Ecology and Development Series No. 3, 2002

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Soil fauna in rainfed paddy field ecosystems: their role in organic matter decomposition and nitrogen mineralization

Cuvillier Verlag Göttingen

Abstract

The increase in food crop production, such as rice, to compensate for population growth in Indonesia should be sustainable in order to maintain environmental quality and conserve natural resources for future generations. In this study, the biological enhancement of soil organism populations and their ecological services, such as organic matter decomposition and nitrogen mineralization has been studied in a rainfed paddy field ecosystem in Pati, Indonesia. The cropping system used by local farmers is (1) two rice seasons, consisting of dry-seeded rice, planted at the beginning of the rainy season and transplanted rice, planted at the end of the rainy season, and (2) a short fallow (dry phase) during the dry season.

In the rice seasons, the soil fauna abundance, biomass and diversity, and the role of soil fauna in litter decomposition and nitrogen mineralization were evaluated in treatment plots with two different bund distances (4m and 8m) and crops cultivated on the bund (control, cassava and mungbean). The short bund distance (4m) would facilitate the movement of the soil fauna from the field (during the flooding) to the bunds, and cultivation of crops on the bunds would increase the soil surface cover thus protecting the soil fauna on the bund from direct sunshine. This was, therefore, expected to enhance the soil fauna population and its ecological services. The soil fauna population was studied using the Berlese funnel extractor method, and litter decomposition using three different mesh-sized (coarse, medium and fine) litterbags. Nitrogen mineralization was studied using undisturbed soil confined within PVC tubes containing ion-exchanged resins.

Generally, abundance, biomass and diversity of soil fauna were lower during the rice field phases than in the dry phase. The most numerous taxa in the dry phase were Oribatida (oribatid mites), whereas Sminthuridae (Collembola) dominated during the rice phases. In terms of biomass, Coleoptera was the most dominant taxon in the dry fallow phase, while their larvae along with the larvae of Diptera were the most dominant taxa under (flooded) rice phases. Earthworms sporadically occurred both in the fallow and in the rice seasons, without any particular pattern. Once they occurred in the soil samples, their biomass could make up for more than 60% of the total.

Though the soil fauna population was suppressed in the field during the (flooded) rice seasons, the physical environmental conditions, such as warm air temperature and high soil moisture may adequately support their activities to play their role in litter decomposition and N-mineralization. In the rice seasons, the short bund distance (4m) tended to increase soil fauna abundance, biomass and diversity. This effect was more pronounced when the bund was cultivated with crops, in which they enhanced macrofauna biomass during the dry-seeded rice. A combined effect of short bund distance and crop-planted bund was also shown in litter decomposition and N-mineralization in the field. Mungbean on the bund increased the litter decomposition, whereas cassava increased N-mineralization, suggesting that both mungbean and cassava are appropriate for bund crops. Thus, the short-bund distance with crops planted on the bund seemed to be favorable habitat for soil fauna population, so that they can enhance their role in soil processes and help in the management of crop residues.

Kurzfassung

In Indonesien ist eine Steigerung der Produktion von Grundnahrungsmitteln wie z.B. Reis erforderlich, um das Bevölkerungswachstum zu kompensieren. Um die Umwelt zu erhalten und die natürlichen Ressourcen für zukünftige Generationen zu schützen, sollte diese Produktionserhöhung nachhaltig sein. Die vorliegende Studie wurde in einem Nassreissystem in Pati auf Java in Indonesien durchgeführt. Das Anbausystem der dortigen Reisbauern besteht aus (1.) einer Anbauphase mit trocken ausgesätem Reis zu Beginn der Regenzeit bzw. ausgepflanztem Reis in überschwemmten Reisfeldern am Ende der Regenzeit, und (2.) einer kurzen Brachephase während der Trockenzeit.

In der Studie wurde die biologische Bewirtschaftung des Nassreissystems zur Förderung der Bodenfaunapopulationen untersucht. Eine mögliche hiervon ausgehende Intensivierung der ökologischen Funktionen der Bodenorganismen wie die Zersetzung von organischem Material und die Mineralisation von Nährstoffen wurde ebenfalls erforscht. Untersuchte Maßnahmen waren eine Verringerung des Abstandes zwischen den Dämmen, die die Reisfelder begrenzen, von 8 auf 4 m und die Bepflanzung der Dämme mit verschiedenen Anbaupflanzen (Maniok und Mungbohne). Es wurde erwartet, dass (1.) ein geringerer Dammabstand (4 m), d.h. eine verringerte Breite der überschwemmten Fläche, es der Bodenfauna in den Feldern erleichtern würde, die Dämme während der Überschwemmung zu erreichen und so die Nassphase zu überleben, und dass (2.) der Anbau von Nutzpflanzen auf den Dämmen die Bodenfauna durch eine Bodenbedeckung vor direktem Sonnenlicht schützen könne. Die Bodenfauna wurde mit Hilfe einer Berlese-Tullgren-Apparatur aus Bodenproben ausgetrieben, sortiert und analysiert. Der Streuabbau wurde durch Einschluss von Reisstroh in Streubeutel unterschiedlicher Lochgrößen (grob, mittel, fein) untersucht. Die N-Mineralisation wurde an ungestörten Bodensäulen in PVC-Rohren mit Anionenaustauschharzen bestimmt.

Im Allgemeinen waren Abundanz, Biomasse und Vielfalt der Bodenfauna während der Anbauphase niedriger als während der Brache. Die häufigsten Taxa während der Brache waren Oribatiden, während in den überschwemmten Reisfeldern Sminthuridae (Collembola) dominierten. Die höchste Biomasse wurde während der trockenen Brachephase durch adulte Coleoptera gebildet, während in den überschwemmten Reisfeldern die Larven von Coleoptera und Dipteralarven dominierten. Regenwürmer kamen sporadisch sowohl während der Brache als auch während der Anbauphasen vor, ohne ein bestimmtes Muster aufzuweisen. Sobald sie in den Bodenproben enthalten waren, betrug ihr Anteil an der Gesamtbiomasse mehr als 60%.

Obwohl die Bodenfaunapopulationen in den (überschwemmten) Anbauphasen reduziert waren, führen möglicherweise die physikalischen Umweltbedingungen wie höhere Temperaturen und hohe Bodenfeuchtigkeit zur erhöhten Aktivität der Bodenfauna hinsichtlich Streuabbau und N-Mineralisation. In den Anbauphasen führte der geringere Dammabstand (4m) meist zur erhöhten Abundanz, Biomasse und Diversität der Bodenfauna. Diese Wirkung wurde durch die Bepflanzung der Dämme, die zu einer Zunahme der Biomasse während der Trockenreisphase führte, verstärkt. Eine kombinierte Wirkung von geringerem Dammabstand mit bepflanztem Damm wurde auch beim Streuabbau und bei der N-Mineralisation im Reisfeld beobachtet. Die Mungbohnenbepflanzung auf dem Damm führte zu erhöhtem Streuabbau, die Maniokbepflanzung wiederum zur erhöhter N-Mineralisation. Diese Tatsache lässt vermuten, dass sowohl Mungbohne als auch Maniok zum Anbau auf den Dämmen geeignet sind. Folglich scheinen der geringere Dammabstand als auch die Bepflanzung der Dämme der Bodenfauna günstige Lebensbedingungen zu bieten, wodurch ihre Rolle in den Bodenprozessen verstärkt und die Bewirtschaftung von Ernteresten unterstützt wird.

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1 INTRODUCTION

The increase in staple food crop production, such as rice and maize, to compensate for population growth has become a major challenge for many developing countries such as Indonesia. To increase food-crop production, farmers are usually driven not by environmental concerns, but by economic issues, such as how to maximize production through use of chemical fertilizers. The continuous use of chemical fertilizers without returning plant residue or manure to the soil will result in soil degradation, groundwater contamination and rising production costs (Feenstra 1997). Soil degradation is reflected in declining agricultural productivity and utility (Katyal and Vlek 2000). Food-crop production, therefore, should be sustainably enhanced in order to maintain environmental quality and conserve natural resources for future generations (UNEP 2001). Sustainable agriculture can be improved through management of cropping systems based on the enhancement of the soil organism population and their ecological services, such as organic matter decomposition and nutrient mineralization (Lavelle *et al.* 2001).

The rainfed lowland paddy ecosystem that is widespread in Indonesia has great potential regarding an increase in the productive area, which has become limited in Indonesia, especially in Java (Syamsiah 1994). However, due to the lack of infrastructure and water resources, and low soil fertility, the productivity of rainfed paddy fields has become lower compared to that of the irrigated rice field system.

1.1 Rainfed lowland paddy field

The rainfed lowland paddy ecosystem covers about 2.6 million ha, of which the largest areas are found in Java (0.8 million ha), South Sulawesi (0.3 million ha), and North Sumatera (0.2 million ha) (Amien and Las 1999). This system is not irrigated and, therefore, totally depends on rainfall. The rainwater is impounded by bunds, and water depth may exceed 50 cm. In Pati District, where the largest area of rainfed paddy fields in Central Java is to be found, local farmers grow two rice crops during the wet season, i.e., dry-seeded rice (*gogorancah*) at the beginning of the rainy season, and transplanted rice with minimum tillage (*walik jerami*) at the end of the rainy season. After the harvest of the second crop, the field is usually fallow during the dry season. A few farmers build on-farm reservoirs (OFRs) to collect excess water during the rainy season and use the water in the dry season to grow the secondary crops, such as mungbean, corn, soybean, peanut, cucumber, etc.

The rainfed paddy field system is characterized by lack of water control, with floods and drought being potential problems. Despite the increase in the area planted with rainfed lowland rice, the yields remain low. According to Amien and Las (1999), rice yields in rainfed areas were 10% to 25% less than the average yield in Java, and 15% to 20% less than the average yield in South Sulawesi. Improvement of rainfed lowland management is, therefore, needed in order to increase yields.

In this study, the biological management of the cropping system to improve the soil fauna population and its function in ecosystem processes was studied in rainfed paddy fields through modification of the bund distance (4m and 8m) and cultivation of crops on the bunds. It was expected that (1) a short bund distance (4m) would facilitate the movement of the soil fauna from fields (during flooding) to bunds and that (2) crops on bunds would increase the soil surface cover thus protecting the soil fauna on the bund from direct sunshine. The short-bund distance and bund cultivation were, therefore, expected to enhance the soil fauna population and its ecological services. In order to benefit from soil fauna activity for sustainable and productive agriculture a better understanding of soil fauna as a soil community and their functions in the regulation of soil fertility is needed.

1.2 Soil fauna as a community

Soil fauna as a component of soil communities may be classified into different categories, depending on the purpose of the study. Soil fauna are often categorized according to the feeding habits, i.e., saprophagous (decomposers) that consume a wide variety of dead higher-plant material as well as microflora, and predators, which feed on micro-, meso- and macrofauna (Petersen and Luxton, 1982). Soil fauna are also classified into three groups according to body size, i.e., microfauna (body width less than 0.2 mm), which include nematodes and protozoa; mesofauna (0.2 mm to 2 mm), including microarthropods (mainly collembolans and mites) and enchytraeids; and macrofauna (2.0 mm to 20.0 mm) with termites, earthworms, ants, beetles, myriapoda and other macroarthropods (Lavelle and Spain 2001).

Collembola and Acari (mites) are dominant animals among microarthropods, both numerically and in terms of biomass (Lavelle and Spain 2001). Collembola comprises seven families, namely Poduridae, Hypogastruridae, Onychiuridae, Isotomidae, Entomobryidae, Neelidae and Sminthuridae, with most of them living in the soil or in such habitats as leaf litter, under bark, in decaying logs, and in fungi. Some species are also found on the surface of fresh water pools or along the seashores. Most soil-inhabiting springtails feed on decaying material, fungi and bacteria, and others feed on arthropod feces, pollen, algae, and other materials (Borror *et al*. 1989).

Acari comprises a very large group of small to minute animals and is divided into six suborders, namely: Holothyrina, Mesostigmata, Ixodida, Prostigmata, Astigmata and Oribatida. They occur in all habitats, both aquatic (fresh and salt water) and terrestrial (Borror *et al*. 1989). The orders that are relevant to soil biology, for instance spider mites (Tetranychidae, member of Prostigmata), are plant feeders, and some other species can cause serious damage to orchard trees, field crops, and greenhouse plants. The most important Acari in relation to the soil fertility are Oribatida or Cryptostigmata. Oribatid mites are found in leaf litter, under bark and stones, and in the soil. They are mainly scavengers and are important in breaking down organic matter and promoting soil fertility (Borror *et al.* 1989).

The other important mesofauna group comprises enchytraeids, which are small white-colored Oligochaeta. Anatomically, they form a relatively simple and uniform group, with body length varying from less than 1 mm for the smallest species to 5 cm for the largest species. They live particularly in terrestrial environments but also in aquatic environments (O'Connor 1967). Although Acari and Collembola are the major animal groups in mesofauna communities, the other minor groups, Protura, Diplura, Pauropoda and Symphyla may be locally important. Protura and Diplura may be panphytophages or predators of other microarthropods. Symphyla may be a serious pest for a wide range of plants (Lavelle and Spain 2001).

In terms of their biomass, abundances and function in ecosystem processes, earthworms, termites and ants are the most important soil fauna in terrestrial ecosystems (Fragoso and Lavelle, 1995; Lavelle *et al.* 1997; Lavelle and Spain 2001). In some tropical rainforests, earthworms accounted for 51% of the total biomass, while termites composed 13%. When it comes to abundance, termites dominated with 37%, followed by ants (23%) and earthworms (9%).

Earthworms are distributed widely in forests, grasslands, farmlands, lakes, marshes, and in the ocean. The earthworm body length varies from a few centimeters to 2-3 meters (Edwards and Bohlen 1996), with the live biomass commonly ranging from 30 to 100 g m^{-2} (Lavelle and Spain 2001). The social insect group termites (Isoptera) consists of approximately 2600 species worldwide. Termites differ greatly in their feeding habits and the type of nest they construct (Martius 2001); some wood-feeding species live entirely in galleries excavated within decaying logs or wood, others construct earth mounds of varying size and complexity. Their importance for soil biology lies in their contribution to soil structure (they move and mix soil and organic matter from different horizons), and to soil chemistry as they play an important role in organic matter decomposition (Amelung *et al*. 2001). Other important insect groups are ants (Formicidae). Ants occur practically everywhere in terrestrial habitats and outnumber in individuals most other terrestrial animals. Most of the species are predators, herbivores or seed feeders, and not decomposers.

The other macroarthropods, such as Coleoptera, Diptera larvae, Myriapoda, etc., may locally be important. Coleoptera are a very important soil animal group in Mexican forests (Fragoso and Lavelle 1995). The Coleoptera, which is the largest order of insects, colonize most of the habitats where insects occur. Some Coleoptera families, such as the Carabidae, Staphylinidae, Scidmaenidae and Pselaphidae, are predators and prey on many other species, whereas Scarabidae, Tenebrionidae, Ptiliidae, Scolytidae, etc., are decomposers (Raw 1967; Hanagarth and Brändle 2001). Diptera larvae occur predominantly in moist or sub-aquatic situations. They are predominantly saprophagous and a relatively small number of them attack living plants, as miners or borers in different parts of the plant. Other soil macroarthropods, such as Isopoda, Aranae, Homoptera, Heteroptera, Hemiptera, Thysanura, and Blattoidea may occasionally be important (Daly *et al*. 1998; Lavelle and Spain 2001).

1.3 The role of soil fauna in ecosystem processes

The important ecosystem processes such as decomposition of organic matter and nitrogen mineralization are influenced by factors such as resource quality, physical environmental conditions (mainly temperature and humidity), and interactions within and between the fungi, bacteria and soil fauna (Sharma *et al*. 1995; Swift 1995). The abundance and diversity of soil organisms may also influence the rate of decomposition and nutrient availability for uptake by plants (Anderson 1998).

