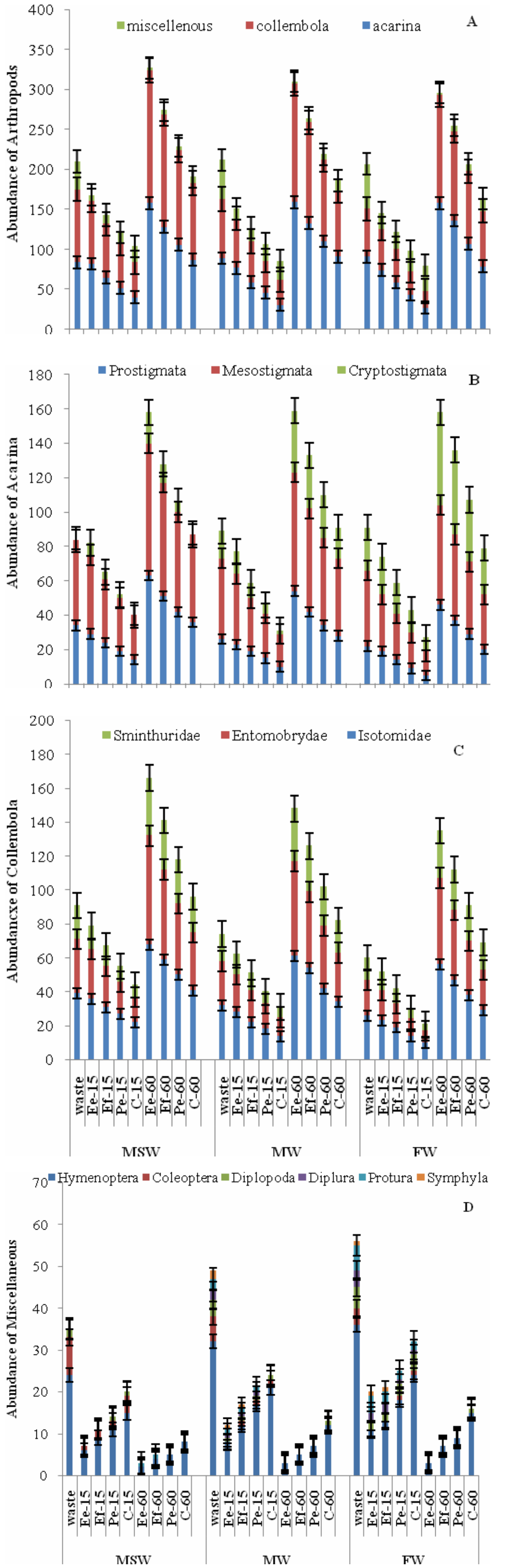

Fig. 1 (**A**) Composition of microarthropods, (**B**) Acarina (Prostigmata, Mesostigmata and Cryptostigmata); (**C**) Collembola (Isotomidae, Entomobryidae and Sminthuridae) and (**D**) miscellaneous (Hymenoptera, Coleoptera, Diplopoda, Diplura, Protura and Symphyla).

41.4, 58.6 and 0.0% at 60 days of MSW compost; and these categories constituted 29.2, 52.8 and 18.0% in MW, 29.9, 53.2 and 16.9% at 15 days and 34.0, 43.4 and 22.6% at 60 days of MW – VC produced by *E. eugeniae*, 32.2, 52.5 and 15.3% at 15 days and 31.6, 45.1 and 23.3% at 60 days of MW – VC by produced by *E. fetida*, 32.6, 56.5 and 10.9% at 15 days and 30.9, 46.4 and 22.7% at 60 days of MW – VC produced by *P. excavatus*, and 32.3, 61.3 and 6.5% at 15 days and 30.8, 49.5 and 19.8% at 60 days of MW – compost, 24.2, 48.4 and 27.5% in the FW, 25.7, 44.6 and 29.7% at 15 days and 29.1, 36.7 and 34.2% at 60 days of FW – VC processed by *E. eugeniae*, 23.7, 45.8 and 30.5% at 15 days and 27.2, 36.8 and 36.0% at 60 days of FW – VC produced by *E. fetida*, 20.9, 48.8 and 30.2% at 15 days and 27.1, 39.3 and 33.6% at 60 days of FW – VC processed by *P. excavatus*, and 18.5, 51.9 and 29.6% at 15 days and 25.3, 40.5 and 34.2% at 60 days of FW – compost (**Fig. 1B**).

It was seen that of the total Collembola, Isotomidae, Entomobrydae and Sminthuridae (**Fig. 1C**) occupied respectively, 42.9, 35.2 and 22.0% in the MSW; 45.6, 36.7 and 17.7% at 15 days and 41.0, 38.6 and 20.5% at 60 days of MSW – VC produced by *E. eugeniae*, 46.3, 35.8 and 17.9% at 15 days and 41.8, 37.6 and 20.6% at 60 days of MSW – VC processed by *E. fetida*, 49.1, 34.5 and 16.4% at 15 days and 42.4, 35.6 and 22.0% at 60 days of MSW – VC processed by *P. excavatus*, and 50.0, 34.1 and 15.9% at 15 days and 42.7, 35.4 and 21.9% at 60 days of MSW – compost, 43.2, 35.1 and 21.6% in MW, 45.2, 35.5 and 19.4% at 15 days and 41.2, 37.8 and 20.9% at 60 days of MW – VC produced by *E. eugeniae*, 43.1, 37.3 and 19.6% at 15 days and 42.9, 35.7 and 21.4% at 60 days of MW – VC processed by *E. fetida*, 45.0, 37.5 and 17.5% at 15 days and 41.2, 36.3 and 22.5% at 60 days of MW – VC processed by *P. excavatus*, and 45.2, 35.5 and 19.4% at 15 days and 41.5, 35.4 and 23.2% at 60 days of MW – compost, 43.3, 35.0 and 21.7% in FW, 44.2, 34.6 and 21.2% at 15 days and 41.5, 37.8 and 20.7% at 60 days of FW – VC produced by *E. eugeniae*, 45.2, 33.3 and 21.4% at 15 days and 42.0, 36.6 and 21.4% at 60 days of FW – VC processed by *E. fetida*, 46.7, 33.3 and 20.0% at 15 days and 41.8, 35.2 and 23.1% at 60 days of FW – VC processed by *P. excavatus*, and 47.6, 33.3 and 19.0% at 15 days and 42.0, 34.8 and 23.2% at 60 days of FW compost.

