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Feeding Rate of Soil Animals in Different Ecosystems in Pati, Indonesia

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The feeding activity of soil animals was measured by using bait lamina test in three main ecosystems, i.e. the teak forest, home garden and rainfed paddy field. Two additional ecosystems in rainfed paddy field, i.e. the old (permanently established bund around paddy fields) and new bunds were examined as well. Three blocks of bait-lamina sticks (each block consisting of 16 individual sticks) were exposed at each location. The bait lamina were retrieved from the soil after two days and visually assessed. Each hole is designated as "fed" (perforated) or "non-fed" hole. The feeding rate is measured as the absolute number of "fed" holes. Soil animals in the old bunds showed the highest feeding activity (55.20%), followed by home garden (39.10%), rainfed paddy field (16.50%), teak forest (15.60%), and new bund (7.80%). The frequency of animals attack to the bait strips also indicated the similar pattern as their feeding activity, i.e. high in the old bunds (0.90), followed by home garden (0.70), teak forest (0.40), new bunds (0.40) and rainfed paddy field (0.30), respectively.

Key words: soil animals, feeding activity, bait-lamina test

Studies of soil ecosystem should include investigation not only in structural but also in functional processes (Meyer 1993; Bolger & Heneghan 1996). The latest approach for testing functional parameters is the bait-lamina test in which the feeding activity of a variety of soil organisms (e.g. earthworms, Collembola, Acari, and Enchytraeidae) is measured (Torne 1990a,b; Kratz 1998), whereas the respiration activity of microorganisms is not detectable (Helling *et al.* 1998). The strategy to integrate functional investigations into soil biology at the ecosystem level has advantage to explain processes of change in dead organic matter and to answer about questions of ecosystem management and soil protection (Luthard 1991).

The bait-lamina test (the Torne method) providing a simple, inexpensive and quick (several days up to few weeks) method to evaluate soil biology activity (Hoffmann *et al*. 1991). Additionally, its nearly no needs training, special skills or equipment. In comparison to the measurement of the other functional parameters such as litter decomposition, the bait-lamina method practically does not disturb the soil substrate.

Torne (1990a) described initially different application systems (PVC-strips, PVC-sticks, and PVC-discs) as well as different bait substrate mixtures (chernozem soil, plaster of Paris, bran flakes powder, milk powder, peptone, manitose, cellulose powder, litter material of bushgrass seeds/ *Calamagrostis epigejos* ROTH, and big string nettle/*Urtica dioica* L.) powder. Later, the bait-lamina test system, modified by *Terra Protecta* GmbH, Berlin, had wide application using a variant of PVC-stripes and a standard substrate mixture containing cellulose and bran flakes powder (70:30, m/m) and traces of active coal.

In principle, the loss of artificial or natural organic material (= bait) exposed to a variety of soil animals in the holes of small plastic strips that are inserted into the soil is measured (Helling *et al.* 1998). The number of empty holes (i.e. from which the bait material was removed by soil animals) as well as their vertical distribution are evaluated. This condition allows using the feeding activity of soil animals as additional functional parameter for the assessment of the biological status of the soils.

Some studies using bait lamina have been performed by many researchers. Filzek *et al.* (2004) evaluated the metal effects on soil animal feeding activity and indicated the highest feeding activity of soil animals was at sites furthest from factory, the intermediate activity was at intervening sites and extremely low activity was at the sites closest to the smelter. The contribution of soil animals to decomposition processes in soil was reported by Gestel *et al.* (2003) using three different test methods (bait lamina, wheat straw degradation, and the cotton-strip assay). Those concluded that the bait-lamina test provides the best reflection of biological activity of soil animals (particularly earthworms) compared to that of microbial activity.

Despite the regular use in temperate region, limited bait-lamina tests also performed in the tropic (Geissen *et al*. 2001). Hence, this study was performed to obtain more data on bait-lamina test in the tropical region. This study was conducted to evaluate the feeding activity of soil animals in the three main ecosystems, i.e. teak forest, home garden and rainfed paddy field ecosystems in Pati, Indonesia. Two additional ecosystems in rainfed paddy field, i.e. the old (permanently established bund around paddy fields) and new bund were examined for feeding activity data. Soil animal abundance and biomass were investigated based on the three main ecosystems to support feeding activity data. As the bait-lamina method is one of the approaches for testing functional parameter, this study was expected to be useful for assessment of biological status of the soil.

