ponse. Further analysis of the *IL-8* gene may help identify more functional polymorphisms associated with altered IL-8 production and susceptibility to TB in the Indian population.

1. Oppenheim, J. J., Zachariae, C. O. C., Mukaida, N. and Matsushima, K., Properties of the novel proinflammatory supergene 'intercrine' cytokine family. *Annu. Rev. Immunol.*, 1991, **9**, 617–648.
2. Broaddus, V. C., Hebert, C. A., Vitangcol, R. V., Hoeffel, J. M., Bernstein, M. S. and Boylan, A. M., Interleukin-8 is a major neutrophil chemotactic factor in pleural liquid of patients with empyema. *Am. Rev. Respir. Dis.*, 1992, **146**, 825–830.
3. Dlugovitzky, D. *et al.*, Levels of interleukin-8 in tuberculous pleurisy and the profile of immunocompetent cells in pleural and peripheral compartments. *Immunol. Lett.*, 1997, **55**, 35–39.
4. Sadek, M. I., Sada, E., Toossi, Z., Schwander, S. K. and Rich, E. A., Chemokines induced by infection of mononuclear phagocytes with mycobacteria and present in lung alveoli during active pulmonary tuberculosis. *Am. J. Respir. Cell Mol. Biol.*, 1998, **19**, 513–521.
5. Mastroianni, C. M., Paoletti, F., Rivosecchi, R. M., Lancella, L., Ticca, F., Vullo, V. and Delia, S., Cerebrospinal fluid interleukin 8 in children with purulent bacterial and tuberculous meningitis. *Pediatr. Infect. Dis. J.*, 1994, **13**, 1008–1010.
6. Bergeron, A. *et al.*, Cytokine patterns in tuberculous and sarcoid granulomas: correlations with histopathologic features of the granulomatous response. *J. Immunol.*, 1997, **159**, 3034–3043.
7. Ameixa, C. and Friedland, J. S., Interleukin-8 secretion from *Mycobacterium tuberculosis*-infected monocytes is regulated by protein tyrosine kinases but not by ERK1/2 or p38 mitogen-activated protein kinases. *Infect. Immun.*, 2002, **70**, 4743–4746.
8. Nau, G. J., Richmond, J. F. L., Schlesinger, A., Jennings, E. G., Lander, E. S. and Young, R. A., Human macrophage activation programs induced by bacterial pathogens. *Proc. Natl. Acad. Sci. USA*, 2002, **99**, 1503–1508.
9. Ma, X., Reich, R. A., Wright, J. A., Tooker, H. R., Teeter, L. D., Musser, J. M. and Graviss, E. A., Association between interleukin-8 gene alleles and human susceptibility to tuberculosis disease. *J. Infect. Dis.*, 2003, **188**, 349–355.
10. Cooke, G. S. *et al.*, Interleukin-8 polymorphism is not associated with pulmonary tuberculosis in the Gambia. *J. Infect. Dis.*, 2004, **189**, 1545–1546.
11. Hull, J., Thomson, A. and Kwiatkowski, D., Association of respiratory syncytial virus bronchiolitis with the *IL-8* gene region in UK families. *Thorax*, 2000, **55**, 1023–1027.
12. Boyum, A., Separation of leucocytes from blood and bone marrow. Introduction. *Scand. J. Clin. Lab. Invest. Suppl.*, 1968, **97**, 7.
13. Miller, S., Dykes, D. and Polesky, H., A simple salting out procedure for extracting DNA from human nucleated cells. *Nucleic Acids Res.*, 1988, **16**, 1215.
14. Hull, J., Ackerman, H., Isles, K., Usen, S., Pinder, M. and Thomson, A., Unusual haplotypic structure of IL8, a susceptibility locus for a common respiratory virus. *Am. J. Hum. Genet.*, 2001, **69**, 413–419.
15. Hacking, D., Knight, J. C., Rockett, K., Brown, H., Frampton, I., Kwiatkowski, D. P. and Hull, J., Increased *in vivo* transcription of an IL-8 haplotype associated with respiratory syncytial virus disease susceptibility. *Genes Immun.*, 2004, **5**, 274–282

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Breakdown of plantation residues by pill millipedes (*Arthrosphaera magna*) and assessment of compost quality

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We employed pill millipedes (*Arthrosphaera magna*) to generate compost from plantation crop residues on a pilot-scale. Three combinations of residues (w/w), viz. areca leaf litter and areca nut husk (1 : 1), cocoa leaf litter and cocoa pod husk (1 : 1) and mixed leaf litter (areca, acacia, cocoa and cashew) (1 : 1 : 1 : 1) in cement tanks were offered to millipedes with adequate moisture up to two months for composting. Particles less than 5 mm of millipede compost weighed about five times higher than control treatments. Total nitrogen ($P = 0.004$), phosphate ($P = 0.0006$) and C/N ratio ($P = 1.19 \times 10^{-6}$) significantly differed between control and treated residues. Organic matter and C/N ratio substantially declined in treated than in control residues. In areca compost, moisture and total nitrogen were elevated and pH was shifted from acidic to neutral. In mixed litter compost, phosphate, calcium and magnesium were elevated. Quality of millipede compost has been compared with vermicompost and importance of pill millipedes in recycling plantation residues has been discussed.