In paddy soils, the mineralization of organic N, P, and S play an important part in the transformation of nutrients. Since N is the principal constraint in rice production, more studies are available on N mineralization than on the mineralization of P and S in paddy soils. Zhu *et al*. (1984) reported that N uptake by rice plants grown on no-N plots in intensive cropping systems was derived from the mineralization of soil N, and ranged from 35 to 139 kg N/ha. Furthermore, they reported that most of the mineralizable N of organic manures, except straw, was released within one month after incorporation and submergence. According to Bucher *et al.* (2002), incorporating rice straw shortly after harvest, before a two-month unflooded fallow period, can improve N and P nutrition of the subsequent rice crop. The application of legume mulch appears to increase the Oligochaeta populations, which are likely to participate in decomposition of legume residues in paddy soils (Yokota and Kaneko 2002).

1.3.1 Soil fauna in terrestrial ecosystems

Soil fauna contribute up to about 30% of the total net nitrogen mineralization in forest and grassland ecosystems (Verhoef and Brussaard 1990). Earthworms participate in the nitrogen cycle through their production of casting and mucus and decomposition of dead tissue. Earthworm activity can increase the nitrogen availability for uptake by plants in shifting agriculture systems in India (Bhadauria and Ramakrishnan 1996). As ecosystem engineers, earthworms, termites and ants can directly or indirectly affect the availability of resources to other organisms through modification of the physical environment (Lavelle *et al.* 1997). For instance, the nest mounds constructed by ants can increase the incidence and abundance of a plant community due to nutrient enrichment of the nest soils (Wilby *et al*. 2001). The increase in plant biomass and total plant nitrogen content due to soil animals, particularly protozoa, is also reported by Bonkowski *et al*. (2001).

Maintaining soil animal diversity is important in order to sustain the ecosystem processes. Naeem *et al*. (1995), in their mesocosm experiment with direct manipulation of diversity under controlled environmental conditions, provided the evidence that ecosystem processes like community respiration, productivity, decomposition, etc., may be negatively affected by the decline of animal species diversity. A laboratory experiment to estimate the decomposition rate using three species of Plecoptera as detritivores indicated that a number of species have significant effects on the leaf litter decomposition rate, which increases with the increase in animal species richness (Jonsson and Malmqvist 2000).

Vreeken-Buijs and Brussaard (1996) indicated the important role of soil microarthropods like Acari (mites) and Collembola, and enchytraeids in increasing the decomposition rates of wheat straw. Adejuyigbe *et al*. (1999) reported that the dynamics of soil microarthropod populations are strongly affected by climatic fluctuation. The population of soil microarthropods is higher in the rainy seasons than in the dry seasons, and their population is greater under natural fallow than under continuous cropping with maize and cassava. Under continuous cropping, they are not subject to unfavorable microclimatic factors such as low soil water content, high soil temperature, and high incident radiation due to reduced cover.

1.3.2 Soil fauna in rice field ecosystems

Population and diversity of soil fauna in flooded systems are different compared to those in non-flooded conditions. Oligochaeta, such as Tubificidae, Naididae and Enchytraeidae, are a major component of soil fauna in wetland rice field conditions (Lavelle *et al*. 1997; Yokota and Kaneko 2002), where they can accelerate nutrient mineralization (Simpson *et al*. 1993a). Larvae of Diptera (Chironomidae and Culicidae), ephydrid flies and collembolans are also abundant in flooded conditions (Settle *et al.* 1996), where they act as decomposers. Lavelle *et al.* (1997) reported that Tubificidae play an important role with regard to soil fertility, because they transport the components of photosynthetic aquatic biomass (cyano-bacteria, micro-algae and aquatic macro-phytes) and their breakdown products from the surface to the deeper soil layer thus providing nutrients to the rice plant.

Besides the positive effects of soil animals in flooded conditions, some soil animals can also cause serious damage to rice plants. Chironomid midge larvae are reported as being the most widespread and serious rice pests in New South Wales

(Stevens 2000). Stem borers are the main insect pest threatening rice plants in many countries, causing severe yield losses. The yellow stem borer *Scirpophaga incertulas* is the most commonly found stem borer in the Philippines (Rubia *et al.* 1996), while the white stem borer *Scirpophaga innotata* causes whiteheads in rice plants in West Java, Indonesia (Rubia *et al.* 1997). The most abundant rice arthropods found in irrigated lowland rice fields in West Africa that cause rice plant damage are diopsid flies, leafhoppers, spiders, Odonata, and stem borers (Oyediran and Heinrichs 2001).

Several collembolan species are important in rice field ecosystems. Along with chironomids and ephydrid flies, collembolans represent 28% of the total abundance of arthropods collected from 12 locations in Javanese rice fields (Settle and Whitten 2000). Approximately 41 collembolan species were found in Java, whereas approx. 96, 502, 128, 118, and 150 species of caddisfly (Trichoptera), ground beetles (Carabidae), water beetles, earwigs (Dermaptera), and Odonata, respectively, had been recorded from Java and Bali (Whitten *et al.* 1997). Up to now, little work has been conducted on soil fauna in rice fields and other ecosystems in Java, Indonesia. Therefore, in this study, a basic assessment of soil fauna in different ecosystems of the region was undertaken.

Because of the different cropping patterns during the wet and dry seasons, the rainfed paddy field system is subject to two contrasting ecological conditions, i.e., a flooded and a dry system. Consequently, the population and diversity of soil fauna, organic matter, and nitrogen mineralization are also different in those systems. Little is known about the influence of the dynamics of the soil fauna on organic matter decomposition in rainfed paddy field systems. Therefore, the study of environmental changes is important to optimize organic matter decomposition and nitrogen mineralization of the cropping sequence.

1.4 Objectives

The study consisted of three main experiments:

1. The study of soil fauna in a rainfed paddy field ecosystem to evaluate the dynamics of soil fauna in dry and flooded phases of the rainfed paddy ecosystem. This study also included a screening of soil fauna in different natural ecosystems of the region, to obtain a general overview of the soil fauna and to assess the potential group diversity in natural ecosystems as a standard against which to compare the

agricultural site. In addition to the soil fauna population, the feeding activity of the soil fauna in different natural ecosystems was evaluated using the bait-lamina method.

2. The study of soil organic matter decomposition to evaluate the role of soil fauna in litter decomposition during the dry and flooded phases of a rainfed paddy field.
3. The study of N mineralization to evaluate the contribution of soil fauna to nitrogen mineralization in the dry and flooded phases of a rainfed paddy field.

The specific objectives of this research were:

1. To study the abundance, biomass and diversity of the soil fauna in the two phases of a rainfed paddy field, namely the dry short fallow period and the flooded phases (dry-seeded rice and transplanted rice) during the rice field subsystem.
2. To study the influence of crops (legumes and cassava) cultivated on the bunds on abundance, biomass and diversity of soil fauna in the fields and on the bunds during the dry and flooded rice-field phase.
3. To study the influence of different bund distances of 4m and 8m on the abundance, biomass and diversity of soil fauna in the fields and on the bunds of the above systems.
4. To study the influence of different bund distances (4m and 8m) and crops (legumes and cassava) cultivated on the bunds on the role of soil fauna in organic matter decomposition and nitrogen mineralization.

1.5 Hypotheses

1. Soil fauna and their ecological services (organic matter decomposition and N mineralization) can be manipulated to the benefit of the farmer through the management of the cropping system.
2. The diversity, biomass and density of the soil fauna in crop-planted bunds are higher than that in bunds without plants.
3. The increase in the soil fauna population in the dry phase (fallow) after the flooded period is faster in plots with crop-planted bunds than in plots without plants on the bunds.

4. The increase in soil fauna population during the dry phase after the flooded period is faster in plots with a short bund distance (4m) than in plots with a long bund distance (8m).
5. Organic matter decomposition and nitrogen mineralization predominantly take place during the dry phase of the rainfed paddy-field ecosystem.

2 MATERIALS AND METHODS

2.1 Study site description

2.1.1 Location

The field study was conducted at the Jakenan Experimental Station of the Central Research Institute for Food Crops in District of Pati, Central Java, Indonesia, situated at 6.75° South Latitude and 111.04° East Longitude (Figure 2.1). The experimental station is located in the center of farm fields. The largest area of rainfed lowland paddy fields is to be found in the District of Pati, covering about 11 percent of the total areas of Central Java.

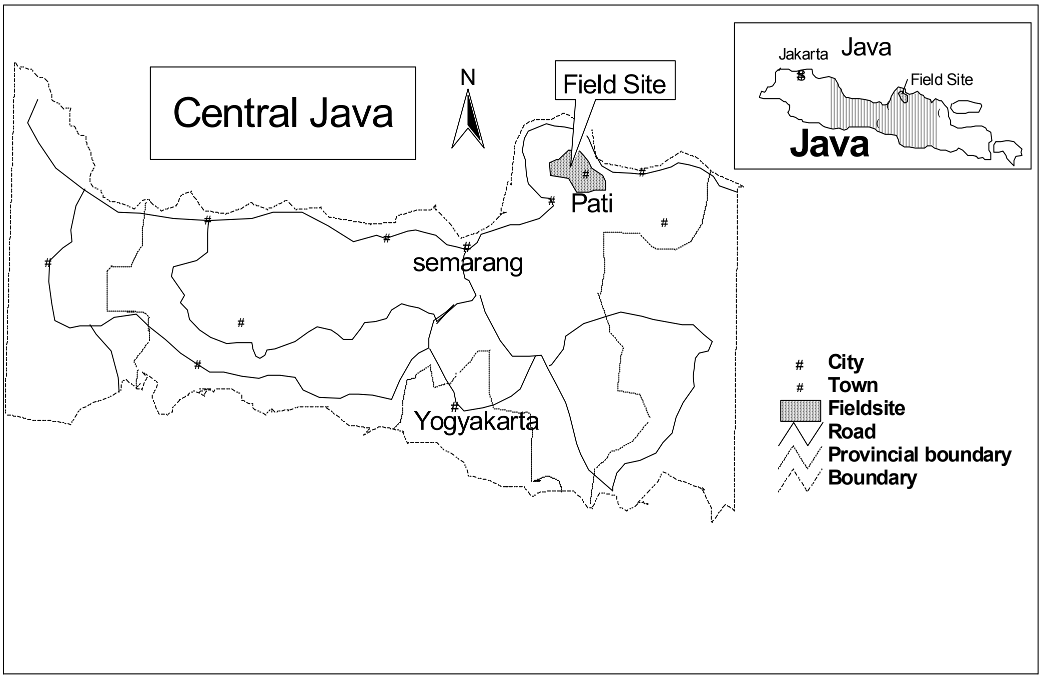


Figure 2.1: Map of Pati, Central Java, Indonesia

2.1.2 Climate

Amount and distribution of annual rainfall in the Pati District are highly variable. Rainfall data from 1991 to 2000 indicate that the average annual rainfall in the region is approximately 1500 mm, with 4 out of 10 years being dry (< 1500 mm) (Figure 2.2).

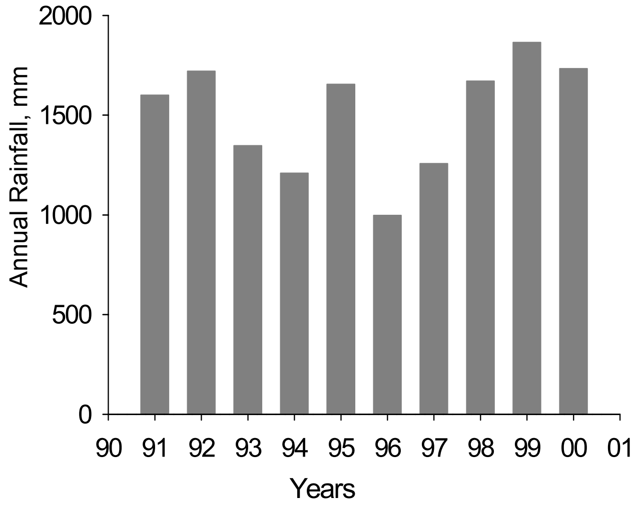


Figure 2.2: Annual rainfall in Pati District, for the period of 1991 to 2000.
Source: Jakenan Experimental Station, Central Research Institute for Food Crops, Pati, Indonesia.

The amount and distribution of monthly rainfall in the region during the study period was also variable. In the dry season from June to September, monthly rainfall ranged between 0 and 79 mm, whereas in the wet season from October to May, it ranged between 74 and 325 mm, with the highest rainfall in November and December (Figure 2.3).

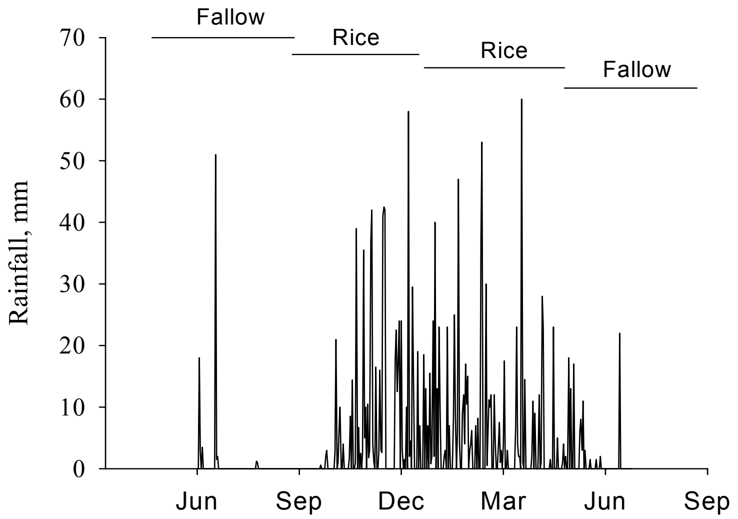


Figure 2.3: Daily rainfall at Jakenan Research Station, Pati, Indonesia, during the study period, from June 2000 to June 2001. Source: Jakenan Experimental Station, Central Research Institute for Food Crops, Pati, Indonesia.

During the study period, daily variations in the minimum temperature ranged between 18.0°C and 25.0°C; the maximum temperature ranged between 27.0°C and 36.5°C (Figure 2.4).

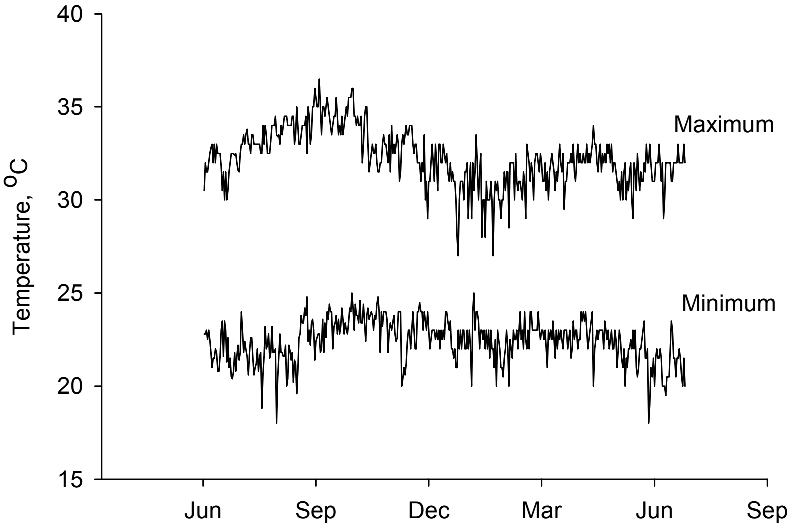


Figure 2.4: Daily minimum and maximum air temperatures at Jakenan Research Station, Pati, Indonesia, during the study period from June 2000 to June 2001. Source: Jakenan Experimental Station, Central Research Institute for Food Crops, Pati, Indonesia.