The activity of the soil animals was evaluated using the bait-lamina method (Torne 1990a). Three randomized locations in the teak forest, two locations in the home garden and four locations in rainfed paddy fields (two locations in the rainfed paddy field and one each on the old bund and the new bund) were selected for the bait lamina. These locations were selected since they represented the different ecosystems and located close to each other (the distance between each location approximately five kilometers). Three blocks of bait-lamina sticks (each block consisting of 16 individual sticks) were exposed at each location for two days (Figure 1).

Bait lamina consist of plastic strips 120 x 6 x 1 mm in size, which have a pointed tip at the lower end. In the lower part (85 mm) of each strip, 16 holes of 1.5 mm diameter are drilled with a 5.5 mm spacing (Figure 2). The holes are filled with bait material, a mixture of cellulose, agar-agar, bentonite, bran flake powder and a small amount of activated carbon. Bait lamina were inserted into the soil in small slits made with a knife in 25 x 25 cm blocks, each block containing 16 bait lamina. They were exposed for two days. At the end of the exposure time, the bait lamina were retrieved from the soil and visually assessed (strips held against the light). Each hole is designated as "fed" (perforated) or "non-fed" hole. The feeding rate is measured as the absolute number of "fed" holes/total number of holes or 16 x 100%.

In addition to the soil animals feeding activity, their abundance and biomass in the three main ecosystems (teak forest, home garden and rainfed paddy field) were also evaluated using a soil corer of 20 cm diameter to the depth of 15 cm (Meyer 1996) from five randomized points in the above ecosystems. The soil fauna was then extracted by using Berlese funnel extractor (Hofer *et al*. 2001). A Berlese funnel is a device for collecting and extracting the active stages of small invertebrates from soil. The extraction was carried out within ten days. The extracted animals were then stored in 70% alcohol and they were identified under stereomicroscope. Larger animals, especially earthworms, were sorted manually by hand (Meyer 1996). The number of individuals (abundance or density) of the extracted animals was calculated as follows (Meyer 1996):

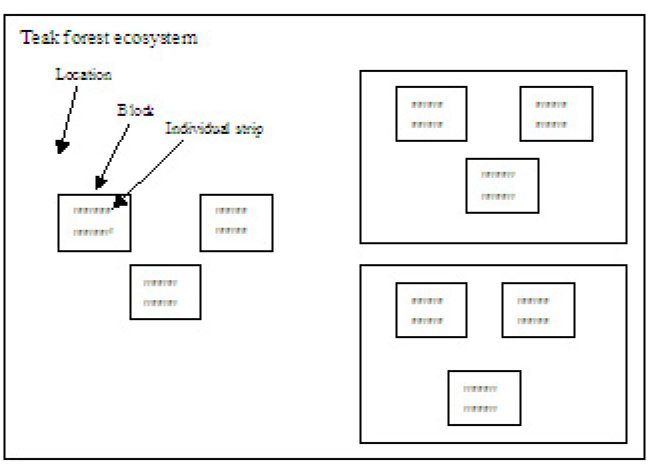

Figure 1. Bait-lamina exposition at three small blocks and three randomized locations (teak forest ecosystem). Each block consisted of 16 strips.

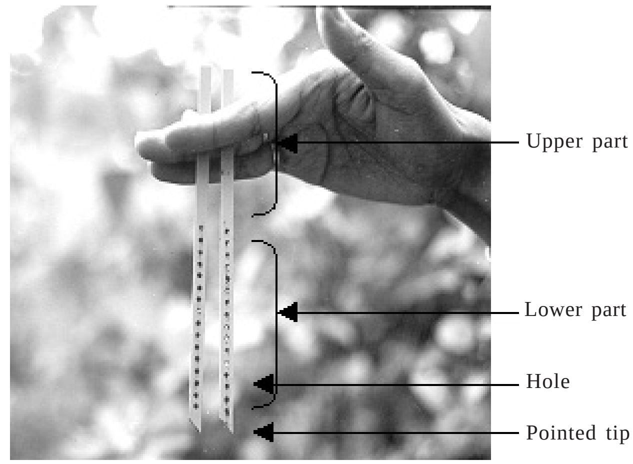

Figure 2. *Bait Lamina.*

$$\frac{IS}{A} = I.cm^{-2}$$

IS: mean number of individuals per sample, A: surface area of the corer (cm^2)*, I: number of individuals, *Area of the corer $= r^2.p = (10\ cm)^2 \times 3.4 = 314\ cm^2$. The value was then converted into m^2.