Keywords: *Arthrosphaera magna*, compost, faecal pellets, nitrogen, organic matter.

EVEN though the global renewable lignocellulosic waste production per annum is about $20–50 \times 10^9$ tonnes, only about 4×10^9 tonnes is utilized[1]. Decomposition and mineralization of such wastes are essential for continued soil productivity in terrestrial ecosystems[2]. Decomposition decreases the mass of organic substance due to physical breakdown of substrate, leaching of soluble materials, and catabolism or oxidation[3]. Although composting has been considered as a means of disposal of waste, the resulting product has significant commercial value. Activities of a consortium of soil organisms bring about composting of plant residues, where saprophagous fauna plays a significant role. Composting organic wastes for agricultural use is one of the improved ways of organic farming. On-farm cycling of organic waste and application of compost are the most popular agronomic measures adopted to maintain soil quality and health. Several serious environmental perturbations can be resolved through management of decomposition or organic cycling[4].

Vermicompost production through earthworms is one of the popular means of optimum utilization of organic

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waste. Turnover rates of soil by earthworms are directly proportional to microbial biomass of ingesta[5]. One thousand tonnes of moist organic matter can be converted into 300 tonnes of compost by earthworms[6]. Transition from chemical to sustainable agriculture requires 3–6 years[7]. This duration can be curtailed to three months by harnessing vermicompost technology[8]. Tropical soils are low in cation exchange capacity, poor in base nutrients (K, Ca and Mg), fragile and easily destroyable after forest clearing. Base nutrient replenishment takes place from addition of plant litter to soil[4,9]. Organic carbon deficiencies reduce the soil storage capacity for N, S, P, thus leading to reduction in soil fertility[4]. Soil mineral aggregates are more stable in the presence of humic substances[10]. Stable mineral soils have C : N : S : P ratio 110 : 10 : 1 : 2.5 and can hold more than 4% carbon[11–13]. Increase in organic N, S and P normally leads to increase in organic carbon[14]. The C/P ratio should be 100 : 1 for microbial activity and digestion. One tonne of farmyard manure supplies 5, 2.5 and 5 kg of total nitrogen, phosphorus and potassium respectively[15]. Appropriate technologies are available for innovative use and recycling of agricultural waste through vermicompost, mushroom cultivation, biogas generation and silage production. Millipedes are the major saprophagous fauna involved in litter decomposition in tropical, subtropical and temperate regions of the world. A spurt in the population of endemic pill millipede, *Arthrosphaera magna* in an organically managed mixed plantation, Varanashi Farms (Adyanadka, Dakshina Kannada, Karnataka, India; 12°42′N, 75°E) resulted in the current study to generate compost from plantation crop waste on a pilot-scale as suitable alternative to vermicompost. The qualities of millipede compost have been assessed and compared with vermicompost.

Adult pill millipedes, *A. magna* Attems were collected from the areca basin of mixed plantation during monsoon (early August 2000) from Varanashi Farms and maintained on mixed leaf litter diet available at mixed plantation with sufficient moisture in circular plastic containers (30 cm height, 45 cm diameter; with small outlets to drain excess water) for two weeks prior to the initiation of experiments. Composting was performed in cement tanks (45 cm height; 45 cm diameter) consisting of small holes at the bottom that would drain excess water (Figure 1). After transferring the organic matter and millipedes, the tanks were kept under a thatched roof to avoid direct sunlight. Each tank was covered with a nylon net to prevent disturbance from predators (Figure 1).