2.2 Cropping system

The experimental design was based on the cropping systems used by local farmers as described in the introduction, namely:

Dry-seeded rice (October to January). In dry-seeded rice, five to seven seeds of rice IR64 variety were dibbled into the holes of a well-pulverized dry soil at 3-4 cm deep at the beginning of the rainy season, spaced at 20 cm x 20 cm. The fertilization treatments were (1) nitrogen at 120 kg ha^{-1}, (2) phosphorus at 60 kg ha^{-1}, (3) potassium at 90 kg ha^{-1} as urea, SP36 (super phosphate) and potassium chloride, respectively. Phosphorus and potassium were broadcast at 7 days after planting, whereas nitrogen was applied in three equal applications (7, 25 and 45 days after planting). Herbicide at 2-4 l ha^{-1} was also applied at 7 days after planting. The soils were then naturally flooded by rainwater, causing a change from oxidized to reduced conditions.

Transplanted rice (March to May). After the rice harvest, the land was prepared for the transplanted rice. All the remaining rice straw was turned over with a hoe, incorporated into the soil and used as organic matter input. The rainwater was then collected in impounded plots, creating flooded conditions in the field. In a separate plot of approx. 5 m x 5 m, rice seedlings were prepared in a nursery using the same procedure as for the dry-seeded rice 25 days prior to planting, but with a tight spacing. The 25-day-old rice seedlings were then transplanted into the flooded soil by hand spaced at 20 cm x 20 cm. Fertilization and herbicide application corresponded to that of the dry-seeded rice.

Short fallow period (June to September). During the dry season, the fields lay fallow as they were completely dry. This was especially the case at the peak of the dry season around August and September, when the monthly rainfall ranged between 0 to 79 mm (Figure 2.3). The field was covered only with grasses and weeds, as crops need a minimum monthly rainfall of 100 mm for normal growth.

2.3 Outline of the experiments

The study focused on three aspects of soil biota: (1) study of soil fauna dynamics in rainfed paddy field and surrounding ecosystems (Section 2.4), (2) study of organic matter decomposition (Section 2.5) and (3) study of nitrogen mineralization in a rainfed paddy-field experiment (Section 2.6).

The soil fauna of different natural ecosystems in the region was screened to obtain a general overview of soil fauna in the surrounding areas. In addition to the soil fauna population, the activity of soil fauna in the different natural ecosystems was evaluated using the bait-lamina method.

Soil fauna dynamics were studied in more detail along with the decomposition of organic matter and N mineralization in a rainfed paddy-field experiment. This experiment was conducted beginning in the fallow period during the dry season, followed by the planting seasons, i.e., dry-seeded rice and transplanted rice during the

rainy season. In order to assess the effect of bund distance and bund planting on soil fauna, experiments were laid out in a 2 x 3 factorial design (Figure 2.5).
The three treatments with ‘crop-planted bunds’ factor were as follows:

1. Plot without plants on the bunds (control),
2. Plot with cassava (*Manihot esculenta*) on the bunds,
3. Plot with mungbean (*Vigna radiata*) on the bunds.

The two treatments of the bund-distance factor were:

1. Plot with bund distance of 4m,
2. Plot with bund distance of 8m.

Cassava and mungbean were selected for this experiment, because these crops are abundant in this area and often cultivated by local farmers. The bund distance was based on that commonly used by farmers, i.e., 8m (control) and the shorter bund distance of 4m was used as treatment. Experimental plots of 12m x 16m each were used in each season, and all sampling was done simultaneously on all treatment plots with four replications.

Organic matter decomposition in various locations of the experimental field was studied using the litterbag method. The contribution of soil fauna to nitrogen mineralization was assessed in undisturbed soil confined in PVC tubes at different locations of the experimental field, retrieved regularly for analysis.

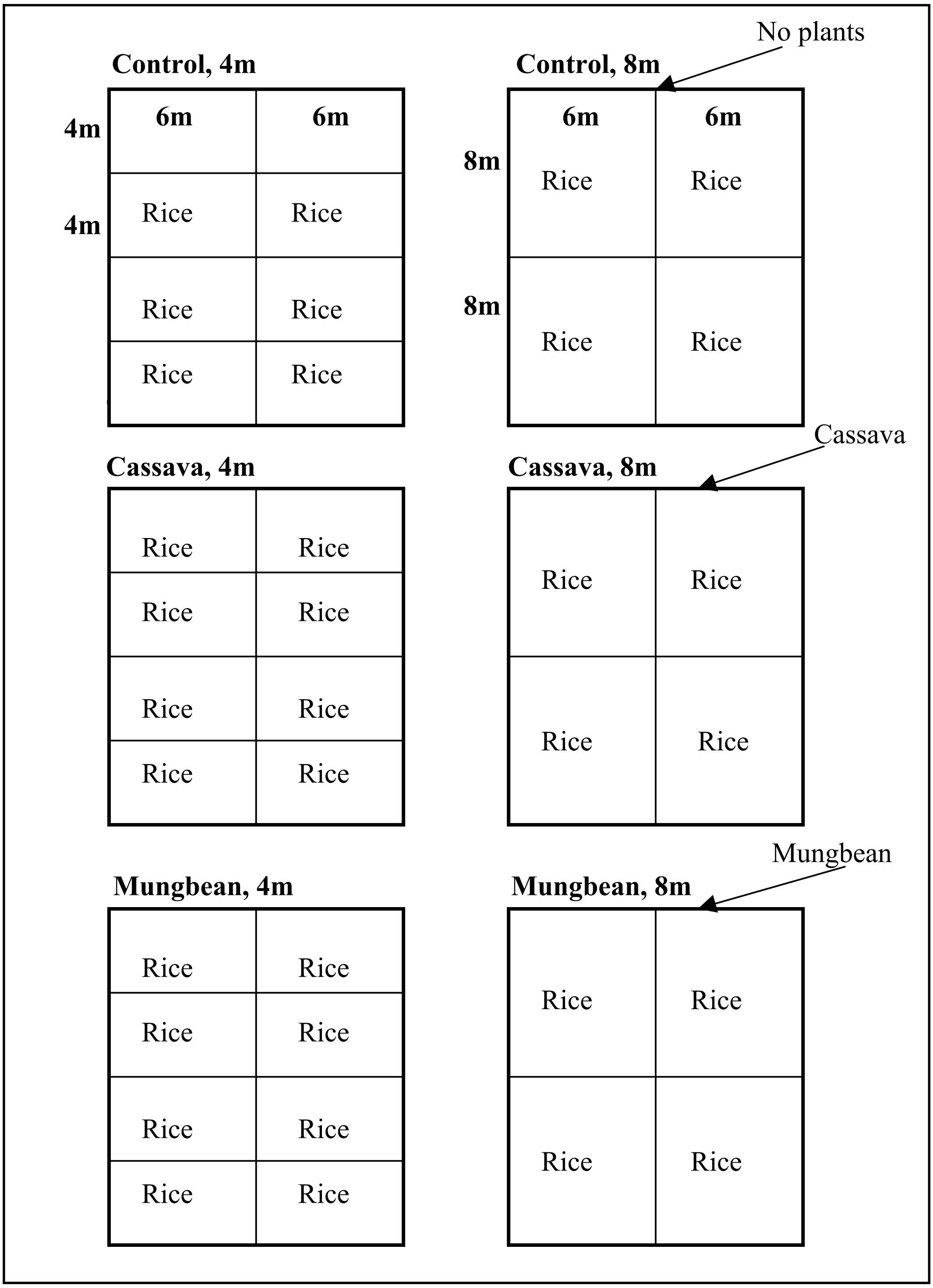


Figure 2.5: Field experimental design. All lines are the bunds, and the rice fields are in between.

2.4 Study of soil fauna in rainfed paddy field and surrounding ecosystems

The study consisted of three steps: (1) screening of soil animals in the different ecosystems in the region, (2) evaluation of soil animal feeding activity using bait strips in the same systems, and (3) study of soil fauna dynamics in rainfed paddy-field experiments.

2.4.1 Screening of soil fauna in different ecosystems in the region

The assessment of soil fauna in the study area aimed at obtaining a general overview of soil fauna abundance and diversity in the natural ecosystems in the region. Three natural ecosystems were found in this area, namely teak forest, established more than 30 years ago, home gardens dominated by cassava, and rainfed paddy fields. Teak forest and home garden ecosystems were selected because they surrounded the experimental area. It was, therefore, to be assessed whether soil fauna in teak forests and home gardens is comparable to the soil fauna in rainfed paddy-field experiments.

The soil fauna was collected using a soil corer of 20 cm diameter to the depth of 0-15 cm (Meyer 1996) from 5 randomized points in the above ecosystems. The soil fauna was then extracted in a Berlese funnel extractor (Beck *et al.* 1998). A Berlese funnel is a device for collecting and extracting the active stages of small invertebrate animals from soil or litter. The soil sample was put into a bucket of 20 cm diameter, which had a 2.0 mm screen at the bottom holding the soil samples but letting the animals pass through. The bucket was placed on top of the big plastic funnel. About 10 cm above the bucket, a small lamp of 40 watt was placed as a source of heat. The animals within the soil samples were forced to move downward to avoid the heat. They then fell into a collecting vial containing ethylene glycol as a preservative (Figure 2.6). The soil fauna was stored in alcohol (70%) and determined under a stereomicroscope.

Larger animals, especially earthworms, were sorted by hand (Meyer 1996). In each ecosystem, 5-10 L of a 0.2-0.4 % formalin solution was poured into an enclosed sampling area (0.5 m^2) repeated at 10-min intervals. Sampling took place during the 30 minutes following the application. The big earthworms expelled from the soil were collected by hand and small ones using a forceps. The earthworms were immediately fixed in 70% ethanol using the labeled plastic container.

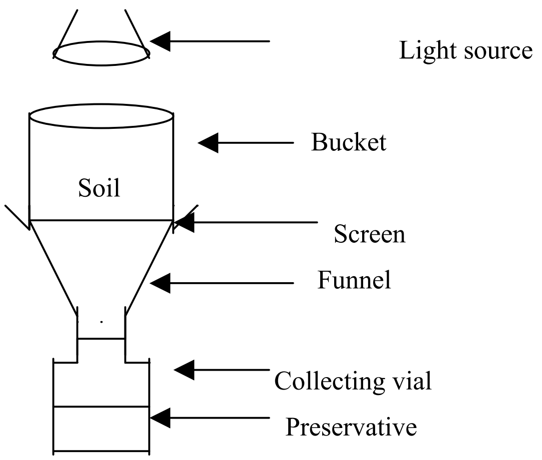


Figure 2.6: Berlese funnel extractor

2.4.2 Bait-lamina feeding activity

In addition to soil-animal abundance, biomass and diversity, the activity of the soil fauna in the teak forest, home garden and rainfed paddy-field ecosystems was also evaluated using the bait-lamina method (Törne 1990a). This took place during the rainy season in November 2000. Three randomized locations in the teak forest, two locations in the home garden and four locations in rainfed rice fields (two locations in the rice field and one each on the old bund and the new bund, respectively) were selected for the bait lamina. Three blocks of bait-lamina sticks (each block consisting of 16 individual sticks) were exposed at each location for two days (Figure 2.7).

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-mm spacing. The holes are filled with bait material, a mixture of cellulose, agar-agar, bentonite, bran and a small amount of activated carbon (Figure 2.8A). Bait lamina were inserted into the soil in small slits made with a knife in 25x25 cm blocks, each block containing 16 bait lamina (Figure 2.8B). 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.

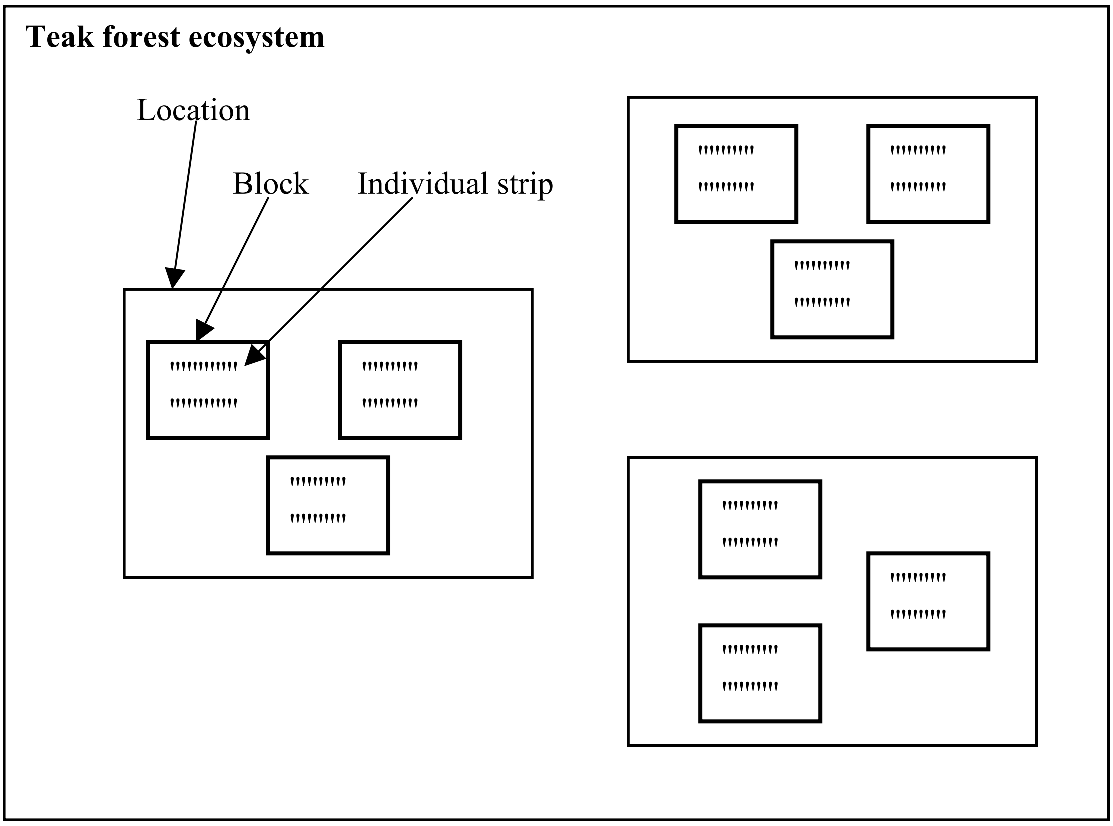


Figure 2.7: Bait-lamina exposition at three small blocks and three randomized locations (teak forest ecosystem). Each block consisted of 16 strips.

Figure 2.8: Bait lamina (A) and bait-lamina exposition in the field (B)

2.4.3 Study of soil fauna dynamics

The density and diversity of soil meso- and macrofauna of an experimental were studied during the whole study period. To evaluate the effect of crop-planted bunds on meso- and macrofauna density and diversity, the soil fauna was collected both in the fields and in the bunds for the treatment plots with crop-planted bunds (no plants, cassava and mungbean). To assess the effect of bund distance on soil fauna density and diversity, the soil fauna was collected both in the fields and in the bunds where these treatments were included (4m and 8m). The soil fauna was sampled using a soil corer of 20 cm diameter to a depth of 0-15 cm (Meyer 1996) from 4 randomized points in the fields and the bunds, respectively, per plot at 30, 60 and 90 days after planting. Soil meso- and macrofauna in each season were then extracted in a Berlese funnel extractor (Beck *et al.* 1998) (Figure 2.6) and the collected animals stored in ethanol (70%) and determined under a stereomicroscope.