Soil fauna biomass was calculated based on their individual dry weight using different regression equations of body length-body weight (Edwards 1967; Petersen & Luxton 1982) (Table 1). These relationships are generally well established for temperate and tropical organisms (Hanagarth & Brandle 2001; Hofer *et al*. 2001).

Bait-Lamina Feeding Activity. Feeding activity is reflected in the percentage of bait patches removed from each strip. The frequency of feeding is a comparison between the number of bait strips attacked by animals (without regarding the number of fed holes), and the total number of strips exposed to the field within one block (16 strips). Soil animals in the old bunds showed the highest feeding activity (55.2%), followed by home garden (39.1%), rainfed paddy field (16.5%), teak forest (15.6%), and new bund (7.8%). The frequency of animal attacks to the bait strips was also high in the old bunds (0.9), followed by the home garden (0.7), teak forest (0.4), new bunds (0.4) and rainfed paddy field (0.3) (Figure 3). The lowest variability of both feeding activity and the frequency of feeding were also found in the old bunds which reflected in the low standard deviation (% of average, Table 2).

The feeding stratification, indicating soil animal activity in various soil depths was also assessed. In general the soil animals fed in the upper part (0-4 cm) of the bait lamina rather than in the lower one (Figure 4). In the rainfed paddy field, although the difference was not clear, there was a tendency

Table 1. Body length and dry weight of individual animals

Taxa	Average body length (mm)*	Average dry weight (mg)	References
Phyllum Arthropoda			
Subphyllum Chelicerata			
Class Arachnida			
Order Aranae	2.96	0.57	Hanagarth and Brandle (2001)
Order Pseudoscorpiones	1.50	0.16	
Order Acari	0.57	0.01	Edwards (1967)
Subphyllum Crustacea			
Class Malacostraca			
Order Isopoda	2.30	0.11	
Subphyllum Atelocerata			
Class Diplopoda			
Order Spirobolida	5.41	0.94	
Class Chilopoda			
Order Scolopendromorpha	4.13	0.05	Hanagarth and Brandle (2001)
Class Symphyla	2.88	0.08	
Class Hexapoda			
Order Protura	2.50	0.01	
Order Diplura	2.51	0.02	
Order Collembola	0.50	0.01	Edwards (1967)
Order Orthoptera	4.64	0.01	Hanagarth and Brandle (2001)
Order Isoptera	1.50	0.60	Petersen and Luxton (1982)
Order Psocoptera	1.07	0.28	Edwards (1967)
Order Hemiptera	2.86	0.34	
Order Homoptera	1.32	0.90	
Order Thysanoptera	1.50	0.02	Hanagarth and Brandle (2001)
Order Coleoptera	3.66	0.70	
Order Coleoptera (larvae)	5.52	0.99	
Order Diptera	1.90	0.45	Edwards (1967)
Order Diptera (Larvae)	3.71	0.80	
Order Trichoptera	2.68	0.22	Hanagarth and Brandle (2001)
Order Lepidoptera (larvae)	6.21	1.98	
Order Hymenoptera	2.29	0.50	
Phyllum Annelida			
Class Oligochaeta	48.13	21.00	Petersen and Luxton (1982)
Class Enchytraeids	4.09	0.03	

*Average body length measured in samples

Table 2. The average values of feeding activity of soil animals in three different ecosystems in Pati, Indonesia

Ecosystems	% Feeding	SD	SD (% of average)	Frequency	SD	SD (% of average)
Teak forest	15.60	12.30	78.80	0.40	0.20	54.90
Home garden	39.10	29.80	76.40	0.70	0.30	49.10
Rainfed paddy	16.50	35.40	215.10	0.30	0.40	125.30
Old bund	55.20	38.70	70.10	0.90	0.10	11.50
New bund	7.80	7.20	91.60	0.40	0.20	50.70

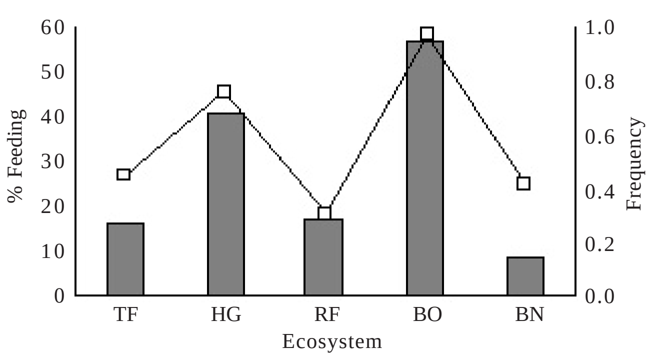

Figure 3. Percentage and frequency of animal feeding in three different ecosystems in Pati, Indonesia (TF: teak forest, HG: home garden, RF: rainfed paddy field, BO: old bund, and BN: new bund). Bars: Feeding activity (%), Lines: Frequency.

for the animals to feed more in the upper part of the bait strips. In almost all locations, the soil animals fed from the upper part (0-4 cm), particularly in the old bund, which showed the highest reduction from the 1^{st} up to the 16^{th} hole of the bait lamina (Figure 4).