Of total Miscellaneous taxa, it was found that Hymenoptera, Coleoptera, Diplopoda, Diplura, Protura and Symphyla occupied respectively, 68.6, 25.7, 5.7, 0.0, 0.0 and 0.0% in MSW; 85.7, 14.3, 0.0, 0.0, 0.0 and 0.0% at 15 days and 66.7, 0.0, 0.0, 0.0, 33.3 and 0.0% at 60 days of MSW – VC produced by *E. eugeniae*, 81.8, 18.2, 0.0, 0.0, 0.0 and 0.0% at 15 days and 80.0, 0.0, 0.0, 0.0, 20.0 and 0.0% at 60 days of MSW – VC processed by *E. fetida*, 78.6, 14.3 and 7.1, 0.0, 0.0 and 0.0% at 15 days and 100.0, 0.0, 0.0, 0.0, 0.0 and 0.0% at 60 days of MSW – VC produced by *P. excavatus*, and 75.0, 20.0, 5.0, 0.0, 0.0 and 0.0% at 15 days and 100.0, 0.0, 0.0, 0.0, 0.0 and 0.0% at 60 days of MSW – compost, 65.3, 12.2, 8.2, 4.1, 6.1 and 4.1% in MW, 66.7, 0.0, 8.3, 8.3, 8.3 and 8.3% at 15 days and 100.0, 0.0, 0.0, 0.0, 0.0 and 0.0% at 60 days of MW – VC produced by *E. eugeniae*, 70.6, 5.9, 5.9, 5.9, 5.9 and 5.9% at 15 days and 100.0, 0.0, 0.0, 0.0, 0.0 and 0.0% at 60 days of MW – VC produced by *E. fetida*, 81.0, 4.8, 4.8, 4.8, 4.8 and 0.0% at 15 days and 100.0, 0.0, 0.0, 0.0, 0.0 and 0.0% at 60 days of MW – VC produced by *P. excavatus*, and 87.5, 8.3, 4.2, 0.0, 0.0 and 0.0% at 15 days and 92.3, 0.0, 7.7, 0.0, 0.0 and 0.0% at 60 days of MW – compost, 64.3, 7.1, 8.9, 7.1, 10.7 and 1.8% in FW, 55.0, 0.0, 10.0, 10.0, 20.0 and 5.0% at 15 days and 100.0, 0.0, 0.0, 0.0, 0.0 and 0.0% at 60 days of FW – VC processed by *E. eugeniae*, 61.9, 0.0, 9.5, 9.5, 14.3 and 4.8% at 15 days and 100.0, 0.0, 0.0, 0.0, 0.0 and 0.0% at 60 days of FW – VC produced by *E. fetida*, 72.0, 4.0, 12.0, 4.0, 8.0 and 0.0% at 15 days and 100.0, 0.0, 0.0, 0.0, 0.0 and 0.0% at 60 days of FW – VC processed by *P. excavatus*, and 75.0, 3.1, 12.5, 3.1, 6.3 and 0.0% at 15 days and 93.8, 0.0, 6.3, 0.0, 0.0 and 0.0% at 60 days of FW – compost (**Fig. 1D**).

In the present study, Collembola and Acarina were found in higher abundance compared to the miscellaneous taxa of arthropods, the former being dominant. Interestingly it was found that across all the composts and VCs the Mesostigmata was present in higher abundance compared to that of Prostigmata and Cryptostigmata, and was dominant among Acarina in the VC microcosm, which was attributable to their predatory activity and availability of plentiful prey in the microcosm and their well being and multiplication.

The present findings clearly indicated the dominance of Isotomidae over Entomobryidae and Sminthuridae among Collembola in all the composts and VCs, which is probably because of their body size with a small forcula. Similar to Mesostigmata, the Hymenoptera also being predatory in nature was represent in good numbers among the miscellaneous groups, probably because of availability of sufficient prey in the VC microcosm. Most mites, and collembola have well-developed mouthparts capable of fragmenting organic matter while feeding on the microflora adhering to the detritus fragments (Seastedt 1984; Reddy 1995). Fragmentation i.e. the conversion to small, fine particles have many important consequences in decomposition and mineralization processes, particularly by creating more surface area for microbial colonization (Webb 1977; Elkins and Whitford 1982; Seastedt 1984). Among the miscellaneous groups, the Formicidae (Hymenoptera) was dominant.

Table 1 Species diversity of Acarina, Collembola and miscellaneous taxa in MSW substrate and its vermicomposts generated by three different species of earthworms at two different intervals of 15 and 60 days.

