Towards organic farming with millipede *Arthrosphaera magna*

Although a huge increase in agricultural productivity has been achieved, currently agriculture is facing severe perturbation of soil qualities such as erosion, depletion of organic contents and persistence of residues of heavy metals and pesticides[1]. Such degradation of soil quality is a consequence of soil pollution, lack of input of organic matter and depletion of soil invertebrate communities[2]. To restore soil health, the practice of organic farming and encouraging the activities of soil invertebrates in agriculture is an essential step. The principal economic values of soil macroinvertebrates include soil turnover, incorporation of organic matter into the mineral horizons, improvement of soil aeration by creating cavities, conversion of organic nitrogen and phosphorus into plant-assimilable forms, stimulation of soil respiratory enzymes, dispersion of microbial propagules and preservation of soil structure through humification. Activities and feeding behaviour of saprophagous macrofauna transform the plant detritus into compact aggregates and mix with the soil and help the movement of matter in soil profile, which is essential for a wide range of animals and microorganisms to establish and interact with each other. Woodlice, millipedes, earthworms and slugs are the major soil macrofauna demonstrated to increase the nutrient leaching from dead-leaf litter and enhance the humification of the soil[3,4]. However, the relationship between soil invertebrates and soil properties is not thoroughly understood.

Millipedes belonging to the genus *Arthrosphaera* are tropical inhabitants, abundant in the upper soil horizons of forests in moist regions[5]. They are endemic and generally responsible for the formation of moder type of humus. They are confined to widely separated land in tropical biomes of Indo-Australian region, South Africa and Madagascar[6]. Peninsular India inhabits about 27 species of *Arthrosphaera*[6]. They are known from the regions of adequate rainfall, particularly forests of Western Ghats and Eastern Ghats[7]. The genus *Arthrosphaera* includes individuals with large body size (length, 3–6 cm; width, 1.5–3 cm)[6,8], when disturbed enrolling into a giant 'pill' hence called 'pill millipedes'. The conglobation (enrolment) is a passive defence mechanism which enables the animal to protect its head, sense organs and appendages against predators. Its diet mainly consists of partially-degraded leaf litter along with soil[9], possibly the gut microflora assist in digestion. The faecal droppings are solid cylindrical pellets consisting of soil and digested/semi-digested macerated organic matter[10]. Because of the bulldozing body size and shape, pill millipedes till the soil, mix it with the litter pieces, draw them inside the soil to the burrows or bring the organic matter from underneath to the top soil, to transform into moder type of humus. Thick litter beds with sufficient moisture harbour pill millipedes, while grasslands and plains totally lack this genus due to insufficient moisture, organic matter, canopy and shade. The activity of *Arthrosphaera* extends up to post-monsoon season, depending upon the soil moisture[7]. At the onset of summer, they burrow into the

Figure 1. ***a***, Eggs; ***b***, Juveniles; ***c***, Adults; ***d***, Faecal castings of *Arthrosphaera magna* found in the basins of arecapalm and ***e***, Heap of compost generated on cashew-leaf litter (Scale bar: ***a***, 2 mm; ***b–e***, 1 cm).

subsoil surface, make a crevice of their body size and enter into a quiescent stage. Each animal is independent with respect to its burrow or nesting behaviour.

Arthrosphaera magna Attems is an endemic species distributed in the forests of coastal Southern India (Karnataka, Maharashtra and Tamil Nadu)[6,7]. Exclusive organic manure application to *Areca* plantations of Varanashi Farms, Adyanadka, Dakshina Kannada over a decade resulted in huge increase of soil macrofauna, particularly *A. magna*. In arecanut palm basins they usually lay the eggs during the monsoon period (June–September). Eggs are spherical, calcareous, white and 1.5–2 mm in diameter (Figure 1 *a*). Activity of juveniles will be seen during monsoon and post-monsoon periods (June–January), they possess dark olive-green colour (Figure 1 *b*). The head of the adult is yellow-brown or olive-brown or olive-green; second segment, collum and other segments are dark-brown with black band bordered with light-yellow colour, forming a narrow stripe (Figure 1 *c*). The adult individual weighs 7.2 g ($n = 15$; range, 5.1–13.7 g), measures 4.6 cm long ($n = 15$; range, 3.8–6 cm) and 2.2 cm wide ($n = 15$; range, 1.8–2.6 cm). Several biotopes of the Western Ghats and the west coast of India surveyed provide favourable conditions for the establishment of *Arthrosphaera*. They occur in many forest locations of Dakshina Kannada, Udupi, Shimoga, Hassan and Kodagu districts of Karnataka which possess good vegetation and canopy cover with thick litter bed. Studies on *Arthrosphaera* in the Western Ghats and the west coast reveal that the individuals of *Arthrosphaera* are location-specific and abundant in the basins of organically cultivated *Areca* gardens than in the forest floor, especially during the southwest monsoon (June–December). The activity of *A. magna* was at a peak during July to October, as indicated by the accumulation of faecal castings (Figure 1 *d*).