Calculation of animal abundances and biomass

The number of individuals (abundance or density) of the extracted animals was calculated as follows (Meyer 1996):

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

IS mean number of individuals per sample
A surface area of the corer (cm^2) *)
I number of individuals
*) Area of the corer = $r^2.\pi = (10\ cm)^2 \times 3.14 = 314\ cm^2$.

Biomass of the soil fauna was calculated based on their individual dry weight using different regression equations of body length-body weight (Table 1.1). These relationships are generally well established for temperate and tropical organisms (Hanagarth *et al.* 1999).

Table 2.1: Body length and dry weight of individual animals.

No.	Taxon	Average Body [a]) Length (mm)	Individual Dry Weight (mg)	References
1	Acari : Oribatida	0.50	0.0011	Edwards (1967)
	Others	0.64	0.0045	Edwards (1967)
2	Collembola :			
	Hypogastruridae	0.50	0.0056	Edwards (1967)
	Onychiuridae	0.50	0.0114	Edwards (1967)
	Isotomidae	0.50	0.0044	Edwards (1967)
	Entomobryidae	0.50	0.0084	Edwards (1967)
	Sminthuridae	0.50	0.0023	Edwards (1967)
	Poduridae	0.50	0.0023	Edwards (1967)
	Neelidae	0.50	0.0023	Edwards (1967)
3	Protura	2.50	0.0004	Hanagarth, *et al*. (1999)
4	Symphyla	2.88	0.0800	Hanagarth, *et al*. (1999)
5	Aranae (Spiders)	2.96	0.5724	Hanagarth, *et al*. (1999)
6	Coleoptera :			
	Carabidae	3.88	0.9128	Hanagarth, *et al*. (1999)
	Staphylinidae	3.28	0.3160	Hanagarth, *et al*. (1999)
	Others	3.81	0.8689	Hanagarth, *et al*. (1999)
	Coleoptera (larvae)	5.52	0.9894	Hanagarth, *et al*. (1999)
7	Diptera	1.9	0.4490	Edwards (1967)
	Diptera (larvae)	3.71	0.8000	Hanagarth, *et al*. (1999)
8	Chilopoda	4.13	0.0521	Hanagarth, *et al*. (1999)
9	Diplopoda	5.41	0.9405	Hanagarth, *et al*. (1999)
10	Diplura	2.51	0.0200	Hanagarth, *et al*. (1999)
11	Hemiptera	2.86	0.3360	Hanagarth, *et al*. (1999)
12	Homoptera	1.32	0.9010	Hanagarth, *et al*. (1999)
13	Hymenoptera :			
	Formicidae	2.56	0.5000	Petersen and Luxton (1982)
	Others	2.03	0.5000	Petersen and Luxton (1982)
14	Isopoda	2.30	0.1130	Hanagarth, *et al*. (1999)
15	Isoptera	1.50	0.6000	Petersen and Luxton (1982)
16	Lepidoptera (larvae)	6.21	1.9800	Hanagarth, *et al*. (1999)
17	Oligochaeta :			
	Earthworms	48.13	21.000	Petersen and Luxton (1982)
	Enchytraeids	4.09	0.0320	Petersen and Luxton (1982)
18	Orthoptera	4.64	0.0100	Hanagarth, *et al*. (1999)
20	Pseudoscorpiones	1.50	0.1587	Hanagarth, *et al*. (1999)
21	Psocoptera	1.07	0.2777	Edwards (1967)
22	Thysanoptera	1.50	0.0200	Hanagarth, *et al*. (1999)
23	Trichoptera	2.68	0.2200	Hanagarth, *et al*. (1999)

[a]) Average body length measured in samples

Calculation of soil animal diversity

Diversity indices were calculated according to Shannon's diversity index (Ludwig and Reynolds 1988). The equation for the Shannon function is

$$H' = -\sum_{i=1}^{s} [(n_i/n) \ln (n_i/n)]$$

Where n_i is the number of individuals belonging to the i^{th} of S species (or animal groups) in the sample and n is the total number of individuals in the sample. The diversity index was calculated for both, number of soil animal groups and their biomass.

The number of abundant and very abundant taxa was also calculated using the Hill's diversity number (Ludwig and Reynolds 1988). The equations of Hill's number are:

$$N1 = e^{H'}$$

N1 = number of abundant taxa in the samples
H′ =Shannon's diversity index

$$N2 = 1/\lambda$$

N2 = number of very abundant taxa in the samples
λ = Simpson's diversity index

$$\lambda = \sum_{i=1}^{s} (n_i/n)$$

λ = Simpson's diversity index
ni = number of individuals belonging to the i^{th}
n = total number of individuals in the sample

The third Hill's number (N3) is the total number of taxa found in the samples

$$N3 = S$$

Although Hill's numbers are rarely used, they have the advantage of providing figures, which actually have a biological meaning (number of abundant and very abundant taxa, and total number of taxa), instead of indices, which do not have units (Ludwig and Reynolds 1988).

Grouping and identification

All samples were sorted and counted in the laboratory using a stereomicroscope. All animals were classified into taxonomic orders except for springtails, beetles, millipedes, centipedes, and Oligochaeta. Springtails and beetles were classified into families. The individuals of the classes of millipedes, centipedes and Oligochaeta were not classified further. Identification was based on Borror *et al*. (1989) and Chu (1949). After the animals had been placed into orders, they were classified based on their body length according to the classification system of Van der Drift (1951) (Table 2.2).

Table 2.2: Classification system of soil fauna categories based on body length

Categories	Body Length (mm)
Microfauna	<0.2
Mesofauna	0.2 – 2.0
Macrofauna	2.0 – 20.0
Megafauna	>20.0

2.5 Study of organic matter decomposition

The organic matter decomposition was studied in the field only using stainless-steel litterbags 20 x 20 cm in size with the following mesh sizes 0.038, 0.25 and 10 mm (Figure 2.9). A mesh size of 10 mm allows access to all meso- and macrofauna; a mesh size of 0.25 mm excludes the soil macrofauna; and a mesh size of 0.038 mm excludes meso- and macrofauna, respectively. Study of litter decomposition was conducted during the whole study period beginning with the fallow, followed by the dry-seeded rice and finally the transplanted rice season. Organic matter decomposition in the bunds was not studied.

The decomposition rate of rice straw was studied in the treatment plots of crop-planted bunds (no plants, cassava and mungbean) with bund distances of 4m and 8m. Seven grams of air-dried rice straw litter were filled into each mesh size of the litterbags. Two sides of the bags were then closed up by waterproof glue. The fine- and medium-meshed bags were marked with individual numbers using a water-proof pen, while the coarse bags were marked using a metal plate with numbers.

Figure 2.9: Litter bags with coarse-, medium- and fine-mesh sizes.

All litterbags were buried in sets of three (fine, medium and coarse). Seventy-two bags were buried at approximately 5 to 7 cm depth in the field only of each treatment plot at the onset of the fallow, dry-seeded rice and transplanted rice season, respectively, giving a total of 216 bags per season (6 treatment plots x 3 mesh sizes x 4 reps x 3 dates). Twenty-four sets were randomly sampled from each plot at each sampling time, i.e., 30, 60, and 90 days of exposure time. No litterbags were exposed in the bunds.

Initial average weights of the exposed material were determined in 12 samples collected on the day the material was exposed to the field. After the litterbags had been harvested, they were emptied over a sieve (0.35 mm), and the litter was rinsed with tap water to remove the soil. The litter content of each bag was dried in paper sheets, then oven-dried (80^{o}C, 48 h) and weighed. The decomposition rate was calculated from the loss of weight after exposition, using the formula for negative exponential regression. In order to assess the mineral content (soil) present in the samples, the litter of selected samples was milled (<0.2 mm) and burned in a muffle furnace (700^{o}C, 4h) to obtain the residue weight. The calculated decomposition rate was corrected for the percentage of the mineral content (residue) in the samples.

2.6 Study of nitrogen mineralization

Nitrogen (N) mineralization was studied by measuring the net nitrogen mineralization in the field and the microbial activity (nitrifiers and denitrifiers) involved in the nitrification and denitrification processes. Both were evaluated in the fields of all treatment combinations with crop-planted bund (no plant, cassava and mungbean) and bund distance (4m and 8m) in the fallow, dry-seeded rice and transplanted rice seasons, respectively. No such samples were taken in the bunds.

2.6.1 Nitrogen mineralization

Net nitrogen mineralization was studied based on the method developed by Raison *et al.* (1987) and Hübner *et al.* (1991), which uses undisturbed soil columns confined within PVC tubes (25 cm depth and 8 cm diameter) containing ion-exchange resins in fine-mesh nylon bags at the bottom of the intact soil core to account for nitrate leaching. A polyurethane-foam disk at the bottom of the tubes was used to fix the fine-mesh nylon bags (Figure 2.10).

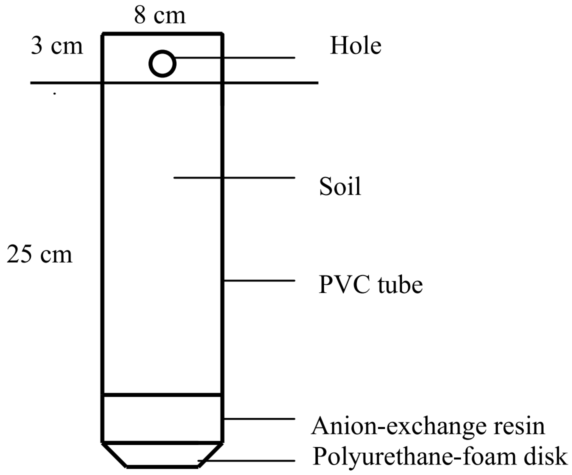


Figure 2.10: Equipment for in *situ* studies of N-mineralization

To obtain intact soil cores, twelve PVC tubes were randomly inserted into the soil at each treatment plot and then carefully withdrawn. A soil layer of about 2-3 cm was removed from the bottom of each core and the fine-mesh nylon bag containing 15 g of anion-exchange resin and 10 g of glass beads (0.3 cm diameter) inserted into the free space. The nylon bag was fixed with the polyurethane foam disk and the tubes were reintroduced into the original holes in the soil for incubation under field conditions. The tops of the tubes were left open to the atmosphere, to allow the nitrogen mineralization products to leach, through rainfall, from the soil columns into the resin bags.

After an incubation period of 4 weeks, the tubes (twelve tubes per treatment plot) were taken out using a bar, which was inserted through the two holes at the edge of the tube (each soil sample and resin bag of three tubes were pooled, which gave 4 replications per plot). The field-moist soil samples and the nylon bags with the anion-exchange resin were then transported at 4^{o}C to the laboratory to determine the ammonium and nitrate contents both in soil and resin.

Determination of ammonium and nitrate

Ammonium and nitrate in the soil samples and nitrate trapped by the resin were determined by the following procedure (Kandeler 1996): nitrate from a subsoil sample weighing 12.5 g was extracted with 50 ml of 2 M KCl. A 0.5 g amount of resin was extracted with 20 ml of 1M NaCl after washing the nylon bags with distilled water, and drying them at room temperature. Both soil and resin extracts were filtered through Whatman No. 42 filter paper. The filtrates were then analyzed for ammonium and nitrate. Ammonium-N was determined using the phenol-nitroprusside-hypochlorite method and measured by an UV spectrophotometer at 636 nm (Keeney and Nelson 1982), whereas nitrate-N was determined using the method of reducing nitrate with copper-sheathed granulated zinc, measuring with an UV spectrophotometer at 210 nm (Kandeler 1996).

Calculation of nitrogen mineralization

Nitrogen mineralization was calculated as the average of 4 replications per treatment plot. First, the concentration of inorganic nitrogen (NO_3-N and NH_4-N) in the soil was determined at the beginning of the exposure time (initial inorganic N). Second, the amount of nitrogen production (NO_3-N and NH_4-N) and present in the resin bags and soil was determined at the end of the exposure time (inorganic N after exposure time). Nitrogen mineralization was then calculated based on the sum of inorganic N (in soil and resin) after the exposure time *minus* the initial inorganic nitrogen in the soil (Kandeler 1996), as presented in the equation below:

$$[(NH_4^+\text{-}N + NO_3^-\text{-}N)_A + (NO_3^-\text{-}N)_B] - [(NH_4^+\text{-}N + NO_3^-\text{-}N)_C] = kg\ N.ha^{-1}$$

A	N_{min} content of the soil after the exposure time (kg N.ha-1)
B	nitrate adsorbed to the resin (kg N.ha-1)
C	initial N_{min} content of the soil (kg N.ha-1)

2.6.2 Nitrifiers and denitrifiers

Nitrification and denitrification processes are primarily mediated by a group of microorganisms. Therefore, the nitrification and denitrification potential was studied by determining the activity of microorganisms involved in those processes using the most probable number (MPN) method (Trolldenier 1996).

Nitrifiers were evaluated by calculating the population of *Nitrosomonas,* one of the nitrifiers oxidizing ammonia to nitrite, and usually the most numerous nitrifiers in soil (Biogeochemical Cycles 1998). The number of *Nitrosomonas* was calculated using the nutrient medium developed by Verstraete (Anas 1989). Culture tubes were inoculated with serially diluted soil suspensions. After a 4-week incubation period, acidification of the medium was recorded by taking color change (red to orange or yellow) as an indication for growth of ammonia oxidizers, and the most probable number of *Nitrosomonas* was then calculated by referring to the MPN table (Trolldenier 1996).

Denitrifiers were also calculated using a medium of nutrient broth supplemented with nitrate; this was a modified medium of Tiedje (1982). From a decimal diluted soil suspension, aliquots were transferred into culture tubes containing inverted Durham tubes. After 2 weeks of incubation, tubes showing gas formation in Durham tubes were recorded, and the most probable number of denitrifiers was calculated by referring to the MPN table (Trolldenier 1996).

2.7 Statistical analysis

Statistical analyses of the data on soil fauna, litter decomposition and nitrogen mineralization were done using analysis of variance using the IRRISTAT Program. The data were analyzed statistically as a factorial randomized block design with three levels of treatments, i.e., the planting seasons (fallow, dry-seeded rice and transplanted rice), crop-planted bund (control, cassava and mungbean) and two bund distance (4m and 8m), with four replications. To evaluate the differences in the treatments, the Least Significant Difference (LSD) test was applied. Data on litter decomposition were also calculated using the exponential decay regression from Sigma plot version 7.0.

To compare the mean value of the data of soil animal population and biomass, the data were also analyzed using the Student's T-test. Before being analyzed, all fauna data were log-transformed to obtain approximately homogenous variances.

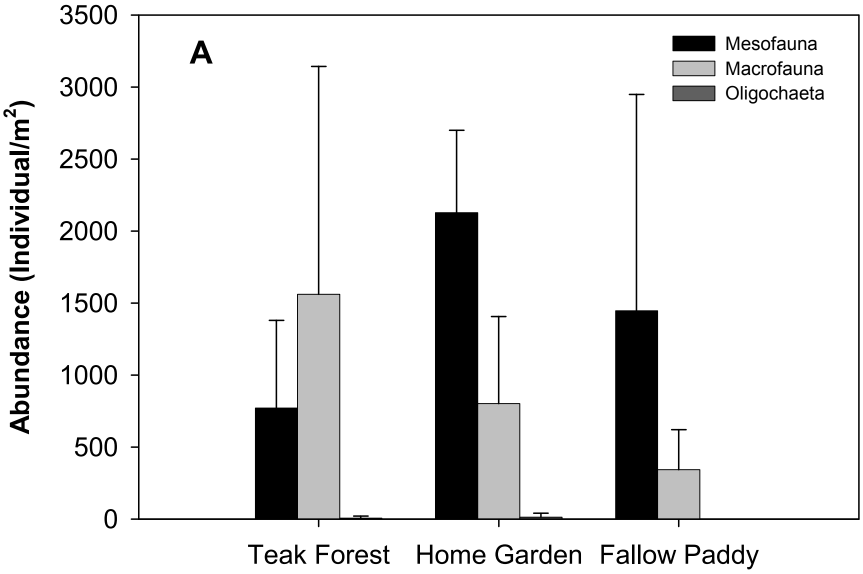
3 RESULTS AND DISCUSSION

3.1 Screening of soil fauna in different ecosystems of the region

In the screening test that was conducted during the fallow period, the total soil fauna abundance determined using the Berlese funnel and hand-sorting method was high in the teak forest (2340 individuals m^{-2}) and home garden (2940 individuals m^{-2}) and low in the fallow paddy field (1790 individuals m^{-2}) (Table 3.1). The teak forest also showed the highest total soil fauna biomass (961 mg m^{-2}), followed by home garden (368 mg m^{-2}) and fallow paddy field (309 mg m^{-2}), respectively (Table 3.2). Nevertheless, due to the high variance of the data, the Student's *t*-test analysis on the log-transformed fauna data showed that the differences in total soil fauna abundance and biomass were not significant in the teak forest, home garden and fallow paddy field ecosystems.