Plantation lignocellulosic waste such as litter of acacia, areca, cocoa, cashew, areca nut husk and cocoa pod husk was employed to produce compost. Freshly fallen areca leaves were gathered from the plantation and leaflets were cut into pieces (5 cm length). Dried areca nut husk was collected from the processing unit and cut into pieces. They were separately allowed for conditioning (partial decomposition for three weeks in tanks with 10 cm bottom soil) by frequent moistening. Cocoa leaves and cocoa pod husk were processed and conditioned like areca waste. Similarly, conditioned leaf litters of areca, acacia, cocoa and cashew were used for compositing as mixed litter. Three types of compost tanks were prepared: (i) Conditioned areca leaf litter and areca nut husk were mixed in 1 : 1 ratio on dry weight basis and quantity equivalent to 5 kg was placed into compost tanks; (ii) Mixture of conditioned cocoa leaves and cocoa pod husk (1 : 1) equivalent to 5 kg dry mass was placed into compost tanks; (iii) Conditioned areca, acacia, cocoa and cashew litter, each equivalent to 1.25 kg dry mass was layered per compost tank (Figure 1). During August 2000, adult millipedes, *A. magna*, acclimatized on organic matter in plastic containers were introduced into compost tanks (10 males and 10 females per tank). For each treatment, three replicates were maintained with appropriate controls. The

Figure 1. ***a***, Cement tanks used to produce compost by pill millipede, *Arthrosphaera magna* (inset). ***b***, Conditioned mixed leaf litter offered to millipedes. ***c***, Digested mixed leaf litter after two months of composting with millipedes. ***d***, Heaps of millipede compost produced from mixed leaf litter. ***e***, Areca leaf litter with areca nut husk.

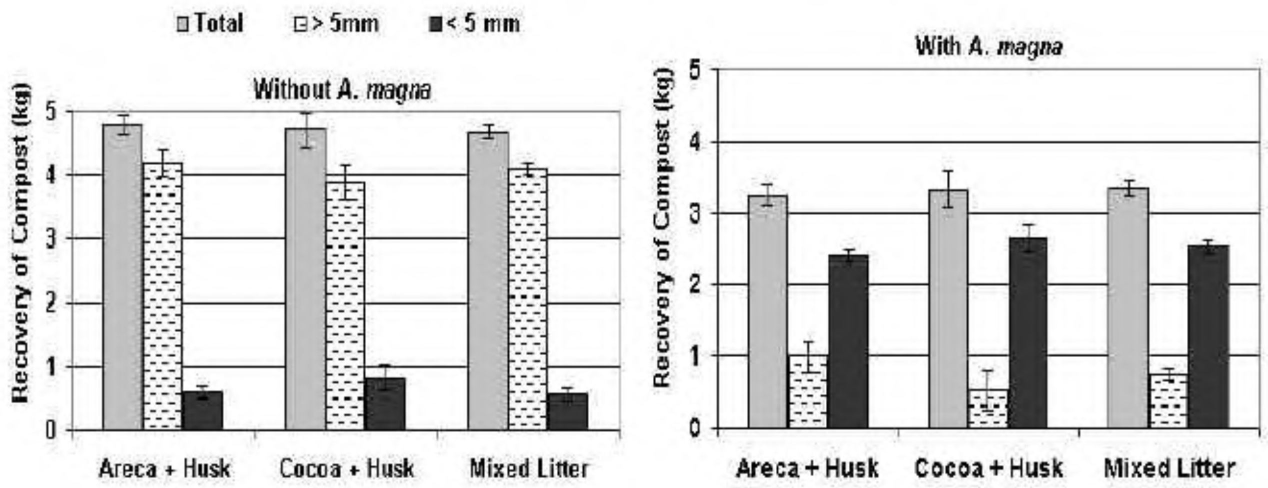

Figure 2. Recovery of compost without (control) and with pill millipedes, *A. magna* (n = 3; mean ± SD).

litter in each tank was sprayed with 500 ml water per day up to two months.

After two months, millipedes were removed from the compost tanks, contents of each tank were transferred separately onto polythene sheets and allowed to air-dry in shade (Figure 1). After drying, total dry weight was determined, sieved through a 5 mm sieve to separate fractions and dry weight of each fraction was recorded. Moisture of compost was determined gravimetrically (%) on drying known amount of air-dried compost at 80°C for 24 h. Oven-dried (80°C, 24 h) compost was pulverized and mixed with water (1 : 20 w/v) and shaken for 30 min to measure pH. Organic matter[16], nitrogen[16], phosphorus[16], potassium[16], calcium and magnesium[16,17] were estimated and expressed in per cent. Three replicates were maintained for all parameters tested. Paired *t*-test was employed[18] to determine difference in nitrogen, phosphate and C/N ratio between the compost generated with and without *A. magna*.