Seasonal fluctuations of the population of *A. magna* at bimonthly intervals in arecanut palm garden (undisturbed palm basins and interspace) and adjoining mixed forest floor were assessed to understand the population dynamics during 1996–97. Total individuals were enumerated per 30 cm^3 of soil along with organic matter. Arecanut palm basin showed higher number of individuals than the forest floor (Table 1). A steep increase in the population was seen in palm basins during monsoon and post-monsoon season. The interspace of palm did not show any individuals, possibly due to insufficient organic matter. It is a well-known fact that land tillage practices in crop husbandry play an important role in the establishment of soil invertebrates, including millipedes. Addition of organic debris to the arecanut palm basin with retention of sufficient moisture has considerably improved the population of *A. magna*. Afforestation, well-spread canopy, organic farming, adequate moisture and no tillage improve the abundance of *Arthrosphaera* spp[11]. On the contrary, deforestation, removal of organic residue, synthetic fertilizers/toxicants, extended dry periods and tillage have a negative impact on the abundance and activities of *Arthrosphaera* spp.

The soil macrofauna is known to have a considerable role in the disintegration and decomposition of organic material added to the soil[8]. *A. magna* is found to feed and process a large variety of plantation litter when offered (*Areca* leaves, sheath and husk; banana leaves and pseudostem; *Cocoa* pod husks and leaves; leaves of *Cocoa*, *Acacia*, cashew, coffee, coconut, jack, mango, pepper and some forest leaf litter). An outdoor experiment was conducted to generate compost, wherein four partially-degraded litter samples (see Table 2) on an equal oven-dry weight basis (5 kg) were separately added to circular cement tanks (diameter, 45 cm; depth, 45 cm). To each tank, ten adult individuals of *A. magna* were introduced. The soil moisture was maintained at field capacity. A corresponding set without millipedes served as control. After eight weeks, the decomposed litter was harvested. The litter pieces were more or less uniformly disintegrated into homogeneous material mixed with millipede faecal castings in treated litter (Figure 1 *e*) against almost entire leaf pieces with less disintegration in untreated litter. The recovery of the decomposed litter was more in case of the treated samples than in the control. The millipede compost and control litter samples were analysed for total nitrogen, phosphorus, potassium and C/N ratio. Nitrogen, phosphorus and potassium increased in treated litter than in untreated litter (Table 2). The narrow C/N ratio in treated samples indicates the enhancement of respiration, influenced by the activities of *A. magna*. The compost recovered from the treated litter was superior in nutrient content than the untreated control.

Thus, this study demonstrated that *A. magna* process the plantation litter efficiently and enrich the soil with compost of high quality. They are suitable for efficient management of solid wastes of

Table 1. Population of *Arthrosphaera magna* in arecanut palm basin and forest floor during 1996–97 (in 30 cm^3; $n = 5$; mean ± SE)

Month and year	Arecanut palm basin	Forest floor
November 1996	2.2 ± 0.6	1.2 ± 0.7
January 1997	6.2 ± 2.4	0.6 ± 0.4
March 1997	4.4 ± 1.1	1 ± 0.6
May 1997	5 ± 2.2	1.2 ± 0.4
July 1997	12.2 ± 4.5	1 ± 0.4
September 1997	34.8 ± 15.7	2.2 ± 1
November 1997	5.6 ± 2	0.4 ± 0.2

Table 2. Composition of compost generated with and without (in parenthesis) *Arthrosphaera magna* on different litters ($n = 3$; mean ± SE)