3.1.1 Abundance and biomass

The mesofauna abundance was higher compared to that of the macrofauna, especially in the home garden and fallow paddy field. Mesofauna numbers in the home garden and paddy field were 2130 and 1450 individuals m^{-2} or 73% and 81% of the total number of soil animals, respectively. Mesofauna numbers were significantly higher in the home garden than in the fallow paddy field and teak forest (Student's *t*-test, $P<0.05$). In general, the mesofauna abundance was dominated by Acari (mites) and Collembola (springtails). Their populations ranged between 20%-35% (mites) and 60%-80% (springtails) of the total mesofauna. According to Lavelle and Spain (2001), Collembola and Acari are generally dominant among mesofauna, both numerically and in terms of biomass. Although mesofauna numbers were high, their biomass was low, as they are small animals with body width ranging between 0.2 – 2 mm. Their biomass in the teak forest, home garden and paddy field accounted for only 5.3 mg, 9.0 mg and 10.5 mg m^{-2} or 0.6%, 2.4% and 3.4% of the total animal biomass, respectively (Figure 3.1B).



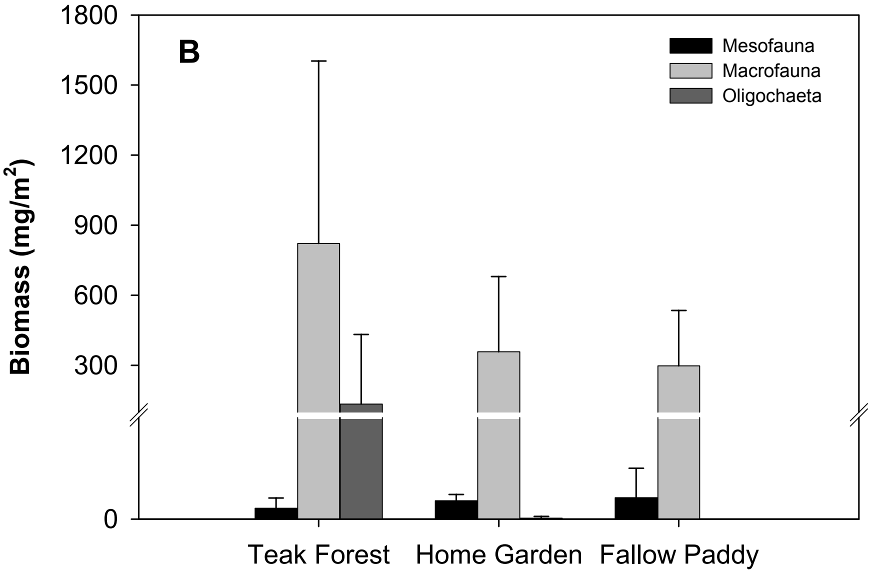


Figure 3.1: The abundance (A) and biomass (B) of soil fauna in ecosystem of teak forest, home garden, and fallow paddy field.

In general, the individual macrofauna numbers were lower than those of the mesofauna, except in the teak forest, accounting for less than 30% of the total number of soil fauna. Nevertheless, their biomass was very high and reached more than 90% of the total biomass (Table 3.2). Although the macrofauna abundance was higher in the teak forest than in the home garden and fallow paddy field, the Student's *t*-test analysis showed no significant difference between macrofauna in those ecosystems. The macrofauna abundance, however, was significantly higher in the home garden than in the rainfed paddy field (Table 3.1). The most numerous macrofauna groups found in the teak forest ecosystem were Formicidae (ants) and Isoptera (termites), while Diplura and Coleoptera (beetles) dominated in the home garden and fallow paddy field, respectively. Oligochaeta occurred only in the home garden and teak forest, and their abundance was very low, attaining less than 1.0% of the total number of soil animals. In the teak forest, however, the biomass of Oligochaeta was high, attaining 134 mg per m^2 or 14.0% of the total biomass.

3.1.2 Diversity

In the teak-forest and home-garden ecosystem, there were more taxa than in the fallow paddy field. The teak forest and home garden had 21 taxa, whereas in the paddy field only 13 taxa were found. Although the teak forest and the home garden contained the same number of taxa, the diversity, calculated according to Shannon's diversity index (Ludwig and Reynolds 1988), was higher in the home garden (2.06) than in the teak forest (1.82), while the fallow paddy field had the lowest animal diversity (1.67). In the teak forest, Hill's number (Ludwig and Reynolds 1988), a number indicating an abundant taxa (N1) was 6.2, while the number of very abundant taxa (N2) was 3.7. In fact, four taxa, namely Formicidae (Hymenoptera), Isoptera, Onychiuridae (Collembola) and Oribatida (Acari) accounted for 79% of the total abundance. The number of abundant taxa in the home garden was higher (8 taxa) than in the other ecosystems, with five of them very abundant (N2) and accounting for 80% of the total abundance, namely Isotomidae and Poduridae (Collembola), Tetranychidae (Acari), Japygidae (Diplura), and Formicidae (Hymenoptera). Meanwhile, in the fallow paddy field five taxa were found to be abundant, with four of them most numerous (88% of the total abundance), i.e., Onychiuridae and Isotomidae (Collembola), Oribatida (Acari), and Coleoptera (Table 3.1).

Table 3.1: Abundances (Individual/m^2) of soil fauna in different ecosystems of the region (soil depth 0-15 cm; averages over five replications)

No.	Taxa	Teak Forest		Home Garden		Fallow Paddy	
		Mean	SD	Mean	SD	Mean	SD
	Mesofauna						
1	Acari: Oribatida (Oribatid mites)	166 a	233	134 a	82	229 a	114
	Tetranychidae (Spider mites)	38	52	166	198	0	0
	Others	57	65	140	80	57	128
	Total Acari	**261 a**	**250**	**440 a**	**188**	**287 a**	**154**
2	Collembola: Isotomidae	140	129	1100	590	446	449
	Poduridae	83	77	471	476	0	0
	Hypogastruridae	0	0	32	39	0	0
	Entomobryidae	26	42	19	17	6	14
	Neelidae	13	29	38	35		14
	Onychiuridae	229	289	6	14	701	1160
	Sminthuridae	0	0	6	14	0	0
	Total Collembola	**490 a**	**440**	**1680 a**	**514**	**1160 a**	**1470**
3	Protura	6	14	0	0	0	0
4	Symphyla	13	17	13	17		0
	Total Mesofauna	**771 a**	**609**	**2130 b**	**572**	**1450 ab**	**1500**
	Macrofauna						
5	Aranae (Spiders)	32	39	32	39	0	0
6	Coleoptera: Carabidae	13	17	0	0	38	86
	Others ad.	6 a	14	32 a	55	198 b	184
	Others la.	0	0	13	17	83	58
7	Chilopoda (Centipedes)	13	17	0	0	6	14
8	Diplopoda (Millipedes) juvenile	19	29	57	79	0	0
9	Diplura: Japygidae	0	0	217	120	0	0
	Anajapygidae	0	0	6	14	0	0
10	Diptera	0	0	0	0	6	14
11	Hymenoptera:						
	Formicidae (Ants)	1190 **ab**	1670	414 **b**	717	6 **ac**	14
	Others	0	0	19	43	6	14
12	Isopoda	6	14	0	0	0	0
13	Isoptera (Termites)	268	581	0	0	0	0
14	Lepidoptera (larvae)	6	14	13	17	0	0
15	Pseudoscorpiones	13	17	0	0	0	0
	Total Macrofauna	**1560 ab**	**1580**	**803 b**	**604**	**344 ac**	**277**
	Oligochaeta:						
16	Earthworms	6	14	0	0	0	0
17	Enchytraeids	0	0	13	29	0	0
	Total Oligochaeta	**6**	**14**	**13**	**29**	**0**	**0**
	Number of Individual/m^2	**2340 a**	**1830**	**2940 a**	**1050**	**1790 a**	**1460**
	Number of Taxa/m^2	**21**		**21**		**13**	
	Shannon's Diversity Index	**1.82**		**2.06**		**1.67**	
	N1 (no. of abundant taxa)	**6.2**		**7.8**		**5.3**	
	N2(no. of very abundant taxa)	**3.7**		**5.0**		**4.0**	

In a row, means followed by a common letter are not significantly different at the 5% level (Student's *t*-test on log-transformed fauna data)

For the three ecosystems, namely teak forest, home garden and fallow paddy field, two groups of animals, i.e., Collembola and Acari, were the dominant taxa in terms of individual numbers. They were not only the most numerous animal groups, especially in the home garden and paddy field, but also always occurred in those ecosystems. Actually, ants were the most abundant animal group in the teak forest; however, they were not dominant in the other two ecosystems, and were rare in the fallow paddy field. Due to the high variance of the data, the high number of ants in the teak forest did not significantly differ from the number of ants in the home garden and paddy field.

The diversity index calculated from soil fauna biomass was higher in the home garden (1.53) than that in the teak forest (1.22) and fallow paddy field (1.21). Three groups of animals dominated the soil fauna biomass in the teak forest, namely Formicidae (ants), Isoptera (termites), and earthworms, making up for more than 90% of the total soil fauna biomass. Ant biomass was high in the teak forest and low in the paddy field. Ants also dominated soil fauna biomass in the home garden, along with Diplopoda and Coleoptera, accounting for 78% of the total soil fauna biomass. Their biomass was significantly higher in the home garden than in the paddy field and did not differ from that in the teak forest. In the fallow paddy field, Coleoptera, both larvae and adults, dominated the soil fauna biomass, accounting for more than 90% of the total in this ecosystem. The number of adults was significantly higher here than in the teak forest and home garden (Table 3.2).

Table 3.2: Biomass (mg/m^2) of soil fauna in different ecosystem of the region (averages over five replications)

No.	Taxa	Teak Forest		Home Garden		Fallow Paddy	
		Mean	SD	Mean	SD	Mean	SD
	Mesofauna						
1	Acari: Oribatida (Oribatid mites)	0.18 **a**	0.26	0.15 **a**	0.09	0.25 **a**	0.12
	Tetranychidae (Spider mites)	0.17	0.24	0.75	0.89	0.00	0.00
	Others	0.26	0.29	0.63	0.36	0.26	0.58
	Total Acari	**0.61 a**	**0.48**	**1.52 bc**	**0.77**	**0.51 ac**	**0.57**
2	Collembola : Isotomidae	0.62	0.57	4.85	2.60	1.96	1.97
	Poduridae	0.19	0.18	1.08	1.10	0.00	0.00
	Hypogastruridae	0.00	0.00	0.18	0.22	0.00	0.00
	Entomobryidae	0.21	0.35	0.16	0.15	0.05	0.12
	Neelidae	0.03	0.07	0.09	0.08	0.01	0.03
	Onychiuridae	2.61	3.29	0.07	0.16	7.99	13.27
	Sminthuridae	0.00	0.00	0.01	0.03	0.00	0.00
	Total Collembola	**3.66 a**	**3.66**	**6.45 a**	**2.27**	**10.00 a**	**14.50**
3	Protura	0.01	0.01	0.00	0.00	0.00	0.00
4	Symphyla	1.02	1.40	1.02	1.40	0.00	0.00
	Total Mesofauna	**5.30 a**	**5.07**	**8.99 a**	**3.08**	**10.50 a**	**14.40**
	Macrofauna						
5	Aranae (Spiders)	18.20	22.30	18.20	22.30	0.00	0.00
6	Coleoptera: Carabidae	11.66	15.90	0.00	0.00	34.90	78.00
	Others ad.	5.53 **a**	12.40	27.70 **a**	47.90	172.00 **b**	159.00
	Others la.	0.00	0.00	12.60	17.30	81.90	57.00
7	Chilopoda (Centipedes)	0.66	0.91	0.00	0.00	0.33	0.74
8	Diplopoda (Millipedes) juvenile	17.00	26.80	53.90	74.60	0.00	0.00
9	Diplura: Japygidae	0.00	0.00	4.33	2.40	0.00	0.00
	Anajapygidae	0.00	0.00	0.13	0.28	0.00	0.00
10	Diptera	0.00	0.00	0.00	0.00	2.86	6.39
11	Hymenoptera:						
	Formicidae (Ants)	592.00 **ab**	836.00	207.00 **b**	359.00	3.19 **ac**	7.12
	Others	0.00	0.00	9.55	21.40	3.19	7.12
12	Isopoda	0.72	1.61	0.00	0.00	0.00	0.00
13	Isoptera (Termites)	161.00	348.00	0.00	0.00	0.00	0.00
14	Lepidoptera (larvae)	12.60	28.20	25.22	34.50	0.00	0.00
15	Pseudoscorpiones	2.02	2.77	0.00	0.00	0.00	0.00
	Total Macrofauna	**822.00 a**	**781.00**	**359.00 a**	**322.00**	**298.00 a**	**238.00**
	Oligochaeta:						
16	Earthworms	134.00	299.00	0.00	0.00	0.00	0.00
17	Enchytraeids	0.00	0.00	0.41	0.91	0.00	0.00
	Total Oligochaeta	**134.00**	**299.00**	**0.41**	**0.91**	**0.00**	**0.00**
	Biomass Total/m^2	**961.00 a**	**933.00**	**368.00 a**	**289.00**	**309.00 a**	**235.00**
	Shannon's Diversity Index	**1.22**		**1.53**		**1.21**	

In a row, means followed by a common letter are not significantly different at the 5% level (Student's *t*-test on log-transformed animal data)

3.1.3 Bait-lamina feeding activity

Feeding activity was assessed during the rainy season in the teak forest, home garden and the rainfed paddy field experiments. The bait-lamina test was used, an easy and quick method for monitoring the feeding activity of soil-living animals. However, this method does not allow differentiation of the animal groups that are involved in the feeding process. The feeding stratification, indicating soil animal activity in various soil depths was also assessed.