Soil Animal Abundances and Biomass. With the exception of the teak forest and the old bund, soil fauna feeding activity in the rainy season showed a similar trend regarding abundance and biomass. Feeding activity, abundance, and biomass were low in the rainfed paddy field and high in the home garden and teak forest. The total soil fauna abundance in teak forest, home garden and rainfed paddy field were 2340 $\pm$ 1830, 2940 $\pm$ 1050, and 1790 $\pm$ 1460 individuals m^{-2}, respectively (Table 3).

The home garden also showed a higher total soil fauna biomass (368 mg m^{-2}), compared to the rainfed paddy field (309 mg m^{-2}). The teak forest had the highest soil fauna biomass (961 mg m^{-2}) due to the occurrence of the group of Isoptera (termites) and earthworms at this site. These animal groups did not occur in the home garden and rainfed paddy field ecosystems. Hymenoptera group was also dominant in the teak forest, compared to other ecosystems (Table 3).

Feeding activity of soil animals clearly differ in different ecosystems. The highest feeding activity and frequency of bait lamina attacks by animals in the old bund might have several reasons. In the wet seasons, when the experiment was conducted, the soil animals in the rainfed paddy field moved and concentrated on the bund because the field was flooded. Dry condition of the bund seems to be a favourable habitat for most of soil animals, since they need oxygen for their respiration. Thus, the population of soil animals was higher in the bund, compared to the field. Widyastuti (2002) reported that during the flooded periods of the rainfed paddy field, soil animal abundance and biomass in the bunds were higher than those in the rainfed paddy field.

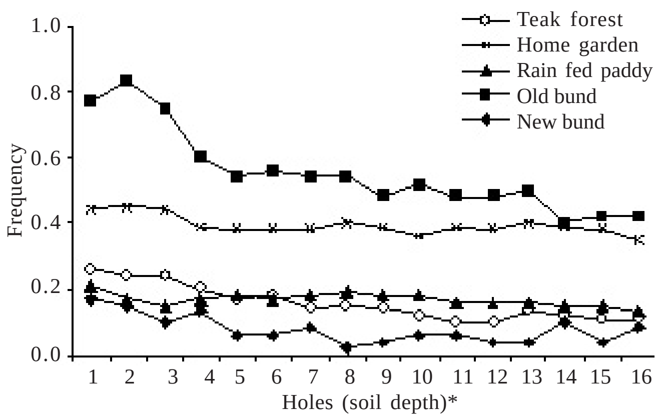

Figure 4. The frequency of bait lamina attacked by animals in various depth of soil in different ecosystems in Pati, Indonesia (*distance between holes = 5.5 mm).

The higher population density led to the increase in feeding activity of soil animals in the old bund. In contrast, the feeding activity declined in the rainfed paddy field. This was correlated with the soil fauna abundance and biomass, which the value was lower in the rainfed paddy field compared to the home garden and teak forest ecosystems. Only six animal groups (Acari, Collembola, Coleoptera, Chilopoda, Diptera, and Hymenoptera) occurred at this site (Table 3).

In their laboratory experiments, Helling *et al.* (1998) demonstrated that feeding activity of collembolans and enchytraeids was strongly correlated with the number of individuals. The limited resource of feed in the old bund may also have caused the soil animals to feed only on bait materials, and this would then have been reflected in high bait-lamina feeding activity in the old bund. The lowest feeding activity of soil animals in the new bund was certainly related to the low population density. The abundance of soil

Table 3. Mean and standard deviation of soil fauna abundances and biomass in teak forest, home garden, and rainfed pady field (soil depth 0-15 cm; averages over five replications)