Litter	Nitrogen (%)	Phosphorus (%)	Potassium (%)	C/N ratio
Arecanut husk and leaves	2 ± 0.02 (1.8 ± 0.02)	0.64 ± 0.02 (0.38 ± 0.01)	2 ± 0.01 (1.29 ± 0.01)	21.7 ± 0.02 (25.8 ± 0.03)
Cocoa pod husks and leaves	2 ± 0.07 (2 ± 0.02)	0.4 ± 0.05 (0.38 ± 0.01)	1.5 ± 0.1 (1.34 ± 0.03)	12.7 ± 0.29 (23.8 ± 0.02)
Cashew leaves	2 ± 0.02 (1.8 ± 0.03)	0.45 ± 0.03 (0.1 ± 0.02)	1.2 ± 0.01 (1 ± 0.01)	12.1 ± 0.05 (24.3 ± 0.03)
Acacia leaves	2.5 ± 0.02 (2 ± 0.02)	0.38 ± 0.01 (0.23 ± 0.02)	1.1 ± 0.02 (1 ± 0.02)	13.4 ± 0.01 (25.8 ± 0.01)

plantation crops and other agricultural residues. Establishment and enhanced activities of *A. magna* in organically-managed arecapalm farms or mixed plantations indicate the rejuvenation of soil-fertility status. These millipedes are sensitive to water-deficit and fail to overcome the limitation of even a single edaphic factor (particularly the soil texture and litter thickness); thus enhancement of their population in any farmyard denotes the restoration of suitable conditions for their natural breeding, establishment and activities. Their sensitive nature may also serve as an authentic measure as indicators of pollution-free status of soil in agricultural, plantation and horticultural farms. Hence, there is an urgent need to study the distribution, conservation strategies, lifecycle, rearing and compost production by *A. magna* found in the Western Ghats and the west coast of India.

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Study of the microflora associated with coconut eriophyid mite as a preliminary step towards pathogen isolation

The coconut eriophyid mite *Aceria guerreronis* Keifer is a serious coconut pest in several states of India. Hidden habitat under the nut bracts, high reproductive rate and a short lifecycle of 10–11 days pose difficulties to control this acarine pest by insecticides, and thorough investigations on parasites, predators and pathogens are essential[1]. Among the pathogens, the targeted group is the fungi, as theoretically, the soft-bodied nature of acari and their inhabit environment with humid microclimates make them good hosts of fungal pathogens[2,3]. However, finding the microflora associated with the insects and their significance may lead to isolation of possible pathogen(s)[4]. The work done on microorganisms associated with the eriophyid mite from the coconuts collected from five districts of Kerala, with the aim to isolate putative pathogen(s) is presented here.

Three to nine-month-old coconuts with different degrees of mite-induced damage stages were collected from Alappuzha, Ernakulam, Kottayam, Thrissur and Kollam districts of Kerala during 1999 September–2000 November from the coconut gardens managed agronomically with chemical fertilizers and pesticides, organics only, chemicals and organics, and unattended (neglected) gardens.

The nuts were brought from the gardens to the laboratory in an open container, as it was observed that bringing them in plastic bags had suffocated the mites, resulting in their mass migration out of their habitat. A total of 286 nuts were screened during this study. For the observation of the mite colonies and any microbial growth, the upper whorl of bracts of larger nuts (more than 5 months old) was carefully removed using a blunt forceps. In case of the younger nuts (3–4 months old), if removal of the upper whorl of bracts was not done carefully, usually the top of the nut broke spilling the contents. Once the upper whorls were removed, the lower whorls could be pried open easily. Yet, during the removal of the bracts, injury was caused to the mites because of the entry of the forceps in the mite colony, many a times resulting in crushing and death of the host. Casualty of the pest because of such handling had to be clearly discerned from other modes of death. Smaller nuts were observed directly using a stereo microscope (Leica Wild M-10) for dead patches of the mite colonies. Slices of the meristematic portion of the larger nuts were used for similar observations. The microorganisms associated were isolated by plating the unsterilized dead, surface-sterilized (with 2.5% $NaOCl_2$, 2 min) dead, unsterilized live, surface-sterilized live eriophyid mites and other mites/insects too from the same habitat on Sabourauds, potato dextrose and Richards Synthetic (for fungi), nutrient (for bacteria) and Kenknights and Munaiers (for actinomycetes) media, incubated at 28 ± 2°C and obser-