Feeding activity

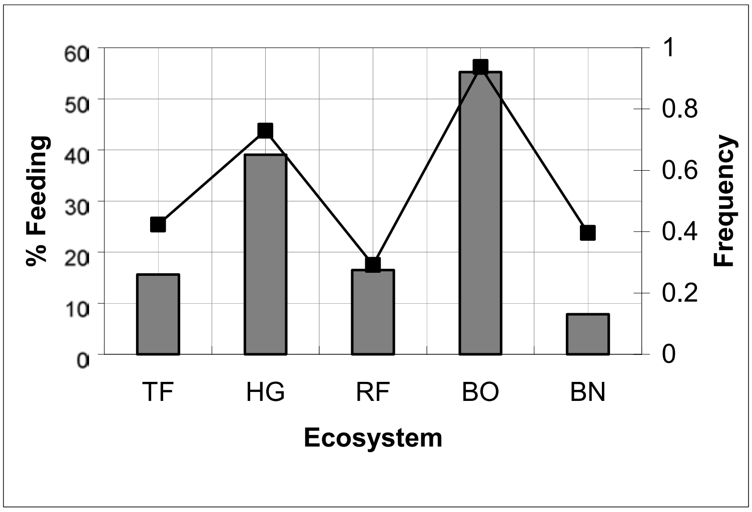
Feeding activity is reflected in the percentage of bait patches removed from each strip. The frequency of feeding is a comparison between the number of bait strips attacked by animals (without regarding the number of fed holes), and the total number of strips exposed to the field within one block (16 strips). Soil animals in the old bunds showed the highest feeding activity (55.2%), followed by the home garden (39.1%), the rice field (16.5 %), the teak forest (15.6 %), and the new bund (7.8 %), respectively. 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 rice field (0.3), respectively (Figure 3.2). The lowest variability of both feeding activity and the frequency of feeding was also found in the old bunds (reflected in the low standard deviation, Table 3.3).

Table 3.3: The average values of feeding activity of soil animals in different natural ecosystems in Pati, Indonesia.

Ecosystems	**% Feeding**	**SD**	**SD (% of average)**	**Frequency**	**SD**	**SD (% of average)**
Teak Forest	15.6	12.3	78.8	0.42	0.23	54.9
Home garden	39.1	29.8	76.4	0.73	0.33	49.1
Rice field	16.5	35.4	215.1	0.29	0.37	125.3
Old bund	55.2	38.7	70.1	0.94	0.11	11.5
New bund	7.8	7.2	91.6	0.40	0.20	50.7

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 as observed during the dry season. Feeding activity, abundance and biomass were low in the flooded rice field and high in the home garden. The highest feeding activity and frequency of bait-strip 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 rice field moved and concentrated on the bund because the field was flooded. Thus, the population of soil animals was higher in the bund, compared to the rice field. The higher population density led to the increase in feeding activity of soil animals in the bund. In contrast, the feeding activity declined in the rice field. 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 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 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 correspond with the high abundance and biomass. 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 and Römbke 1994; Heisler 1994); here the high population density was not always followed by high feeding activity. Litter as a source of feed for soil animals is abundant on the forest floor and may be the reason for the low bait-lamina feeding activity.



Bars = Feeding activity (%)
Lines = Frequency

Figure 3.2: Percentage and frequency of animal feeding in different natural ecosystems in Pati, Indonesia (TF = teak forest, HG = home garden, RF = rice field, BO = old bund and BN = new bund)

Feeding stratification

The average values of feeding activity depth indicate that, in general, the soil animals fed in the upper part (0-4 cm) of the bait-lamina rather than in the lower part (Table 3.4). In the rice field, although the difference was not obvious, there was a tendency 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, although the reduction from the 1st hole to the 16th hole of the bait-lamina was higher in the teak forest (60%) than in the old bund (45%) (Figure 3.3). This was presumably due to the fact that almost all soil organisms live in the top soil layer, because they feed on litter or organic matter, which is abundant there.

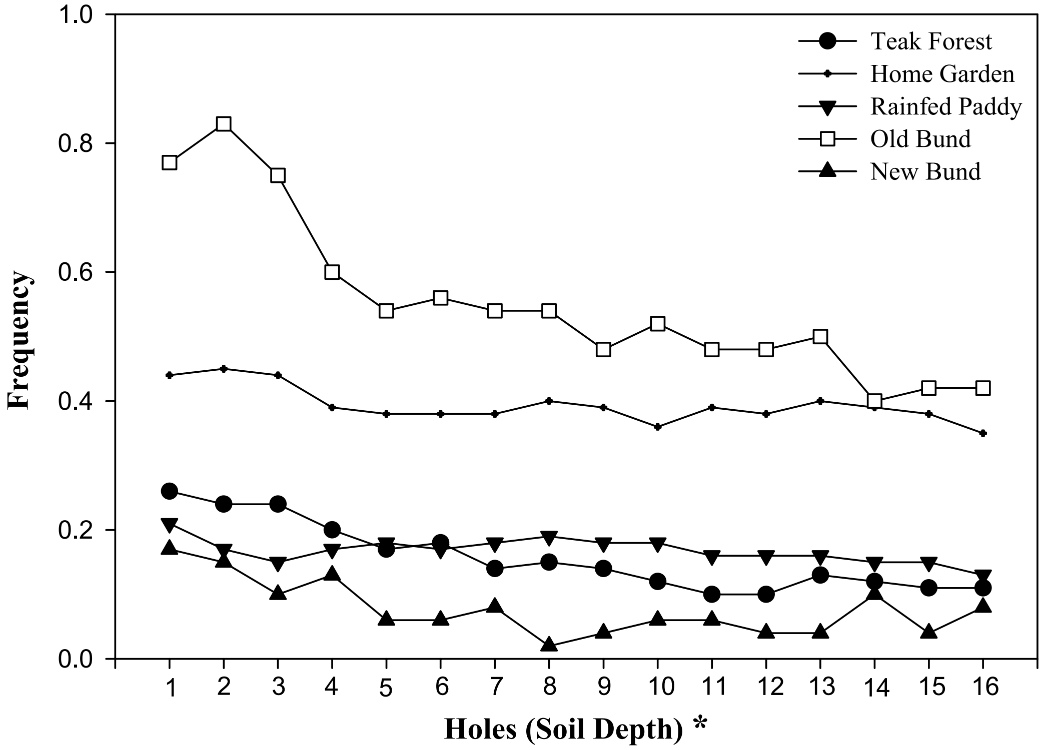


Figure 3.3: The frequency of bait lamina attacked by animals in various depth of soil in different natural ecosystems in Pati, Indonesia (* : between hole, # = 0.55 cm)

Resume

In the fauna survey during the dry season, soil fauna in the teak forest and home garden showed a higher abundance compared to the fallow paddy field, and their biomass was higher in the teak forest than in the home garden and paddy field. In these three ecosystems, two groups of animals, i.e. Collembola and Acari, were the dominant animals in terms of individual numbers. They were not only the most numerous groups, but also always occurred in those ecosystems. Three groups of animals dominated soil animal biomass in the teak forest, namely Formicidae (ants), Isoptera (termites), and earthworms. Formicidae also dominated soil animal biomass in the home garden, along with Diplopoda and Coleoptera, whereas in the fallow paddy field, both larvae and adults of Coleoptera dominated soil animal biomass.

The activity of soil fauna in these ecosystems during the rainy season (teak forest, home garden and rainfed paddy field) was also evaluated by measuring their feeding activity using the bait-lamina test. Soil fauna feeding activity was high in the home garden and low in the rainfed paddy field, as expected from soil fauna abundance and biomass. However, although soil fauna abundance and biomass were high in the teak forest, their feeding activity was low at this site. In addition, feeding activity was determined in the old bunds (permanently established bund around rice fields). Here, animal-feeding activity was the highest.

3.2 Soil fauna dynamics in rainfed paddy field

3.2.1 Soil fauna dynamics in fallow and rice field phases

In a rainfed paddy field, which undergoes two different conditions, i.e., a terrestrial phase during the fallow periods and a flooded phase during the periods of dry-seeded rice and transplanted rice, the soil fauna population changed dynamically following the seasonal changes. On average, the abundance of the soil fauna during the rice-field phases was lower than that in the fallow phase, while the soil fauna biomass was higher in the rice field, especially in the bund (Table 3.4 and 3.6).

Soil fauna abundance

The evaluation of soil fauna abundance was started in the fallow phase (August to October), continued into the rice phases, i.e., dry-seeded rice (November to January) and transplanted rice (March to May), and ended in the early fallow (June). In the fallow phase, soil fauna was extracted from soil samples taken at six randomized points at each sampling time. The total number of soil fauna decreased from August (3340 individuals m^{-2}/ ind. m^{-2}) to September (1230 ind. m^{-2}) and October (228 ind. m^{-2}). The decline of the soil fauna abundance during the fallow period is presumably due to the fact that the soils underwent desiccation, especially in the peak of the dry season around September and October.

In the rice phase, the soil samples were taken from four randomized points in both the field and the bund of the six treatments (see Section 2.3). The soil fauna was then extracted from the soil samples using the Berlese funnel method and evaluated at each sampling time during the dry-seeded rice and transplanted rice seasons, respectively. In the early fallow, shortly after the final harvesting, the bunds were destroyed and soil samples were taken from four randomized points in each treatment plot.

Table 3.4: Average soil fauna abundance (Individual/m^2) and diversity in fallow, dry-seeded rice and transplanted rice (soil depth 0-15 cm).

1 Fallow a)	**August**				**September**				**October**			
	Field		**Bund**		**Field**		**Bund**		**Field**		**Bund**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Mesofauna	3140	2220			1120	424			181	89		
Macrofauna	196	98			101	86			37	37		
Oligochaeta	11	26			11	16			11	16		
Total	3340	2300			1230	446			228	136		
Diversity	1.7	0.2			0.7	0.3			1.6	0.7		
2 Dry-Seeded Rice	**November**				**December**				**January**			
Mesofauna	1010	1550	882	382	179	145	246	243	139	89	199	91
Macrofauna	96	158	55	48	15	13	21	16	29	56	31	26
Oligochaeta	56	133	5	6	9	15	7	6	0	0	3	6
Total	1160	1530	942	424	203	134	273	228	169	111	233	86
Diversity	1.0	0.4	1.5	0.2	1.6	0.6	1.8	0.5	1.5	0.2	1.8	0.3
3 Transplanted Rice	**March**				**April**				**May**			
Mesofauna	608	835	1160	1070	186	182	602	241	1050	473	1340	688
Macrofauna	44	48	130	128	36	27	102	52	188	261	96	74
Oligochaeta	1	3	3	6	0	0	41	26	3	4	0	0
Total	653	882	1290	1200	222	183	746	267	1240	547	1600	719
Diversity	1.7	0.4	1.7	0.5	2.0	0.2	2.1	0.3	2.2	0.3	2.4	0.4
4 Fallow a)	**June**											
Mesofauna	2280	1630										
Macrofauna	556	825										
Oligochaeta	10	4										
Total	2850	1670										
Diversity	1.9	0.2										

a)In fallow periods, the bunds were destroyed

Table 3.4 shows that at the beginning of the dry-seeded rice (November), the soil fauna occurred in much higher numbers compared to those observed in October. Their numbers recovered somewhat during field preparation, but declined both in the field and in the bund from November to December, and stayed low in January. At the onset of transplanted rice, the abundance of soil fauna again reached higher numbers, both in the field and in the bund. They were lower in the subsequent sampling (April) but rose at the end of the transplanted rice (May). In early fallow, one month after the rice had been harvested and the field drained, soil fauna abundance increased to higher numbers than those observed in May (Figure 3.4).

Mesofauna abundance exhibited a pattern similar to that of the macrofauna. Abundance was high at the onset of the new cropping system, i.e., at the beginning of the dry-seeded rice (November), transplanted rice (March) and early fallow (June) periods (Figure 3.4A and 3.4B). Nevertheless, in general, their numbers indicated distinct seasonal changes, decreasing during the flooded periods, then starting to increase during the transplanted rice season and reaching the high numbers in the early fallow phase, shortly after the field had been drained (Table 3.4).

During the dry-seeded rice and transplanted rice phases, soil fauna abundance in the bund was significantly higher than that in the field (Table 3.5). This was particularly observed in the case of the meso- and macrofauna (Figure 3.4A and 3.4B) and is presumably due to the fact that conditions in the bund are more aerobic than in the field, which may be more favorable for most soil fauna.

Table 3.5: ANOVA test on soil fauna abundance and biomass at two different sampling sites (field and bund) and sampling times (F mean of field, B mean of bund).

	Sampling Times P	Sampling Sites P
Dry Seeded Rice:		
Abundance	<0.01	<0.05 (B>F)
Biomass	<0.05	ns
Transplanted Rice:		
Abundance	<0.01	<0.01 (B>F)
Biomass	<0.01	<0.01 (B>F)

Oligochaeta (enchytraeids and earthworms) abundance did not show any particular pattern, i.e., they occurred both in the fallow and the rice field periods. In the fallow period, Oligochaeta occurred in equal numbers at each sampling time, whereas in dry-seeded rice, they occurred both in the field and in the bund, except in January, when they occurred only in the bund. In transplanted rice, Oligochaeta occurred mostly in the bund, particularly in April, when their abundance was highest (Figure 3.4C). According to Lavelle and Spain (2001), Oligochaeta are semi-aquatic animals and live equally well in terrestrial and aquatic environments.

Soil fauna biomass

The total biomass of the soil fauna showed a pattern similar to that of soil fauna abundance. Meso- and macrofauna biomasses significantly decreased from August to October, and showed high values at the beginning of the dry-seeded rice (November) and transplanted rice (March) periods. They reached the highest values in the early fallow, shortly after the field had been drained (Figure 3.4). In the fallow period, mesofauna biomass ranged from 3-5% of the total biomass, whereas the macrofauna biomass fraction was 94-96%. Oligochaeta biomass accounted for only about 1% of the total biomass, since only enchytraeids (small Oligochaeta) occurred in the samples during the fallow periods (Table 3.6).

In the dry-seeded rice and transplanted rice fields, the biomasses of meso- and macrofauna were generally lower than those in the fallow, especially in dry-seeded rice. In dry-seeded rice, biomasses tended to decrease from November to January, and in transplanted rice they increased gradually reaching the highest levels in early fallow, one month after the field had been drained.

Oligochaeta biomass in rice field periods fluctuated strongly, ranging from 0% to more than 90% of the total biomass. During the dry-seeded rice period, earthworms occurred in the soil samples both in the field and in the bund. Since earthworms are large animals with an average body weight of approximately 21 mg individual^{-1}, when they occurred in soil samples, their biomass could make up for more than 60% of the total. This is the case in November and December. In transplanted rice, earthworms only occurred in the bund at the April sampling, whereas at other sampling occasions, they did not occur, so that the Oligochaeta biomass was also low.

The biomass of soil fauna in rice field periods exhibited a pattern similar to soil fauna abundance. The biomass in the bund, particularly during transplanted rice period, was significantly higher than in the field (Table 3.5), especially in the case of meso-and macrofauna (Figure 3.4A and 3.4B). Meanwhile, Oligochaeta biomass did not exhibit any particular pattern. They occurred sporadically in the field and in the bund (Figure 3.4C).

Soil fauna diversity

Soil fauna abundance-based diversity, calculated according to the Shannon diversity index (Ludwig and Reynolds 1988), was higher in the fallow phase than in the rice field phase. In the fallow phase, the diversity index declined from August (1.73) to September (0.73) and rose again till October (1.59). The soil fauna biomass-based diversity exhibited a similar trend. In the fallow period, a sub-group of Collembola, i.e., Hypogastruridae and Isotomidae and a sub-group of Acari, namely Oribatida or oribatid mites, were the most numerous animal groups among the mesofauna. Collembola play a significant role regarding the food web dynamics, because they are among the most important consumers in many soil ecosystems (Borror *et al*. 1989 and Daly *et al*. 1998). Oribatid mites are the most important Acari with regard to soil fertility, as they play an important role in breaking down organic matter and promoting soil fertility (Borror *et al*. 1989).

Coleoptera (beetles) and Diplura (diplurans) were the most numerous animal groups among the macrofauna during the fallow periods. In terms of biomass, groups of beetles dominated. They were not only high in biomass, but also occurred at each sampling occasion. Although some beetle families, such as Staphylinidae, Pselaphidae and Cicindellidae, are predators, other families are saprophagous and phytophagous, while Diplura may be both panphytophagous and predatory (Raw 1967 and Lavelle and Spain 2001). Thus, some of them could contribute to the decomposition processes during the fallow periods.