Figure 2 shows the recovery of compost produced with and without millipedes. Two months of composting the conditioned plantation residues with millipedes substantially reduced the weight. Weight of particles > 5 mm declined, while that of particles < 5 mm increased in treated compost. Weight of particles < 5 mm was about five times higher in treated than in control compost. Table 1 presents physico-chemical characteristics of compost. Moisture was high in treated than in control compost, while pH shifted from acidic (control) to neutral (treated). Total nitrogen was elevated in compost of treated areca and mixed litter. Phosphate, calcium and magnesium were increased in treated residues. Except for mixed litter, potassium was high in treated residues. Organic matter and C/N ratio substantially declined in treated residues. Paired *t*-test revealed that total nitrogen ($P = 0.004$), phosphate ($P = 0.0006$) and C/N ratio ($P = 1.19 \times 10^{-6}$) were significantly different between control and treated residues.

The total area under areca cultivation in India is about 254,000 ha, while cocoa is 14,100 ha[19]. One hectare of areca palms generates about 5–6 tonnes residue per annum and an equal quantity of residues is obtained from cocoa grown as mixed crop with areca palms. Areca palm waste supplies 5260, 1337 and 230 tonnes, while cocoa waste 540, 72 and 244 tonnes of N, P and K respectively[20]. Fertilizer dose required for areca palm is 100 : 40 : 140 g N, P and K per annum[21]. It is evident that within two months, about 88% of areca and 75% cocoa residues were converted into granular, odourless vermicompost by earthworms in southwest India[19]. Through vermicompost it is possible to meet about 50, 32.5 and 26% of N, P and K requirements of areca palms respectively[19]. In our study, areca and cocoa residues on composting with *A. magna* yielded about 70% recovery, out of which over 50% consists of fine particles (< 5 mm), which might have elevated the moisture retention ability due to increased surface area. Steep decline in C/N ratio was seen between control and treated residues. On comparison of C/N ratio of millipede compost with vermicompost produced on areca and cocoa waste (Table 2), a drop in C/N ratio of areca (33.36 vs 23.18) and cocoa (21.9 vs 14.78) waste was seen in vermicompost, while its relative decline for areca (25.8 vs. 21.7) and cocoa (23.91 vs 12.4) waste was higher in millipede compost in our study. Significant difference in C/N ratio between compost produced with and without millipedes ($P = 1.19 \times 10^{-6}$) shows the impact of millipedes on composting.

Annual litter production in acacia plantations (*Acacia auriculifomis*) ranges between 9.3 and 12 tonnes/ha in Kerala (southern India)[22], out of which phyllodes constitute 62–69%. The weight loss of acacia phyllodes on soil surface per annum ranged between 64.4 and 86%, while it was between 92.6 and 94.5% on burial in soil[22]. This rate of decomposition is lower than the decay rates of other major plantation litters in Kerala. Significant amount of

Table 1. Comparison of qualities of compost generated by *Arthrosphaera magna* on different plantation residues ($n = 3$, mean ± SD)

Residue	Treatment	Moisture (%)	pH	Organic matter (%)	Nitrogen (%)	C/N ratio	Phosphate (%)	Potassium (%)	Calcium (%)	Magnesium (%)
Areca	Control	58.25 ± 3	6.5 ± 0.01	79.9 ± 1.8	1.8 ± 0.04	25.8 ± 0.1	0.4 ± 0.02	1.29 ± 0.03	2.4 ± 0.1	0.93 ± 0.12
wastes[a]	With *A. magna*	69.75 ± 3.56	6.7 ± 0.1	75.18 ± 1.52	1.98 ± 0.04	21.7 ± 0.01	0.64 ± 0.05	1.98 ± 0.03	2.63 ± 0.21	1.03 ± 0.06
Cocoa	Control	236.9 ± 2.72	6.77 ± 0.06	81.76 ± 1.44	1.98 ± 0.04	23.91 ± 0.2	0.35 ± 0.04	1.34 ± 0.02	2.13 ± 0.06	1.93 ± 0.06
wastes[b]	With *A. magna*	267.6 ± 6.88	7.13 ± 0.06	41.89 ± 2.85	1.97 ± 0.09	12.4 ± 0.11	0.39 ± 0.1	1.49 ± 0.02	2.5 ± 0.1	1.77 ± 0.06
Mixed	Control	129.3 ± 65.74	6.3 ± 0.35	81.42 ± 4.47	1.89 ± 0.1	25.03 ± 0.78	0.25 ± 0.16	1.6 ± 0.16	1.92 ± 0.37	1.5 ± 0.37
leaf litter[c]	With *A. magna*	147 ± 73.3	6.72 ± 0.25	54.15 ± 13.8	2.12 ± 0.22	14.9 ± 3.96	0.46 ± 0.11	1.44 ± 0.34	2.27 ± 0.35	1.53 ± 0.44

[a]Shredded areca leaf litter and areca nut husk (1 : 1 w/w) (5 kg dry mass) conditioned for three weeks and composted with and without *A. magna* for two months.
[b]Shredded cocoa leaf litter and pod husk (1 : 1 w/w) (5 kg dry mass) conditioned for three weeks and composted without and with *A. magna* for two months.
[c]Areca, cocoa, cashew and acacia leaf litters, conditioned for three weeks mixed in 1 : 1 : 1 : 1 ratio (w/w) (5 kg dry mass) and composted without and with *A. magna* for two months.