Acarina	**MSW**	**Ee-15**	**Ef-15**	**Pe-15**	**C-15**	**Ee-60**	**Ef-60**	**Pe-60**	**C-60**
Prostigmata									
Bdella sp.	+	+	+	+	+	+	+	+	+
Bdellodes sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 1	+	+	+	+	+	+	+	+	+
Morpho sp. 2	+	+	+	+	-	+	+	+	+
Morpho sp. 3	-	+	-	-	-	+	+	-	-
Mesostigmata									
Macrocheles sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 1	+	+	+	+	+	+	+	+	+
Morpho sp. 2	+	+	+	+	-	+	+	+	+
Morpho sp. 3	+	+	-	-	-	+	+	+	+
Morpho sp. 4	+	-	-	-	-	+	+	+	+
Morpho sp. 5	-	-	-	-	-	+	+	-	-
Morpho sp. 6	-	-	-	-	-	+	-	-	-
Cryptostigmata									
Oribatula sp.	-	+	+	+	-	+	+	+	-
Morpho sp. 1	-	-	-	-	-	+	-	-	-
Morpho sp. 2	-	-	-	-	-	-	-	-	-
Morpho sp. 3	-	-	-	-	-	-	-	-	-
Collembola	**MSW**	**Ee-15**	**Ef-15**	**Pe-15**	**C-15**	**Ee-60**	**Ef-60**	**Pe-60**	**C-60**
Isotomidae									
Isotomiella sp.	+	+	+	+	+	+	+	+	+
Isotomodes sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 1	+	+	+	+	+	+	+	+	+
Folsomia sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 2	-	+	+	+	-	+	+	+	+
Morpho sp. 3	-	+	-	-	-	+	+	+	+
Morpho sp. 4	-	-	-	-	-	+	+	+	+
Proisotoma sp.	-	-	-	-	-	+	+	+	-
Morpho sp. 5	-	-	-	-	-	+	+	+	-
Morpho sp. 6	-	-	-	-	-	+	+	+	-
Entomobrydae									
Isotoma sp.	+	+	+	+	+	+	+	+	+
Isotomurus sp.	+	+	+	+	+	+	+	+	+
Entomobrya sp.	+	+	+	+	+	+	+	+	+
Lepidoseira sp.	-	+	+	+	-	+	+	+	-
Tullbergia sp.	-	+	-	-	-	+	+	-	-
Morpho sp. 1	-	-	-	-	-	+	-	-	-
Sminthuridae									
Sminthurinus sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 1	-	+	+	+	-	+	+	+	+
Morpho sp. 2	-	-	-	-	-	+	+	+	-
Miscellaneous	**MSW**	**Ee-15**	**Ef-15**	**Pe-15**	**C-15**	**Ee-60**	**Ef-60**	**Pe-60**	**C-60**
Hymenoptera									
Morpho sp. 1	+	+	+	+	+	+	+	+	+
Morpho sp. 2	+	+	+	+	+	-	-	-	+
Morpho sp. 3	+	-	-	-	+	-	-	-	-
Morpho sp. 4	-	-	-	-	-	-	-	-	-
Coleoptera									
Edaphus sp.	+	+	+	+	+	-	-	-	-
Cryptophagid sp.	+	-	-	-	-	-	-	-	-
Diplopoda									
Glomeris sp.	+	-	-	+	+	-	-	-	-
Protura									
Acerentulus sp.	-	-	-	-	-	+	+	-	-

Table 2 Species diversity of Acarina, Collembola and miscellaneous taxa in MW substrate and its vermicomposts generated by three different species of earthworms at two different intervals of 15 and 60 days.

Acarina	MW	Ee-15	Ef-15	Pe-15	C-15	Ee-60	Ef-60	Pe-60	C-60
Prostigmata									
Bdella sp.	+	+	+	+	+	+	+	+	+
Bdellodes sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 1	+	+	+	+	+	+	+	+	+
Morpho sp. 2	-	-	-	-	-	+	+	+	-
Morpho sp. 3	-	-	-	-	-	+	-	-	-
Mesostigmata									
Macrocheles sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 1	+	+	+	+	+	+	+	+	+
Morpho sp. 2	+	+	+	-	-	+	+	+	+
Morpho sp. 3	+	+	-	-	-	+	+	+	+
Morpho sp. 4	-	-	-	-	-	+	+	+	-
Morpho sp. 5	-	-	-	-	-	+	+	-	-
Morpho sp. 6	-	-	-	-	-	-	-	-	-
Cryptostigmata									
Oribatula sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 1	-	+	-	-	-	+	+	+	-
Morpho sp. 2	-	-	-	-	-	+	+	-	-
Collembola	**MW**	**Ee-15**	**Ef-15**	**Pe-15**	**C-15**	**Ee-60**	**Ef-60**	**Pe-60**	**C-60**
Isotomidae									
Isotomiella sp.	+	+	+	+	+	+	+	+	+
Isotomodes sp.	-	+	+	+	+	+	+	+	+
Morpho sp. 1	+	+	+	+	+	+	+	+	+
Folsomia sp.	-	+	+	+	+	+	+	+	+
Morpho sp. 2	+	+	+	+	-	+	+	+	+
Morpho sp. 3	-	+	-	-	-	+	+	+	+
Morpho sp. 4	-	-	-	-	-	+	+	+	-
Proisotoma sp.	-	-	-	-	-	+	+	+	-
Morpho sp. 5	-	-	-	-	-	+	+	+	-
Morpho sp. 6	-	-	-	-	-	+	+	-	-
Entomobrydae									
Isotoma sp.	+	+	+	+	+	+	+	+	+
Isotomurus sp.	+	+	+	+	+	+	+	+	+
Entomobrya sp.	+	+	+	+	-	+	+	+	-
Lepidoseira sp.	-	+	+	-	-	+	+	-	-
Tullbergia sp.	-	-	-	-	-	+	+	-	-
Morpho sp. 1	-	-	-	-	-	+	-	-	-
Sminthuridae									
Sminthurinus sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 1	-	+	+	+	+	+	+	+	+
Miscellaneous	**MW**	**Ee-15**	**Ef-15**	**Pe-15**	**C-15**	**Ee-60**	**Ef-60**	**Pe-60**	**C-60**
Hymenoptera									
Morpho sp. 2	+	-	-	+	+	-	-	-	-
Morpho sp. 3	+	-	-	-	-	-	-	-	-
Morpho sp. 4	+	+	+	+	+	+	+	+	+
Coleoptera									
Edaphus sp.	+	-	+	+	+	-	-	-	-
Cryptophagid sp.	+	-	-	-	-	-	-	-	-
Diplopoda									
Glomeris sp.	+	+	+	+	+	-	-	-	+
Diplura									
Japyx sp.	+	+	+	+	-	-	-	-	-
Protura									
Acerentulus sp.	+	+	+	+	-	-	-	-	-
Symphyla									
Scutigerella sp.	+	+	+	-	-	-	-	-	-