Table 3.6: Average soil fauna biomass (mg/m^2) and diversity in fallow, dry-seeded rice and transplanted rice (soil depth 0-15 cm).

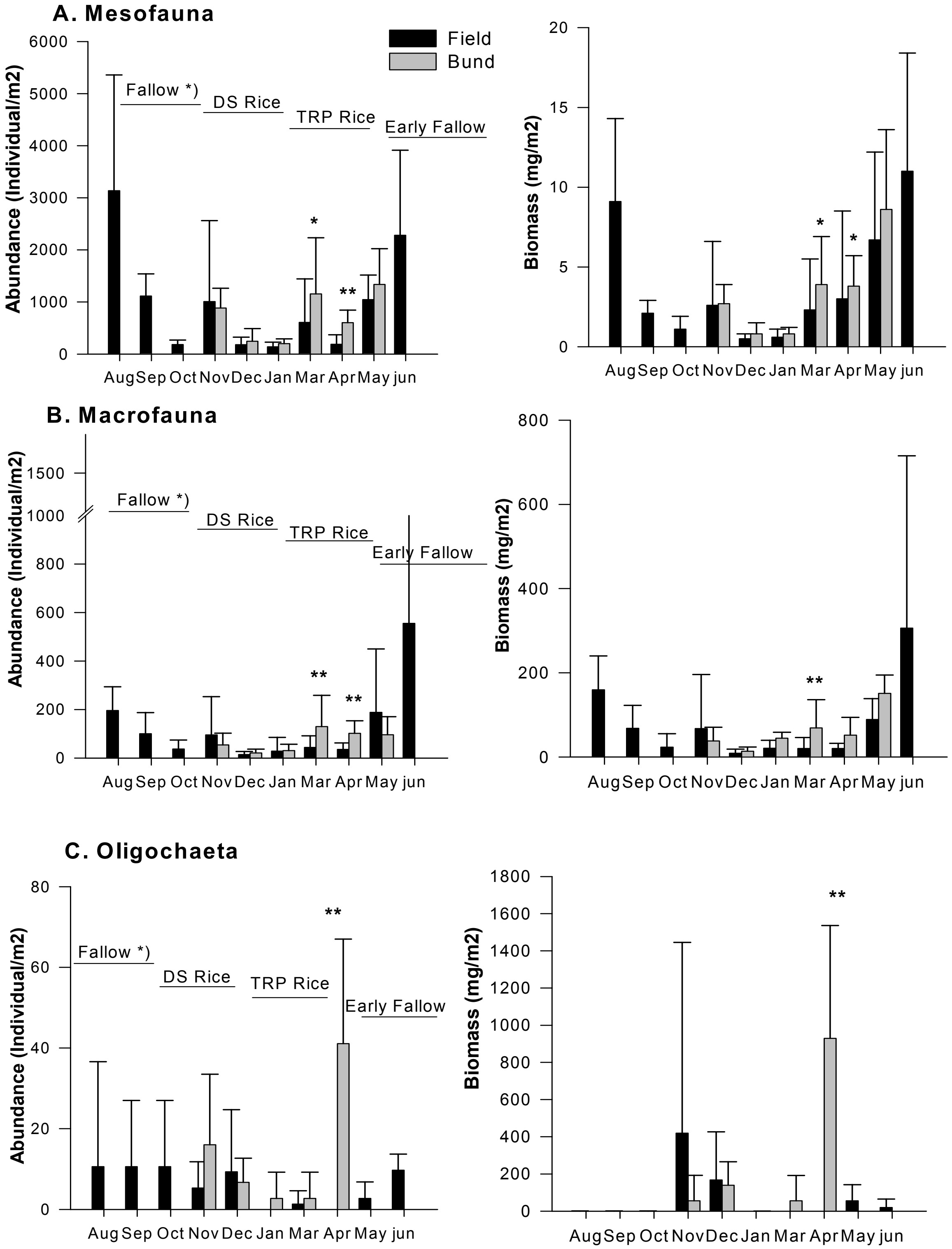
1. Fallow a)	**August**				**September**				**October**			
	Field		**Bund**		**Field**		**Bund**		**Field**		**Bund**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Mesofauna	9.1	5.2			2.1	0.8			1.1	0.8		
Macrofauna	160.0	80.4			68.2	54.4			23.4	32.2		
Oligochaeta	0.3	0.8			0.3	0.5			0.3	0.5		
Total	169.0	83.1			70.6	55.1			24.9	33.3		
Diversity	1.63	0.14			1.04	0.32			1.15	0.23		
2. Dry Seeded Rice	**November**				**December**				**January**			
Mesofauna	2.6	4.0	2.7	1.2	0.5	0.3	0.8	0.7	0.6	0.5	0.8	0.4
Macrofauna	67.4	129.0	37.9	32.9	9.2	9.4	13.8	9.9	20.7	18.8	44.7	13.9
Oligochaeta	419.0	1030.0	55.8	137.0	167.0	259.0	139.0	126.0	0.0	0.0	0.1	0.2
Total	489.0	1010.0	96.5	160.0	177.0	266.0	154.0	132.0	21.3	44.8	45.6	13.7
Diversity	0.67	0.43	1.32	0.39	0.42	0.31	0.47	0.22	0.70	0.47	0.96	0.32
3. Transplanted Rice	**March**				**April**				**May**			
Mesofauna	2.3	3.2	3.9	3.0	3.0	5.5	3.8	1.9	6.7	5.5	8.6	5.0
Macrofauna	20.3	25.8	69.0	67.2	20.2	12.3	52.1	42.0	89.2	49.5	151.0	43.6
Oligochaeta	0.0	0.0	55.7	137.0	0.0	0.0	929.0	607.0	55.7	86.3	0.0	0.0
Total	22.7	24.4	129.0	193.0	23.2	15.5	985.0	587.0	152.0	73.7	160.0	45.3
Diversity	1.31	0.35	1.55	0.43	1.10	0.54	0.38	0.27	1.74	0.64	2.14	0.26
4. Fallow a)	**June**											
Mesofauna	11.0	7.4										
Macrofauna	306.0	409.0										
Oligochaeta	18.9	45.5										
Total	336.0	399.0										
Diversity	1.68	0.60										

a) In fallow periods, the bunds were destroyed

During the flooded periods or rice field phases, the higher abundance and biomass of soil fauna in the bund were accompanied by a higher diversity of soil fauna abundance and biomass. The soil animal group that still remained in the field during the dry-seeded rice comprised mostly Collembola and larvae of Coleoptera and Diptera. Earthworms and enchytraeids were only occasionally found, although they have a higher biomass than macrofauna. In the bund, the soil fauna was found to be more diverse, e.g., it contained Collembola, Acari, Diptera, Oligochaeta, Coleoptera, and Hymenoptera (Formicidae or ants).

At the beginning of the transplanted rice period, the rainfall started to decline (Table 3.1), and the water in the field gradually receded; soil fauna was, therefore, more diverse both in the field and in the bund. Soil fauna in the field was still dominated by Collembola, followed by Acari (particularly oribatid mites), Coleoptera (Staphylinidae) and Plecoptera, whereas the soil animal groups that occurred in the bund were mainly Collembola, Acari, Diptera, earthworms, and Orthoptera. In general, Collembola, namely Sminthuridae, were the most numerous in the field during the flooded periods (Figure 3.6A), followed by oribatid mites (Figure 3.5).

In early fallow, one month after the field had been drained, the most numerous animal groups were still Collembola; however different families occurred, i.e., Hypogastruridae and Entomobryidae, followed by oribatid mites. In terms of biomass, Coleoptera and Hymenoptera (Formicidae) dominated. The presence of Collembola, Acari, and larvae and adults of Coleoptera during both the dry and the flooded periods was important for maintaining the soil fertility, since most of them act as decomposers.



*) In fallow periods, the bunds were destroyed

Figure 3.4: Soil animal abundance and biomass in fallow, dry-seeded rice (DS rice) and transplanted rice (TRP rice)(soil depth 0-15 cm; ANOVA on log-transformed fauna data, **: $P<0.01$; *:$P<0.05$)

Dynamics of oribatid mites

In terms of individual numbers, oribatid mites were the dominant group among Acari, being present at each sampling. The high population dynamics are shown in Figure 3.5. At the first sampling (during fallow), the number of oribatid mites was highest (1200 ind. m^{-2}). According to Lavelle and Spain (2001), resistance of Acari to water and temperature stress is high, i.e., they can withstand desiccation up to –6.0 Mpa (pF 5) before having to move to wetter areas. As a consequence, their population densities may be highest during the dry and hot seasons. Their numbers decreased at the subsequent sampling dates, i.e., approximately 1000 ind. m^{-2} in September and 32 ind. m^{-2} in October. During the flooded periods, oribatid mites still survived, though they occurred only in very low numbers, ranging from 15 to 37 ind. m^{-2}. At the end of the transplanted rice season (May), the number of oribatid mites started to increase and reached 303 ind. m^{-2} (field) and 170 ind. m^{-2} (bund). Oribatid mite numbers peaked again at 649 ind. m^{-2} in June when the field had been drained, shortly after the harvest. This condition was probably more favorable for oribatid mites.

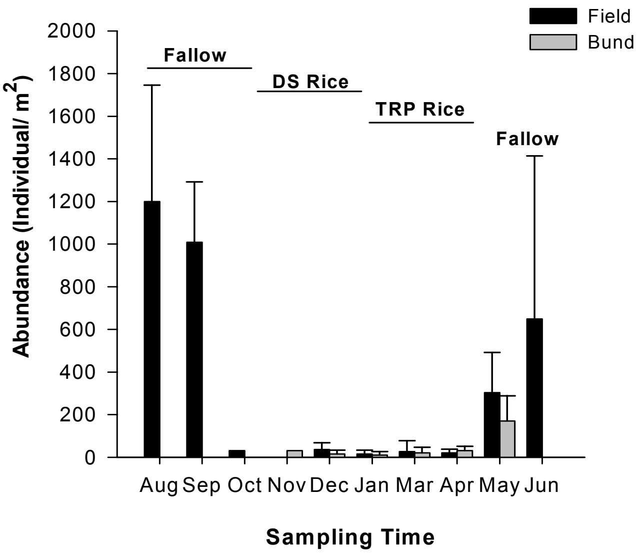


Figure 3.5: Dynamics of oribatis mites in fallow, dry-seeded rice (DS Rice) and transplanted rice (TRP Rice) (soil depth 0-15 cm).

Dynamics of Collembola

Soil fauna groups of Collembola were present in the soil at each sampling time, from the dry to the flooded phase. However, different groups appeared at each sampling time as exhibited in Figure 3.6 and 3.7, alternating between Sminthuridae, Hypogastruridae, Entomobryidae, and Isotomidae. During the flooded periods, Sminthuridae were the most numerous groups, but they did not appear during the fallow periods. The Sminthuridae or common springtails occur mainly on wet and acid soils and on water surfaces (Daly *et al.* 1998 and Alford 1999). At the beginning of the dry-seeded rice season, Sminthuridae occurred in high numbers, i.e., 860 ind. m^{-2} (field) and 610 ind. m^{-2} (bund). They were still present in December and January, but in lower numbers; they occurred again in high numbers at the beginning of the transplanted rice season. At the following sampling, their numbers started to decrease and reached the lowest value at the last sampling in June (Figure 3.6A). Sminthuridae were not influenced by the sampling location (field and bund), i.e., they occurred in almost equal numbers, both in the field and in the bund.

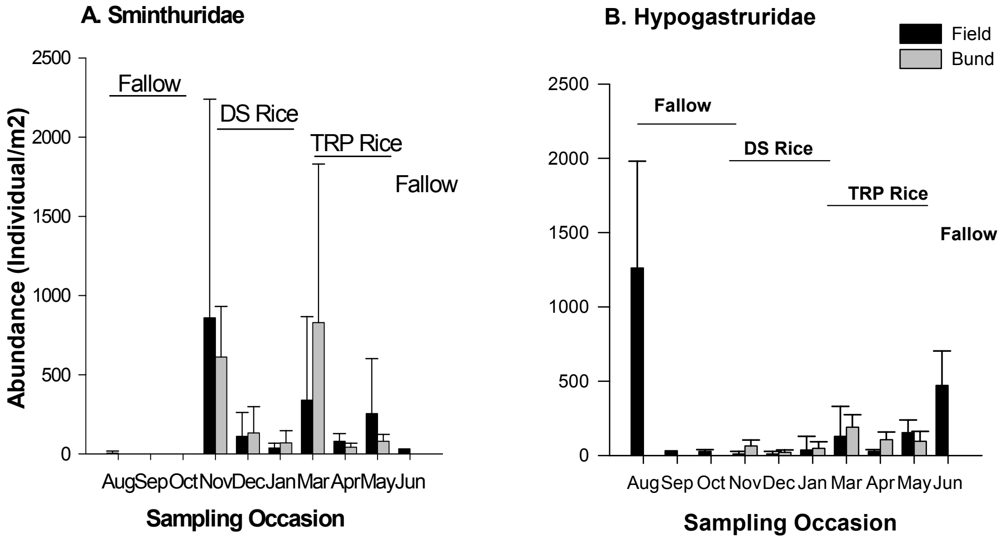


Figure 3.6: Dynamics of Sminthuridae and Hypogastruridae in fallow, dry-seeded rice (DS Rice) and transplanted rice (TRP Rice) (soil depth 0-15 cm).

Hypogastruridae were the more dominant group among Collembola during the fallow period and they disappeared or occurred only in very low numbers during the flooded periods (Figure 3.6B). The abundance of Entomobryidae was very low in fallow periods; they even disappeared in September and remained low in dry-seeded rice. The number of Entomobryidae started to increase in transplanted rice, particularly in the bunds, where their numbers were higher than in the fields. They reached their highest number at the subsequent sampling time, i.e., in the early fallow period (Figure 3.7A). Isotomidae were also found abundantly during the fallow (Figure 3.7B). The highest numbers were observed in August. Numbers started to decrease in September and October, staying low during the rice field periods, especially in transplanted rice, but re-appearing in high numbers in the early fallow.

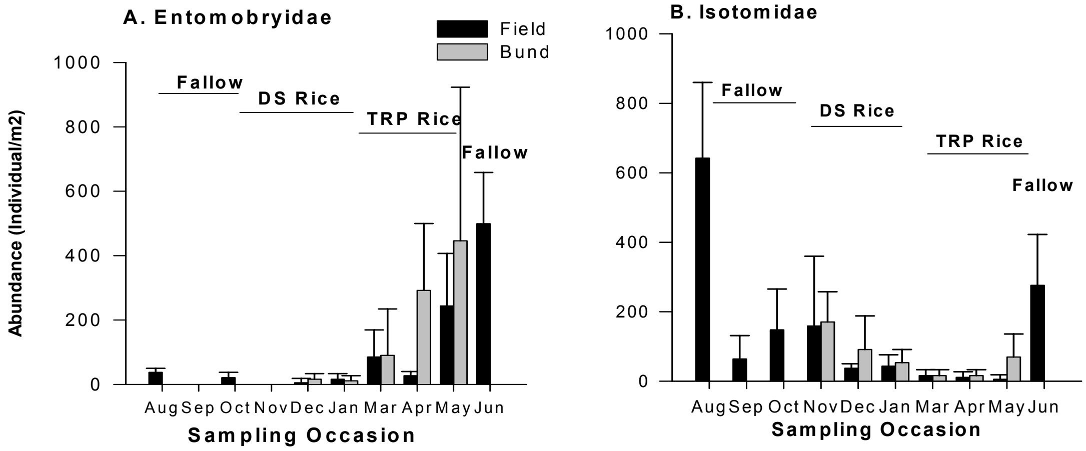


Figure 3.7: Dynamics of Entomobryidae and Isotomidae in fallow, dry-seeded rice (DS Rice) and transplanted rice (TRP Rice) (soil depth 0-15 cm).