Table 2. Comparison of qualities of compost generated by *A. magna* and earthworms

Residue	pH		Organic carbon (%)		Nitrogen (%)		C/N ratio		Phosphate (%)		Potassium (%)		Reference (millipede/ earthworm)
	C	T	C	T	C	T	C	T	C	T	C	T	
Areca waste[a]	6.5	6.7	46.4	43.6	1.8	1.98	25.8	21.7	0.4	0.64	1.29	1.98	Present study (Millipede)
Areca leaves*	8.1	7.3	33.7	33.1	1.01	1.38	33.36	23.18	0.08	0.35	0.96	0.98	19 (Earthworm)
Cocoa waste[b]	6.77	7.13	47.4	24.3	1.98	1.97	23.91	12.4	0.35	0.39	1.34	1.49	Present study (Millipede)
Cocoa waste**	8	7.5	28	24.4	1.29	1.65	21.9	14.78	0.19	0.19	0.27	0.32	19 (Earthworm)
Mixed leaf litter[c]	6.3	6.72	47.2	31.4	1.89	2.12	25.03	14.9	0.25	0.46	1.6	1.44	Present study (Millipede)

[a–c]See Table 1 for details.
*Dried areca leaves (100 kg) incubated with watering for 30 days and composted with (1 kg) and without earthworm (*Eudrilus eugeniae*) for two months.
**Dried cocoa leaves and pod husk (100 kg) incubated with watering for 30 days and composted with (1 kg) and without earthworm (*E. eugeniae*) for two months.
C, Control; T, Treated.

organic carbon input to soil from acacia phyllodes was found during decomposition. However, soil pH was significantly lowered (pH 4.7) in these plantations than in adjacent lands[22]. N, P, K, Ca and Mg in acacia phyllodes were 1.38, 0.085, 0.04, 0.035 and 0.0075% respectively[22]. On-farm recycling of plantation crop residues will be of advantage to provide desired nutrients to plantation crops. Our earlier study has revealed that *A. magna* preferred mixed leaf litter diet than monolitter diet[23]. The current study revealed elevated N, P and K, and narrow C/N ratio in mixed leaf litter composted with millipedes. Significant difference in total nitrogen ($P = 0.004$) and phosphorus ($P = 0.0006$) between compost with and without the influence of millipedes shows the importance of composting with millipedes.

Saprophagous invertebrates are known to change the microenvironmental conditions of litter through aeration and rigorous mixing of litter with mineral soil[24]. Maraun and Scheu[24] found that concentrations of nitrogen and phosphorus increased due to digestion and faecal pellet formation in pill millipedes (*Glomeris marginata*). Fragmented litter in faeces was accessible to microorganisms that release nitrogen on further decomposition. Smit and van Aarde[25] found significantly higher concentration of elements in compost from millipedes than in control. Field experiments by Nicholson *et al.*[26] and Webb[27] showed that ash and phosphorus were high in faecal pellets of millipedes. McBrayer[28] compared uningested leaf litter and faecal pellets of millipedes and found 600 times smaller particle size; increased pH, moisture and bacterial count; decreased fungal count and carbon in faecal pellets. Bocock[29] found low C/N ratio in millipede faeces than in the ingested litter. Decline in C/N ratio was seen between ingested leaf litter and faeces generated by *Glomeris* spp.[30]. The C and N of millipede faecal pellets decreased with total mass loss up to 44–50% of the initial value[31]. The highest rate of decomposition of faecal pellets was seen between 124 and 209 days, when the mass of the pellets declined to 63% of the initial value[31]. The current study that revealed a steep decline of C/N ratio in cocoa leaf litter + cocoa pod husk and mixed leaf litter composted with *A. magna* (12.4–14.9) compared to control (23.91–25.03), suggests its suitability for application. Leaf litter compost supplies heavy inoculum of microorganisms[32] and moulds, which are known to shift the compost pH from acidic towards neutral (pH, 6–7)[33]. Fragments of leaf litter in the faeces have a greater surface area for microbial colonization, which enhances the rate of decomposition[34,35]. In our study, *A. magna* produced fine particles of faecal matter on three kinds of residues offered (areca + husk, cocoa + husk and mixed litter), which might provide greater surface area for microbial colonization.