Spatio-temporal variation of microarthropods

The data in details on the abundance of different taxa of microarthropods across different types of VCs, are first of its kind, and thus, little information in detail is available in the literature to compare with the present findings. The abundance of Acarina (**Table 1**) such as Mesostigmata, Prostigmata and Cryptostigmata, and Collembola (**Table 2**) such as Isotomidae, Entomobryidae, Iand Sminthuridae, and other miscellaneous taxa (**Table 3**) – Hymenoptera (Formicidae) decreased when the composting process progressed from 0 days to 15 days, but interestingly, increased during 15 to 60 days of composting process. Their numbers were higher in MSW than MW and FW and in the ranking order of MSW > MW > FW (**Fig. 1**). The abundance of Diplopoda, Diplura, Protura and Symphyla in the substrates were in the ranking order of FW > MW > MSW. The abundance of Coleoptera decreased from 0 to 15 days and however, they were not found at 60 days of processing in all the three substrates; the MSW showed higher abundance of Coleoptera than other two in the order MSW > MW > FW during first 15 days. The abundance of Diplopoda decreased gradually from 0 to 15 to 60 days of processing in FW, MW and MSW; being absent in the VC harvested at 60 days of processing of MSW. The abundance of Diplura, Protura and Symphyla were very less. Except for the Diplopoda and

Table 3 Species diversity of Acarina, Collembola and miscellaneous taxa in FW substrate and its vermicomposts generated by three different species of earthworms at two different intervals of 15 and 60 days.

Acarina	**FW**	**Ee-15**	**Ef-15**	**Pe-15**	**C-15**	**Ee-60**	**Ef-60**	**Pe-60**	**C-60**
Prostigmata									
Bdella sp.	+	+	+	+	+	+	+	+	+
Bdellodes sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 1	+	+	+	+	+	+	+	+	+
Morpho sp. 2	-	-	-	-	-	+	+	-	-
Morpho sp. 3	-	-	-	-	-	-	-	-	-
Mesostigmata									
Macrocheles sp.	+	+	+	+	-	+	+	+	+
Morpho sp. 1	+	+	+	+	+	+	+	+	+
Morpho sp. 2	+	+	-	-	-	+	+	+	-
Morpho sp. 3	+	-	-	-	-	+	+	+	-
Morpho sp. 4	-	-	-	-	-	+	+	-	-
Morpho sp. 5	-	-	-	-	-	-	-	-	-
Morpho sp. 6	-	-	-	-	-	-	-	-	-
Cryptostigmata									
Oribatula sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 1	+	+	+	+	+	+	+	+	+
Morpho sp. 2	-	-	-	+	-	+	+	+	-
Morpho sp. 3	-	-	-	-	-	+	+	-	-
Collembola	**FW**	**Ee-15**	**Ef-15**	**Pe-15**	**C-15**	**Ee-60**	**Ef-60**	**Pe-60**	**C-60**
Isotomidae									
Isotomiella sp.	+	+	+	+	+	+	+	+	+
Isotomodes sp.	-	+	+	+	-	+	+	+	+
Morpho sp. 1	+	+	+	+	+	+	+	+	+
Folsomia sp.	-	+	+	-	-	+	+	+	+
Morpho sp. 2	-	+	-	-	-	+	+	+	+
Morpho sp. 3	-	-	-	-	-	+	+	+	+
Morpho sp. 4	-	-	-	-	-	+	+	+	-
Proisotoma sp.	-	-	-	-	-	+	+	+	-
Morpho sp. 5	-	-	-	-	-	+	+	+	-
Morpho sp. 6	-	-	-	-	-	+	+	+	-
Entomobrydae									
Isotoma sp.	+	+	+	+	+	+	+	+	+
Isotomurus sp.	+	+	+	+	+	+	+	+	+
Entomobrya sp.	-	+	+	+	-	+	+	+	-
Lepidoseira sp.	-	+	+	-	-	+	+	+	-
Tullbergia sp.	-	-	-	-	-	+	-	-	-
Sminthuridae									
Sminthurinus sp.	+	+	+	+	+	+	+	+	+
Morpho sp. 1	-	+	+	-	-	+	+	+	+
Miscellaneous	**FW**	**Ee-15**	**Ef-15**	**Pe-15**	**C-15**	**Ee-60**	**Ef-60**	**Pe-60**	**C-60**
Hymenoptera									
Morpho sp. 1	+	-	-	-	-	-	-	-	-
Morpho sp. 2	+	-	-	-	-	-	-	-	-
Morpho sp. 3	+	+	+	+	+	+	+	+	+
Morpho sp. 4	+	+	+	+	+	-	-	-	+
Coleoptera									
Edaphus sp.	+	-	-	+	+	-	-	-	-
Cryptophagid sp.	-	-	-	-	-	-	-	-	-
Diplopoda									
Glomeris sp.	+	+	+	+	+	-	-	-	+
Polyzonium sp.	+	-	-	-	-	-	-	-	-
Diplura									
Japyx sp.	+	+	+	+	+	-	-	-	-
Protura									
Acerentulus sp.	+	+	+	+	+	-	-	-	-
Acerentomon sp.	+	-	-	-	-	-	-	-	-
Symphyla									
Scutigerella sp.	+	+	+	-	-	-	-	-	-

Coleoptera, all the microarthropod species showed higher abundance in VC processed by *E. eugeniae* than that of *E. fetida* and *P. excavatus* and that of sole compost. The reverse was true for the abundance of Diplopoda and Coleoptera and the order was compost > VC produced by *P. excavatus* > VC by *E. fetida* > VC by *E. eugeniae*.