Taxa	Teak forest		Home garden		Rainfed paddy field	
	Abundance (indv/m²)	Biomass (mg/m²)	Abundance (indv/m²)	Biomass (mg/m²)	Abundance (indv/m²)	Biomass (mg/m²)
Phyllum Arthropoda						
Subphyllum Chelicerata						
Class Arachnida						
Order Aranae	32 ± 39	18.2 ± 22.3	32 ± 39	18.2 ± 22.3	0.0 ± 0.0	0.0 ± 0.0
Order Pseudoscorpiones	13 ± 17	2.0 ± 2.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Order Acari	261 ± 250	0.6 ± 0.5	440 ± 188	1.5 ± 0.8	287 ± 154	0.5 ± 0.6
Subphyllum Crustacea						
Class Malacostraca						
Order Isopoda	6 ± 14	0.7 ± 1.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Subphyllum Atelocerata						
Class Diplopoda						
Order Spirobolida	19 ± 29	17.0 ± 26.8	57 ± 79	53.9 ± 74.6	0.0 ± 0.0	0.0 ± 0.0
Class Chilopoda						
Order Scolopendromorpha	13 ± 17	0.7 ± 0.9	0.0 ± 0.0	0.0 ± 0.0	6 ± 14	0.3 ± 0.7
Class Symphyla	13 ± 17	1.0 ± 1.4	13 ± 17	1.0 ± 1.4	0.0 ± 0.0	0.0 ± 0.0
Class Hexapoda						
Order Protura	6 ± 14	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Order Diplura	0.0 ± 0.0	0.0 ± 0.0	223 ± 134	4.5 ± 2.7	0.0 ± 0.0	0.0 ± 0.0
Order Collembola	490 ± 440	3.7 ± 3.7	1680 ± 514	6.5 ± 2.3	1160 ± 1470	10.0 ± 14.5
Order Isoptera	268 ± 581	161.0 ± 348.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Order Coleoptera	19 ± 31	17.2 ± 28.3	45 ± 72	27.7 ± 47.9	319 ± 328	206.9 ± 237.0
Order Diptera	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	6 ± 14	2.86 ± 6.39
Order Lepidoptera (larvae)	6 ± 14	12.6 ± 28.2	13 ± 17	25.2 ± 34.5	0.0 ± 0.0	0.0 ± 0.0
Order Hymenoptera	1190 ± 1670	592.0 ± 836.0	433 ± 760	216.6 ± 380.4	12 ± 28	6.4 ± 14.2
Phyllum Annelida						
Class Oligochaeta	6 ± 14	134.0 ± 299.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Class Enchytraeids	0.0 ± 0.0	0.0 ± 0.0	13 ± 29	0.4 ± 0.9	0.0 ± 0.0	0.0 ± 0.0
Number of individual	2340 ± 1830		2940 ± 1050		1790 ± 1460	
Total biomass		961.0 ± 933.0		368.0 ± 289.0		309.0 ± 235.0

fauna in the new bund is low because the soil structures that provide a habitat for soil fauna have not yet been established. The high feeding activity and frequency in the home garden corresponded with the high abundance and biomass (Table 3). The soil animals belong to macrofauna living closely to the soil surface in the home garden, such as ants (Hymenoptera), millipedes (Diplopoda), Aranae, and some groups of mesofauna (Acari and Collembola) were mainly responsible for feeding on bait lamina. However, in the teak forest, although soil fauna abundance and biomass were high, their feeding activity and frequency were low. Some field experiments using bait lamina showed similar results (Federschmidt & Römbke 1994; Heisler 1994). Hence, the high population density was not always followed by high feeding activity.

The difference between feeding activity and population density can also be explained as follows: litter as a source of feed for soil animals is abundant on the forest floor, thus the introduced amount of food via baits was not attractive for soil animals and this may be the reason for the low bait-lamina feeding activity. Mueller *et al.* (1994) also reported the similar result. The highest feeding activity of soil animals was found at the alpine tundra site where source of feed was restricted, while the lowest activity was recorded in the birch-forest soil where source of feed was more abundant than that in alpine tundra site.

In almost all locations, the soil animals tended to feed more in the upper part of the bait strips (0-4 cm), particularly in the old bund, which the reduction from the 1st hole to the 16th hole of the bait lamina was the highest. This was presumably due to almost all soil organisms live in the top soil layer, because they feed on litter or organic matter, which is abundant there. Gongalsky *et al*. (2004) reported the similar result that maximal activity of soil animals was always observed at a depth of 0-4 cm from the soil surface.

In general, the soil animal feeding activity corresponds with their abundances and biomass, as shown in the ecosystem of rainfed paddy field and home garden. The removal of the rice straw (as shown in the paddy field) is correlated to decrease in feeding activity. Whereas, litter layer still available in the home garden have caused the increase in feeding activity. This indicates that the information gained from bait-lamina test is useful for improved description of biological status of tropical soils, e.g. nutrient cycling through soil fauna activities.

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