Consumption of litter by soil saprophagous fauna replenishes the soil nutrients and prevents elemental leaching by rain[36]. Diplopods are important sinks for calcium[37] and accumulate Ca and Mg up to fivefold higher than raw leaf litter[36]. They are also known to possess 327.33 mg Ca/g (ash-free dry mass) than other arthropods (1.89 mg/g ash-free dry mass)[37]. In calcareous soil, millipede faecal pellets remain stable without morphological changes for long duration[31]. Such stability has been connected to high Ca ions in soil[38], preventing Ca erosion. In the current study, composts of *A. magna* (except for Mg in cocoa residues) showed elevated Ca and Mg ion concentration. Dangerfield and Milner[39] suggested that soil acts as roughage and decreases the retention time and leads to rapid throughput of faecal pellets. The faecal pellets produced on ingestion of leaf litter with mineral soil were stable than those produced on feeding leaf litter alone[40]. The rates of retention were shorter on ingestion of mixtures of leaf litter and mineral soil than exclusively leaf litter[41]. The average weight of a faecal pellet of *A. magna* collected from the field (23.8 ± 8.9 mg) is higher than the mixed litter diet (18.9 ± 1.83 mg) in our study; this may be due to lack of offering soil along with leaf litter. Feeding plantation leaf litter along with soil may provide more information on the size, weight and stability of faecal pellets. The presence of enzymes and growth hormones (auxins and cytokinins) in vermicompost has been reported[42–44]. Enhanced phosphatase activity in earthworm casts has been predicted due to the activity of microflora[45]. However, no information is available on the quality of millipede compost, particularly the growth factors and hormones that are essential for plant growth and maturity. Millipedes harbour cellulolytic bacteria and fungi in their guts. Such association helps degrade plant litter, as in termites[46]. Fungi are the source of several classes of phenol-oxidizing enzymes (e.g. tyrosinase, laccase and peroxidase). These enzymes are involved in detoxification of phenolics of plant litter[47]. Fungal enzymes acquired during feeding may contribute to the digestion of cellulose, hemicellulose and pectin in the gut of wood- and litter-feeding arthropods[47]. The proportion of microorganisms colonizing leaf litter is a valuable nutritional source to millipedes to assimilate plant litter with high efficiency[48]. Fungi in decomposing litter provide precursors of vitamins and hormones to saprophagous fauna. Fungal tissue is a good source of choline and B-vitamins[49,50]. Arable soil in the tropics and subtropics is poor in organic matter due to high temperature and intense microbial activity[33].

Although farmyard manure serves as a good source of almost all plant nutrients[51], it is insufficient for some plantation crops[19]. Comparison of pill millipede compost with vermicompost produced by earthworm, *E. eugeniae* employing plantation residues (areca leaf litter, cocoa leaf litter and cocoa pod husk) (see Table 2) in the Central Plantation Crops Research Institute Regional Station, Vittal, Dakshina Kannada, reveals shift in pH towards neutral, elevation of nitrogen, phosphate, potassium and narrow C/N ratio in contrast to control. This indicates that pill millipede compost will be an alternative to vermicompost. In spite of realizing the importance of millipedes in soil quality improvement in temperate and tropical regions, no serious attempts have been made to produce compost by millipedes on agricultural residues. As farmyard manure partially meets the requirements of N, P and K of plantation crops, mixing millipede compost in appropriate proportions with farmyard manure might help overcome nutritional deficiencies. Millipede compost can be generated on-farm within three months (during monsoon and post-monsoon season in southwestern India) and hence, it will be an added advantage for efficient recycling of plantation residues. Since ingestion of leaf litter and faecal matter production by *A. magna* is higher than other tropical millipedes[23,52], it is worth considering *A. magna* for on-farm composting of agricultural waste in South India.

1. Kelley, J. and Paterson, R., Crop residues as a resource – the use of fungi to upgrade lignocellulosic wastes. *Biol. Int.*, 1997, **35**, 16–20.
2. Vitousek, P., Nutrient cycling and nutrient use efficiency. *Am. Nat.*, 1982, **119**, 553–572.
3. Seastedt, T. R., The role of microarthropods in decomposition and mineralization processes. *Annu. Rev. Entomol.*, 1984, **29**, 25–46.
4. Hartenstein, R., Earthworm biotechnology and global biogeochemistry. *Adv. Ecol. Res.*, 1986, **15**, 379-409.
5. Hartenstein, R. and Amico, L., Production and carrying capacity for the earthworm *Lumbricus terrestris* in culture. *Soil Biol. Biochem.*, 1983, **15**, 51–54.
6. Tapiador, D. D., Vermiculture and its potential in Thailand and other Asian countries, First National Earthworm Growers Convention, Metro Manila, Philippines, 1981.
7. Bhawalker, U. S. and Bhawalker, V. U., Vermiculture technology. In *Organics in Soil Health and Crop Production* (ed. Thampan, P. K.), Peekay Tree Crops Development Foundation, Cochin, 1993, pp. 69–85.
8. Bhawalker, U. S., Seminar on Low External Input Sustainable Agriculture, Amsterdam, The Netherlands, 1991.
9. Jordan, C. F., *Tropical Ecology*, Hutchinson Ross, Pennsylvania, 1981.