The present findings indicated the niche preference of these microarthropods across the compost and VC microcosms, and close relationships between the microarthropods like Acarina, Collembola and micro-organisms like bacteria and fungi as reported by many earlier workers (Ausmus and Witkamp 1974; van der Drift and Jansen 1977; Hanlon and Anderson 1979; Ineson *et al.* 1982; Parker *et al.* 1984; Seastedt 1984; Reddy 1995). It was reported that the respiration rates of microorganisms especially bacteria, which reflect their activity generally and increase in the microarthropods (van der Drift and Jansen 1977; Addison and Parkinson 1978; Santos *et al.* 1981; Reddy 1995). Microarthropods like Symphyla, Pauropoda and Protura, are typical to well-structured soils like that of woodland or grassland (Wallwork 1970). Symphyla, Protura and Diplura particularly were absent in the waste disposal site and however, were present in the woodland and grassland areas (Menta *et al.* 2008).

Species composition

A total of 16 species and morpho-species of Acarina, 19 species of Collembola and 12 species of miscellaneous taxa were identified from MSW (**Tables 1-3A**), MW (**Tables 1-3B**) and FW's (**Tables 1-3C**) compost and VC. The species composition of Prostigmata (Acarina) (**Table 1**) in all the samples includes *Bdella* species, *Bdellodes* species, morpho species 1, morpho species 2 and morpho species 3, the most dominant being the former *Bdella* sp. followed by *Bdellodes* sp. ; the species composition of Mesostigmata (Acarina) comprised *Macrocheles* sp., morpho species 1, morpho species 2, morpho species 3, morpho species 4, morpho species 5 and morpho species 6, the first one was the dominant species; species composition of Cryptostigmata (Acarina) includes *Oribatula* sp. morpho species 1, morpho species 2 and morpho species 3, the most dominant being *Oribatula* sp. followed by morpho species 1.

Table 2 showed the species composition of Collembola in all the samples. Species composition of Isotomidae was in the order of *Isotomiella* sp., *Isotomodes* sp., morpho species 1, *Folsomia* sp., morpho species 2, Morpho species 3, morpho species 4, Proisotoma species, morpho species 5, morpho species 6, respectively. The species composition of Entomobryidae (Collembola) was *Isotoma* sp., *Isotomurus* sp., *Entomobrya* sp., *Lepidoseira* sp., *Tullbergia* sp. and morpho species 1, present in descending order in all samples. Species composition of Sminthuridae (Collembola) was *Sminthurinus* sp., morpho species 1 and morpho species 2, the former being the most dominant species.

Species composition of Hymenoptera (miscellaneous) was in the order of morpho species 1, morpho species 2, morpho species 3 and morpho species 4. In case of Coleoptera the species composition was *Edaphus* sp. followed by *Cryptophagid* sp. Species composition of Diplopoda comprised *Glomeris* sp. followed by *Polyzonium* sp. Diplura and Symphyla included only one species namely *Japyx* sp. and *Scutigerella* sp., respectively. Protura comprised *Acerentulus* sp. followed by *Acerentomon* sp. (**Table 3**).

The numbers of species were higher in VC than that of compost. The higher value may be due to availability of microorganisms and nutrient rich materials; the action of earthworms formed the microbial-rich food for the microarthropods (Subler *et al.* 1998).

Relationship between micro arthropod densities and physico-chemical parameters

The relationship between microarthropods (Acarina, Collembola and miscellaneous arthropods) and the physico-chemical parameters – N (**Fig. 2**), P (**Fig. 3**), K (**Fig. 4**), Ca (**Fig. 5**) and Mg (**Fig. 6**) showed positive and significant co-relationships between their abundance and the nutrients in the VC, and that of total Acarina (**Figs. 2-6A**), and total Collembola (**Figs. 2-6B**), whereas interestingly the relationships were negative and significant with the abundance of miscellaneous taxa like Hymenoptera and Diplopoda (**Figs. 2-6C**) ($P < 0.05$). It indicated that with the increase in the concentrations of nutritional characteristics such N, P, K, C and Mg in the VC the densities of Acarina and Collembola increased, while the densities of Hymenoptera and Diplopoda decreased. These microarthropods are considered to play an important role in the nutrient dynamics (Seastedt 1984; Reddy 1995; Kautz *et al.* 2006). It is assumed that microarthropods have an indirect effect on nutrients due to their mouth parts and ability to fragment decaying organic material and thereby increasing the surface area and its availability for microbial colonization (Petersen and Luxton 1982). Furthermore, Petersen (2002) emphasized the catalytical effects of soil microarthropods on nutrient turnover.

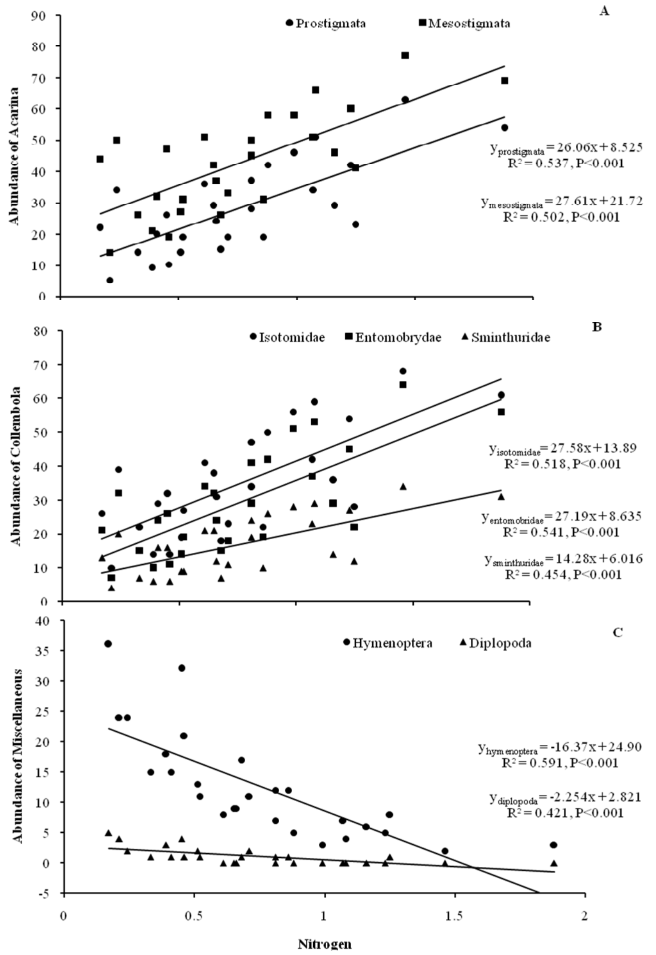

Fig. 2 Relationship between abundance of (**A**) Acarina (Prostigmata and Mesostigmata); (**B**) Collembola (Isotomidae, Entomobryidae and Sminthuridae) and (**C**) miscellaneous groups – (Hymenoptera and Diplopoda) with the nitrogen content of all the substrates, composts and vermicomposts.