10. Turchenek, L. W. and Oades, J. M., Organo-mineral particles in soils. In *Modification of Soil Structure* (eds Emerson, W. W. *et al.*), Wiley, New York, 1978.
11. Walker, T. W. and Adams, A. F. R., Studies on soil organic matter I. Influence of phosphorus content of parent materials in accumulation of carbon, nitrogen, sulphur and organic phosphorus in grassland soils. *Soil Sci.*, 1958, **85**, 307–318.
12. Williams, C. H., Williams, E. G. and Scott, N. M., Carbon, nitrogen, sulfur and phosphorus in some Scottish soils. *J. Soil Sci.*, 1960, **11**, 334–346.
13. Bramas, D. L. and Riquier, J., *Organic Matter and Soil Fertility*, Wiley, New York, 1968.
14. Jenkinson, D. S. and Rayner, A. D. M., The turnover of soil organic matter in some of the Rothamsted classical experiments. *Soil Sci.*, 1977, **123**, 293–305.
15. Hagerty, D. J., Pavoni, J. L. and Heer, J. E., *Solid Waste Management*, Von Nostrand Reinhold, New York, 1973.
16. Jackson, M. L., *Soil Chemical Analysis*, Prentice Hall International, USA, 1973.
17. Kanwar, S. L. and Chopra, J. S., *Analytical Agricultural Chemistry*, Kalyani Publishers, New Delhi, 1981.
18. *STATISTICA for Windows*, Stat Soft, Inc., USA, 1995.
19. Chowdappa, P., Biddappa, C. C. and Sujatha, S., Efficient recycling of organic wastes in arecanut (*Areca catechu*) and cocoa (*Theobroma cocao*) plantation through vermicomposting. *Indian J. Agric. Sci.*, 1999, **69**, 563–566.
20. Biddappa, C. C., Upadhyay, A. K., Hegde, M. R. and Palaniswami, C., Organic matter recycling in plantation crops. *J. Plantation Crops*, 1996, **24**, 71–85.
21. Khader, K. B. A., Manurial experiments on arecanut. *J. Plantation Crops*, 1990, **17**, 39–50.
22. Sankaran, K. V., Balasundaran, M., Thomas, T. P. and Sujatha, M.P., Litter dynamics, microbial associations and soil studies in *Acacia auriculiformis* plantations in Kerala, KFRI Research Report No. 91, Kerala Forest Research Institute, Peechi, 1993, pp. 1–56.
23. Ashwini, K. M. and Sridhar, K. R., Leaf litter preference and conversion by a saprophagous tropical pill millipede, *Arthrosphaera magna* Attems. *Pedobiologia*, 2005, **49**, 307–316.
24. Maraun, M. and Scheu, S., Changes in microbial biomass respiration and nutrient status of beech (*Fagus sylvatica*) leaf litter processed by millipedes (*Glomeris marginata*). *Oecologia*, 1996, **107**, 131–140.
25. Smit, A.-M. and van Aarde, R. J., The influence of millipedes on selected soil elements: a microcosm study on three species occurring on coastal sand dunes. *Funct. Ecol.*, 2001, **15**, 51–59.
26. Nicholson, P. B., Bocock, K. L. and Heath, O. W., Studies on the decomposition of the faecal pellets of a millipede (*Glomeris marginata* Villers). *J. Ecol.*, 1966, **54**, 755–766.
27. Webb, D. P., Regulation of deciduous forest litter decomposition by soil arthropod faeces. In *The Role of Arthropods in Forest Ecosystem* (ed. Mattson, W. J.), Springer-Verlag, Heidelberg, 1977, pp. 57–69.
28. McBrayer, J. F., Exploitation of deciduous leaf litter by *Apheleria montana* (Diplopoda: Eurydesmidae). *Pedobiologia*, 1973, **13**, 90–98.
29. Bocock, L. L., The digestion and assimilation of food by *Glomeris*. In: *Soil Organisms* (eds Doeksen, J. and van der Drift, J.), North Holland, Amsterdam, 1963, pp. 85–91.
30. Marcuzzi, G., Experimental observations on the role of *Glomeris* spp. (Myriapoda, Diplopoda) in the process of humification of litter. *Pedobiologia*, 1970, **10**, 401–406.
31. Tajovský, K. Šanùètrková, H., Hánl, L. and Balík, L., Decomp osition of faecal pellets of the millipede *Glomeris hexasticha* (Diplopoda) in forest soil. *Pedobiologia*, 1992, **36**, 146–158.
32. Eberhardt, D. L. and Pipes, W. O., The fungus flora of composts. *Trans. Br. Mycol. Soc.*, 1974, **35**, 215–220.
33. Guar, A. C. and Sadasivam, K. V., Theory and practical considerations of composting organic wastes. In *Organics in Soil Health and Crop Production* (ed Thampan, P. K.), Peekay Tree Crops Development Foundation, Cochin, 1993, pp. 1–21.
34. Jenson, V., Decomposition of angiosperm tree leaf litter. In *Biology of Plant Litter Decomposition* (eds Dickinson, C. H. and Pugh, G. J. F.), Academic Press, London, 1974, pp. 69–104.
35. Hopkin, S. P. and Read, H. J., *The Biology of Millipedes*, Oxford University Press, Oxford, 1992.
36. Krivolutzky, D. A. and Pokarzhevsky, A. D., The role of soil animals in nutrient cycling in forest and steppe. *Ecol. Bull.*, 1977, **25**, 253–260.
37. Reichle, D. E., Shanks, M. H. and Crossley, D. A., Calcium, potassium and sodium content of forest floor arthropods. *Ann. Entomol. Soc. Am.*, 1969, **62**, 57–62.
38. Kubíková, J. and Rusek, J., Development of xerotermic rendzinas – A study in ecology and soil microstructure. *Rozpr. ÈSAV, Mat. Pøír.*, 1976, **86**, 1–78.
39. Dangerfield, J. M. and Milner, A. E., Ingestion and assimilation of leaf litter in some tropical millipedes. *J. Zool.*, 1993, **229**, 683–693.
40. Mwabvu, T., Soil in millipede diet: implications on faecal pellet stability and nutrient release. *Pedobiologia*, 1996, **40**, 495–497.
41. Dangerfield, J. M., Ingestion of mineral soil/litter mixture and faecal pellet production in the southern African millipede *Alloporus uncinatus* (Attems). *Pedobiologia*, 1993, **37**, 159–166.
42. Neilson, R. L., Presence of plant growth substances in earthworms demonstrated by paper chromatography and the wet pea test. *Nature*, 1965, **208**, 1113–1114.
43. Krishnamurthy, R. V. and Vajranabhaiah, S. N., Biological activity of earthworm casts: An assessment of plant growth promoter levels in the casts. *Proc. Indian Acad. Sci.*, 1986, **95**, 341–351.
44. Bhawalkar, U. S., Proceedings of National Seminar on Agricultural Biotechnology, Gujarat Agriculture University, Navrani, 1989.
45. Vinotha, S. P., Parthasarathi, K. and Ranganathan, L. S., Enhanced phosphatase activity in earthworm casts is more of microbial origin. *Curr. Sci.*, 2000, **79**, 1158–1159.
46. Romell, L. G., An example of myriapods as mull formers. *Ecology*, 1935, **16**, 67–71.
47. Martin, M. M., Biochemical implications of insect mycophagy. *Biol. Rev.*, 1979, **54**, 1–21.
48. Bignell, D. E., Relative assimilation of ^{14}C-labelled microbial tissue and ^{14}C-plant fibre ingested with leaf litter by the millipede *Glomeris marginata* under experimental conditions. *Soil Biol. Biochem.*, 1989, **21**, 819–827.
49. Hodgman, C. D., Weast, R. C., Shankland, R. S. and Selby, S. M., *Hand Book of Chemistry and Physics*, Chemical Rubber Publishing Co, Cleveland, 1959.
50. Millier, M. W., *The Pfizer Handbook of Microbial Metabolites*, McGraw-Hill, New York, 1961.
51. Palaniappan, S. P. and Natarajan, K., Practical aspects of organic matter maintenance in soil. In *Organics in Soil Health and Crop Production* (ed. Thampan, P. K.), Peekay Tree Crops Development Foundation, Cochi, 1993, pp. 23–41.
52. Lawrence, J. M. and Samways, M. J., Litter breakdown by the Seychelles giant millipede and the conservation of soil process on Cousine Island, Seychelles. *Biol. Conserv.*, 2003, **113**, 125–132.

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