Cole *et al.* (2004) reported from a microcosm experiment, that nutrient release from a mixture of plant litter fragments and soil increased with increasing microarthropod density. Nitrogen can potentially be mineralized by the grazing and excretory activities of microarthropods (Seastedt 1984). Microarthropod feeding activities on microflora probably result in rapid recycling of most nitrogen within the system (i.e. within vermicomposting microcosm). Microarthropods probably speed up mineralization of phosphorus (Seastedt and Crossley 1980). Other studies, however, have reported increased concentrations of phosphorus in the system containing microarthropods (Seastedt and Crossley 1983). Fragmentation and increase of potassium are due to microarthropod activities (Gosz *et al.* 1973; Seastedt and Crossley 1980). This element appears to be poorly regulated by microarthropod activities (McBrayer 1977; Ineson *et al.* 1982; Reddy 1995). The amount of calcium was found in living and dead microarthropod exoskeletons, which increase the calcium content in VC (Krivolutzky and Pokarzhevsky 1977; Seastedt and Tate 1984; Reddy 1995; Cromack *et al.* 1977; Crossley 1977). A couple of studies reported no microarthropod effect on absolute increases in Mg (Ward and Wilson 1973; Pokarzhevsky 1979).

Relationship between predatory microarthropods with other groups of microarthropods

Relationships were established through regression analyses between densities of predators like Prostigmata (**Fig. 7**) and Mesostigmata (**Fig. 8**) (Acarina) and other groups of microarthropods. It was found that densities of Prostigmata and Mesostigmata both showed significant positive relationship

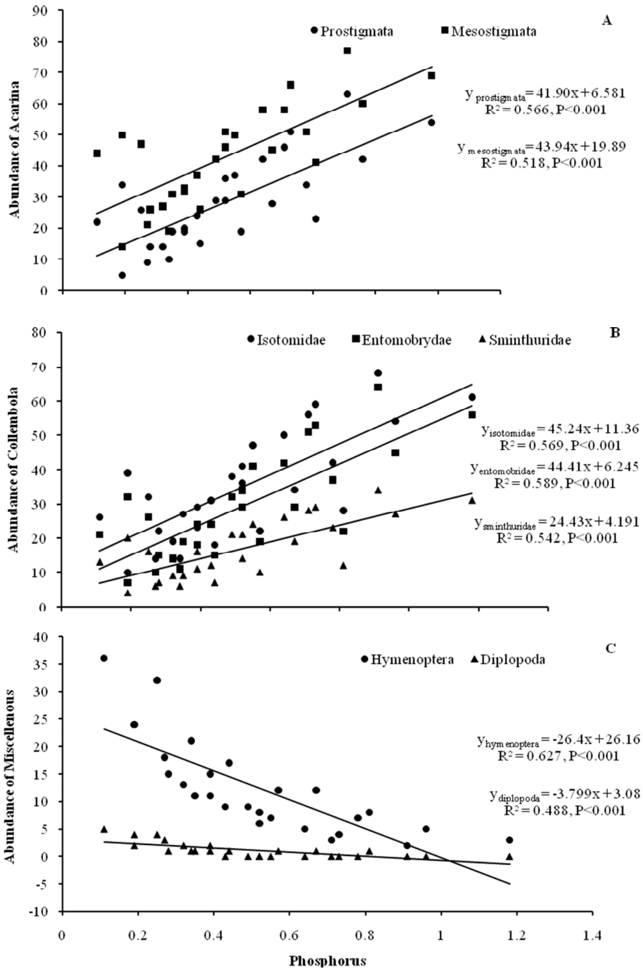

Fig. 3 Relationship between abundance of (**A**) Acarina (Prostigmata and Mesostigmata); (**B**) Collembola (Isotomidae, Entomobryidae and Sminthuridae) and (**C**) miscellaneous groups (Hymenoptera and Diplopoda) with the phosphorus content of all the substrates, composts and vermicomposts.

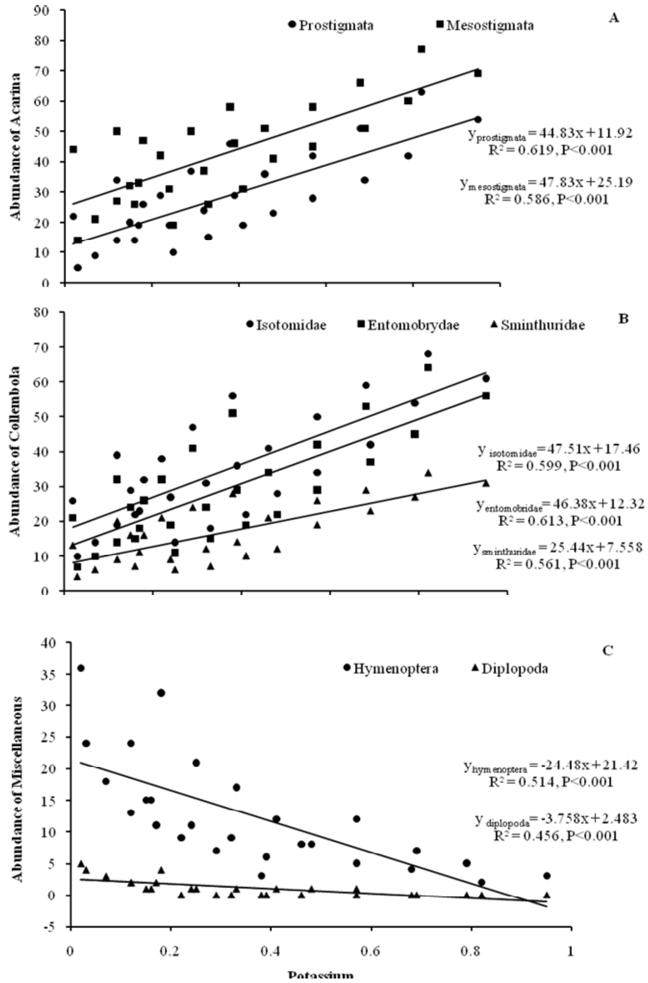

Fig. 4 Relationship between abundance of (**A**) Acarina (Prostigmata and Mesostigmata); (**B**) Collembola (Isotomidae, Entomobryidae and Sminthuridae) and (**C**) miscellaneous groups (Hymenoptera and Diplopoda) with the potassium content of all the substrates, composts and vermicomposts.

with each other and with that of different taxa of Collembola like Isotomidae, Entomobryidae and Sminthuridae ($P < 0.05$) in the vermicomposting microcosm; whereas interestingly there was no relationship with Cryptostigmata and miscellaneous groups. Regression analyses clearly showed that predators (Prostigmata and Mesostigmata) had positive relationships with the densities of all the groups of Collembola and no effect on other group of microarthropods, i.e., the miscellaneous group. It showed that the densities of Prostigmata and Mesostigmata increased with the increase of Collembola, but not other microarthropods in the microcosm. The microarthropod taxa, the Prostigmatid and Mesostigmatid mites include species that are predaceous (Seastedt 1984; Moore *et al.* 1988; Reddy 1995). Mesostigmata was identified as the predators of other microarthropods by many earlier workers (Wallwork 1976; Norton 1990; Koehler 1997). Prostigmatid mites have also been reported to regulate densities of microarthropods' groups (Edwards *et al.* 1967), whose densities in turn may also affect organic matter decomposition rates.

CONCLUSIONS

The present study clearly showed the close association of microarthropods - different taxa of Acarina (Prostigmata. Mesostigmata and Cryptostigmata), Collembola (Isotomidae, Entomobryidae and Sminthuridae) and miscellaneous groups of microarthropods (Formicidae – Hymenoptera, Coleoptera, Diplopoda, Protura, Diplura and Symphyla) during the vermicomposting process and VC of biodegradable urban waste materials. Among the microarthropods, Collembola was the dominant group followed by Acarina and the miscellaneous groups, and among Collembola, Isotomidae was dominant, while among Acarina, Mesostigmata was dominant and among the miscellaneous groups, Formicidae (Hymenoptera) was dominant in the vermicomposting microcosm. The densities of these microarthropods showed significant correlations between the prey and predator taxa of microarthropods in the vermicopmposting microcosm, and also with the concentrations of various major nutrients of the VC in the microcosmos. These microarthropods also played significant role during the vermicomposting process. The detailed information presented in this paper is first of its kind in the literature.

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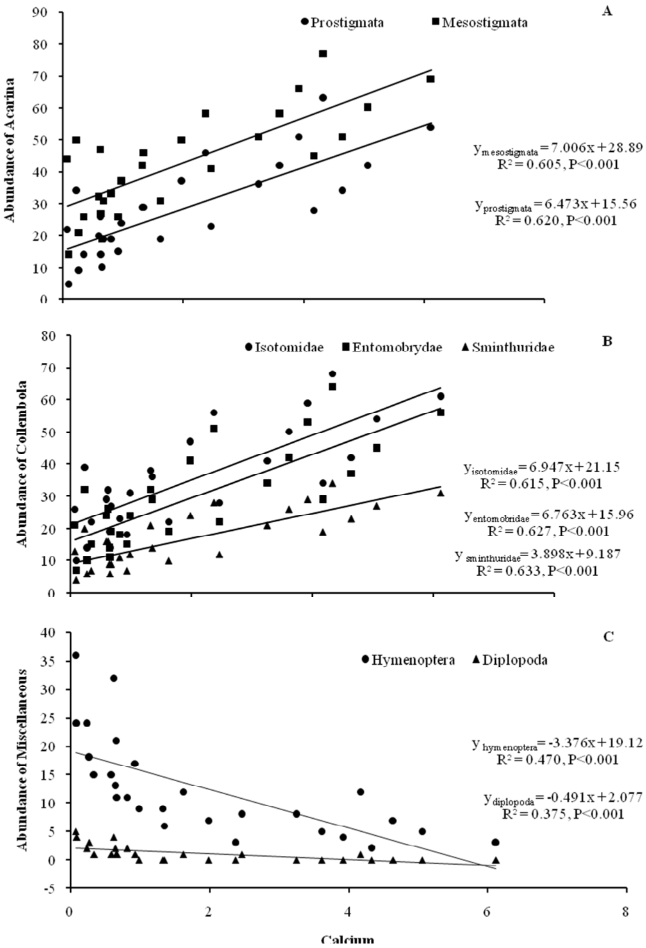

Fig. 5 Relationship between abundance of (**A**) Acarina (Prostigmata and Mesostigmata); (**B**) Collembola (Isotomidae, Entomobryidae and Sminthuridae) and (**C**) miscellaneous groups (Hymenoptera and Diplopoda) with the calcium content of all the substrates, composts and vermicomposts.

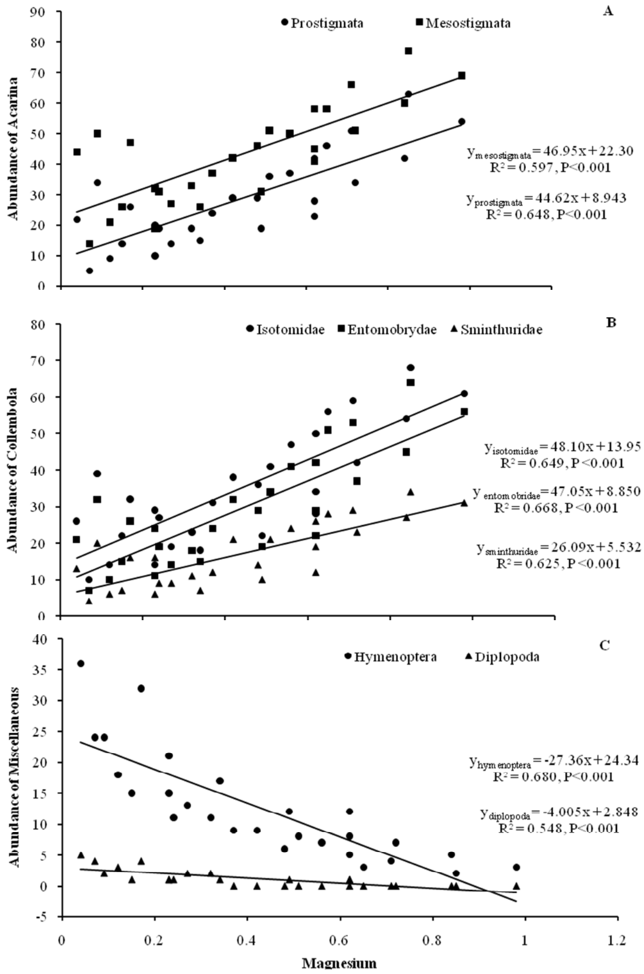

Fig. 6 Relationship between abundance of (**A**) Acarina (Prostigmata and Mesostigmata); (**B**) Collembola (Isotomidae, Entomobryidae and Sminthuridae) and (**C**) miscellaneous groups (Hymenoptera and Diplopoda) with the magnesium content of all the substrates, composts and vermicomposts.

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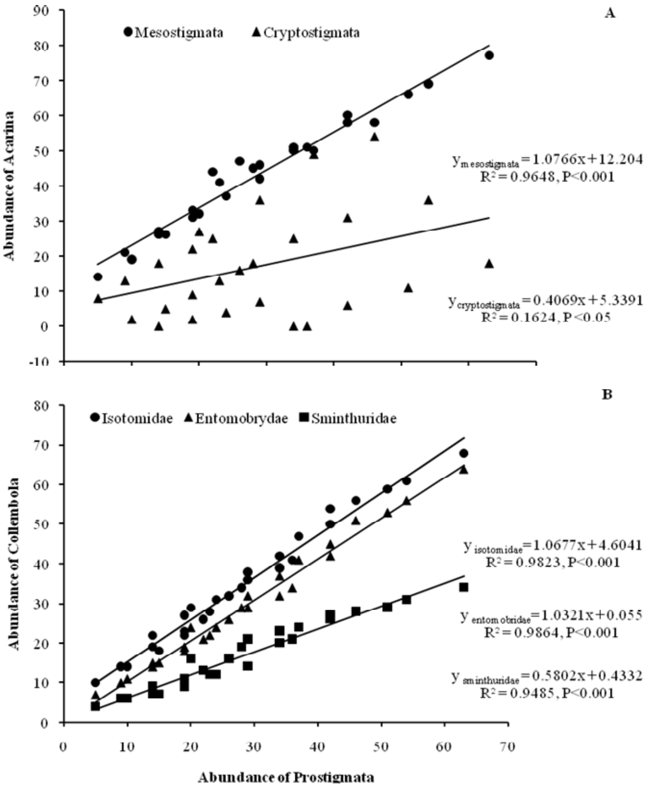

Fig. 7 Relationship between abundance of predatory mite – Prostigmata with (**A**) Acarina (Mesostigmata and Cryptostigmata); (**B**) Collembola (Isotomidae, Entomobryidae and Sminthuridae) in all the substrates, composts and vermicomposts.

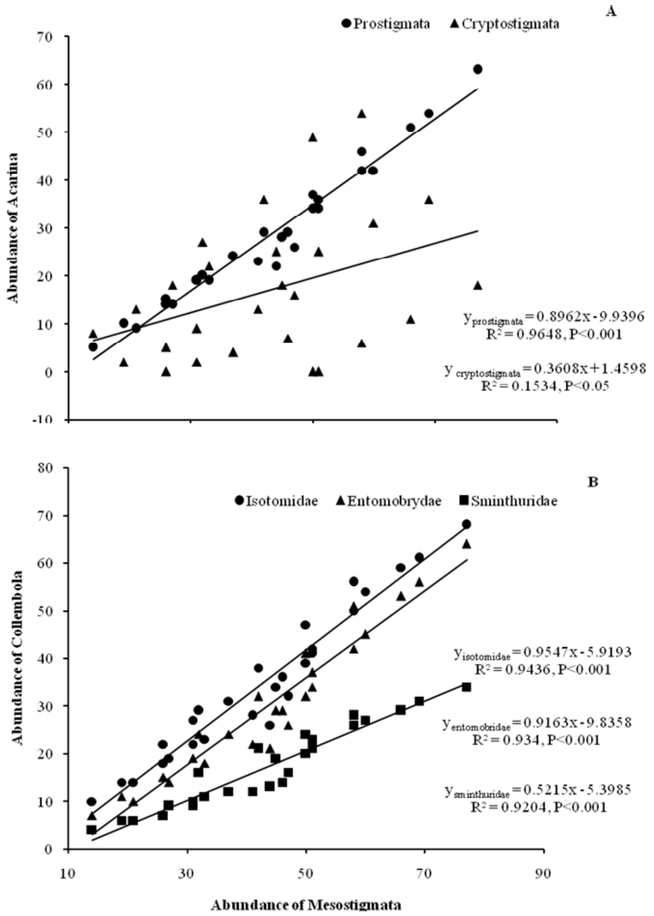

Fig. 8 Relationship between abundance of predatory mite – Mesostigmata with (**A**) Acarina (Prostigmata and Cryptostigmata); (**B**) Collembola (Isotomidae, Entomobryidae and Sminthuridae) in all the substrates, composts and vermicomposts.

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