Resume

In the rice field phase (during the flooded periods), soil fauna abundance and biomass, with the exception of Oligochaeta, were generally lower than in the fallow (non-flooded), especially in the early fallow period. Soil fauna abundance and biomass were consistently high at the onset of each cropping system. During the flooded periods, meso- and macrofauna abundance and biomass in the bunds were significantly higher than those in the field. Oligochaeta occurred both in the fallow and the rice seasons, without any particular trend.

The diversity indices of soil fauna (based both on abundance and biomass) were higher in the fallow phase than in the flooded phase, and higher in the bunds than in the fields. During the fallow phase, Oribatida of the Acari and some groups of Collembola, namely Hypogastruridae, Entomobryidae and Isotomidae, were the most numerous. In terms of biomass, Coleoptera (beetles) were a dominant group among the soil fauna. In the rice season, Sminthuridae of the Collembola was the most abundant fauna group.

Coleoptera and Diptera larvae were dominant fauna groups among the soil fauna with regard to biomass.

3.2.2 The effect of bund distance and crop-planted bunds on soil fauna abundance, biomass and diversity

Bund distance

To evaluate the effect of two different bund distances of 4m and 8m on soil fauna abundance, biomass and diversity, the soil fauna was extracted from soil samples taken from four randomized points in the six treatment plots (see Section 2.3). Samples were taken from the field and the bund every 30 days during the dry-seeded rice, transplanted rice and early fallow periods.

Dry-seeded rice. During the dry-seeded rice season, mesofauna abundance and biomass in the plots with short bund distance (4m) did not significantly differ from that in the plots with long bund distance (8m) (Anova test on log-transformed fauna data). However, approximately 50% of the individual results (for different months) showed that mesofauna abundance tended to be higher in the 4-m plots than in the 8-m plots, biomass showing an even greater increase in the 4-m plots (67%). Irrespective of bund distance, both in the fields and in the bunds, mesofauna abundance and biomass were mostly dominated by Collembola, particularly animals from the Sminthuridae group. Although the mesofauna groups in the fields were similar to those in the bunds, their number and biomass were higher in the bund than in the field (Tables 3.7 and 3.8).

The macrofauna abundance and biomass exhibited the same trend as the mesofauna, numbers and biomass being higher in the 4-m plots than in the 8-m plots, both in the field and in the bund (Figure 3.8 B). Approximately 75% of the individual results (for different months) indicated that macrofauna abundance and biomass were higher in 4-m plots. In November, macrofauna abundance and biomass in 4-m plots were even significantly higher than in the 8-m plots, both in the fields and in the bunds (Tables 3.7 and 3.8). The most numerous taxa of macrofauna in 4-m plots were larvae of Diptera and Coleoptera. The short bund distance (4 m) may facilitate the movement of the macrofauna from the fields to the bunds when the field is flooded and conditions are unfavorable.

Table 3.7**:** Average soil fauna abundance (Individual/m^2) and diversity for two different bund distances (4m and 8m) in dry-seeded rice (soil depth 0-15 cm).

	Field				Bund			
	4m		8m		4m		8m	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	November							
Mesofauna	510 **a**	403	1510 **a**	2260	1010 **a**	511	753 **a**	232
Macrofauna	173 **a**	210	19 **b**	17	88 **a**	50	21 **b**	5
Oligochaeta	3 **a**	5	109 **a**	188	8 **a**	8	3 **a**	5
Total	685	586	1640	2200	1110	559	777	238
Diversity	1.22	0.13	0.88	0.60	1.69	0.24	1.40	0.15
	December							
Mesofauna	138 **a**	60	220 **a**	210	130 **a**	51	361 **a**	324
Macrofauna	19 **a**	5	11 **a**	18	27 **a**	17	16 **a**	16
Oligochaeta	3 **a**	5	16 **a**	21	8 **a**	8	5 **a**	5
Total	160	52	247	191	165	48	382	304
Diversity	1.93	0.18	1.32	0.81	1.96	0.10	1.65	0.72
	January							
Mesofauna	186 **a**	95	93 **a**	64	226 **a**	81	173 **a**	110
Macrofauna	8 **a**	8	50 **a**	81	35 **a**	39	27 **a**	12
Oligochaeta	0 **a**	0	0 **a**	0	5 **a**	9	0 **a**	0
Total	194	96	143	140	266	73	199	99
Diversity	1.42	0.22	1.54	0.13	1.81	0.26	1.86	0.32

In a row under each sampling sites (field and bund), means followed by a common letter are not significantly different at the 5% level (ANOVA on log-transformed data).

The Oligochaeta population also tended to be higher in 4-m plots than 8-m plots, at least in 50% of the individual months of sampling (Figure 3.8 C). Since earthworms are large soil animals, when they occurred in the soil samples their biomass could make up more than 90% of the total biomass, as observed in the fields of the 8-m plots in November and December (Table 3.8).

During the dry-seeded rice period, soil fauna diversity (based both on abundance and biomass) was higher in the 4-m plots than in the 8-m plots (Tables 3.7 and 3.8). In fact, soil fauna abundance in the 8-m plots was dominated by Sminthuridae (Collembola), enchytraeids and earthworms, whereas in the 4-m plots, soil fauna was more diverse comprising, for example, Collembola, enchytraeids, earthworms, and Diptera larvae. Some Coleoptera groups were also found, especially in the bund. In terms of biomass, Coleoptera and Diptera larvae were the dominant animals in both plots. Although Oligochaeta have a high biomass, they were not the dominant animal group, since they occurred only occasionally in the samples.

Table 3.8: Average soil fauna biomass (mg/m^2) and diversity for two different bund distances (4m and 8m) during dry-seeded rice (soil depth 0-15 cm).

	Field				Bund			
	4m		8m		4m		8m	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	November							
Mesofauna	7.4 **a**	0.9	3.9 **a**	5.8	3.0 **a**	1.5	2.5 **a**	0.9
Macrofauna	128.0 **a**	174.0	6.8 **b**	11.2	62.1 **a**	30.5	13.8 **b**	5.9
Oligochaeta	0.1 **a**	0.1	838.0 **a**	1450.0	112.0 **a**	193.0	0.1 **a**	0.1
Total	136.0	175.0	849.0	1460.0	177.0	210.0	16.3	6.8
Diversity	0.85	0.50	0.49	0.36	1.38	0.44	1.25	0.43
	December							
Mesofauna	0.5 **a**	0.2	0.5 **a**	0.5	0.5 **a**	0.1	1.2 **a**	1.0
Macrofauna	10.3 **a**	4.5	8.1 **a**	14.0	15.9 **a**	9.6	11.7 **a**	11.8
Oligochaeta	55.7 **a**	96.5	279.0 **b**	348.0	167.0 **a**	167.0	112.0 **a**	96.5
Total	66.5	101.0	287.0	361.0	184.0	172.0	124.0	106.0
Diversity	0.59	0.28	0.25	0.26	0.40	0.20	0.54	0.25
	January							
Mesofauna	0.8 **a**	0.6	0.4 **a**	0.3	1.0 **a**	0.4	0.6 **a**	0.3
Macrofauna	2.8 **a**	2.5	38.6 **a**	63.5	16.4 **a**	16.7	21.3 **a**	13.6
Oligochaeta	0.0 **a**	0.0	0.0 **a**	0.0	0.2 **a**	0.3	0.0 **a**	0.0
Total	3.6	2.7	39.0	63.7	17.6	16.6	21.9	13.3
Diversity	0.85	0.06	0.56	0.69	0.91	0.11	1.00	0.49

In a row under each sampling sites (field and bund), means followed by a common letter are not significantly different at the 5% level (ANOVA on log-transformed data).

Transplanted rice. The trend of meso- and macrofauna abundance and biomass exhibited during the dry seeded rice was also shown during the transplanted rice period, where abundance and biomass were higher in the 4-m plots than in the 8-m plots. Here, more than 50% of the results for the different months indicated that meso- and macrofauna were higher in 4-m plots than in 8-m plots. Macrofauna abundance in March and May and biomass (only May) in the 4-m plots were significantly higher than in the 8-m plots.

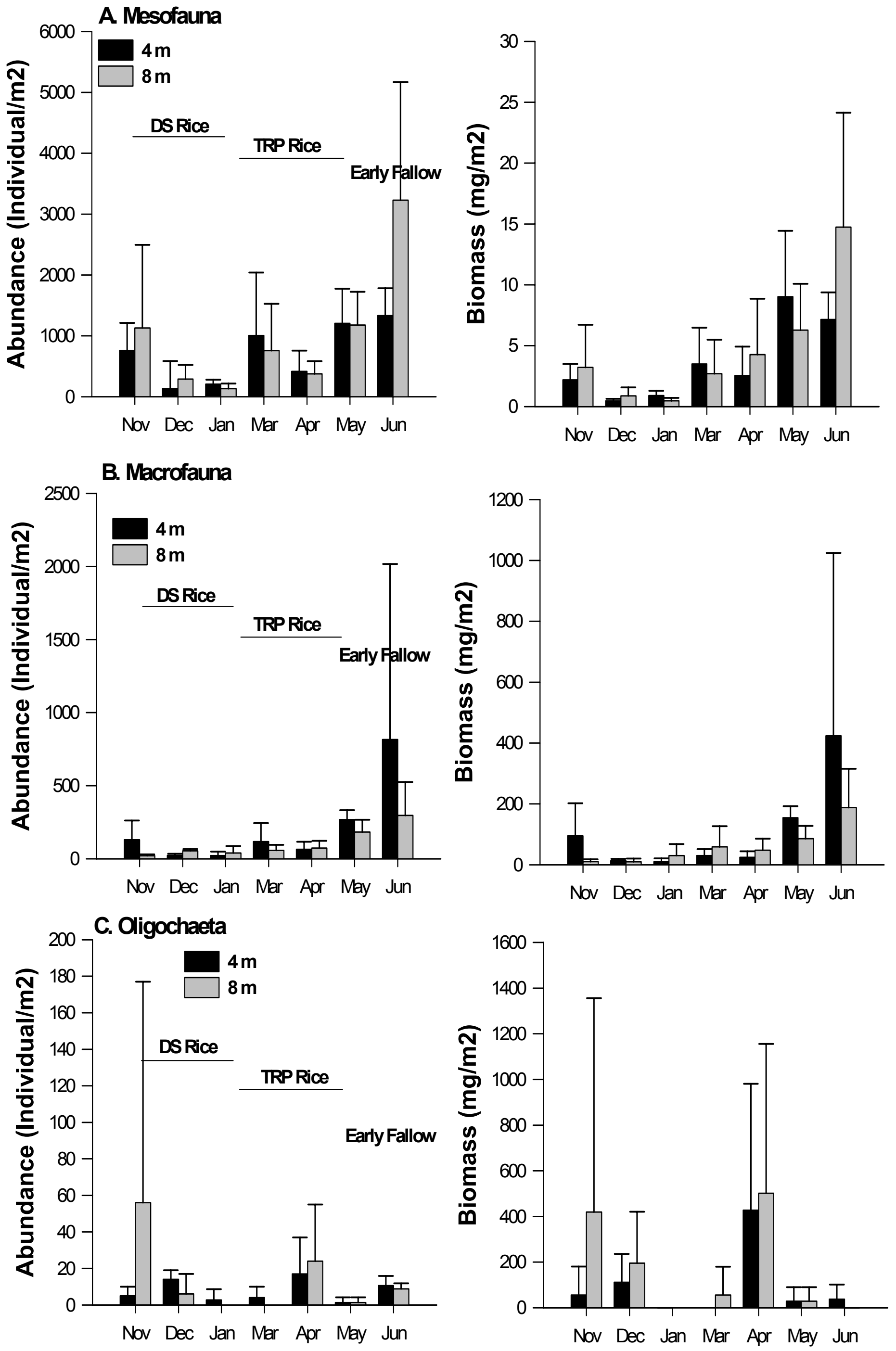


Figure 3.8: The effect of 4-m and 8-m bund distances on soil fauna abundance and biomass in dry-seeded rice (DS Rice), transplanted rice (TRP Rice) and early fallow (soil depth 0-15 cm; ANOVA on log- transformed fauna data; *: $P<0.05$, **: $P<0.01$)

The Anova test on log-transformed fauna data did not show any significant differences in soil fauna abundance and biomass between the 4-m and 8-m plots (Tables 3.9 and 3.10). This is presumably due to the high variance of the fauna data. The mesofauna, both in the 4-m plots and 8-m plots, was still dominated by Collembola (Sminthuridae and Hypogastruridae), and Acari (oribatid mites). In the bund, animal groups of Acari were more diverse, e.g. oribatid mites, spotted acari and spider mites.

Table 3.9: Average soil fauna abundance (Individual/m^2) and diversity for two different bund distances (4m and 8m) in transplanted rice (soil depth 0-15 cm).

	Field				Bund			
	4m		8m		4m		8m	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	March							
Mesofauna	345 **a**	231	871 **a**	1220	1670 **a**	1360	645 **a**	503
Macrofauna	24 **a**	24	64 **a**	63	210 **a**	148	50 **b**	17
Oligochaeta	3 **a**	5	0 **a**	0	5 **a**	9	0 **a**	0
Total	372	259	934	1280	1880	1517	695	517
Diversity	1.55	0.55	1.76	0.36	1.66	0.57	1.67	0.48
	April							
Mesofauna	88 **a**	8	284 **b**	232	740 **a**	187	464 **a**	231
Macrofauna	19 **a**	12	53 **a**	28	112 **a**	35	93 **a**	72
Oligochaeta	0 **a**	0	0 **a**	0	35 **a**	18	48 **a**	35
Total	106	18	337	209	886	213	605	271
Diversity	1.93	0.15	2.06	0.17	2.04	0.45	2.13	0.14
	May							
Mesofauna	1150 **a**	694	945 **a**	216	1260 **a**	701	1410 **a**	822
Macrofauna	236 **a**	83	141 **b**	97	300 **a**	49	223 **a**	84
Oligochaeta	3 **a**	5	3 **a**	5	0 **a**	0	0 **a**	0
Total	1390	766	1090	308	1560	750	1640	852
Diversity	2.35	0.31	1.43	0.57	2.47	0.42	2.22	0.43

In a row under each sampling sites (field and bund), means followed by a common letter are not significantly different at the 5% level (ANOVA on log-transformed data).

In 4-m plots, larvae and adults of Coleoptera and Diptera (the adult occurred mainly in the bund), Hymenoptera, Homoptera and Aranae were the dominant taxa of the macro fauna. Coleoptera and Diptera also occurred in the 8-m plots, but their numbers were lower. During the transplanted rice period, the different bund distance did not generally influence Oligochaeta abundance and biomass. Earthworms mainly occurred in the bund, so that Oligochaeta biomass was higher in the bunds than in the fields. Enchytraeids mostly occurred in the field (Table 3.10).

Table 3.10: Average soil fauna biomass (mg/m^2) and diversity for two different bund distances (4m and 8m) in transplanted rice (soil depth 0-15 cm).

	Field				Bund			
	4m		8m		4m		8m	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	March							
Mesofauna	1.3 **a**	1.1	3.4 **a**	4.5	5.7 **a**	3.3	2.1 **a**	1.2
Macrofauna	31.8 **a**	34.8	8.8 **a**	7.7	28.2 **a**	13.5	110.0 **a**	78.2
Oligochaeta	0.0 **a**	0.0	0.1 **a**	0.1	0.0 **a**	0.0	112.0 **a**	193.0
Total	33.1	34.0	12.2	3.4	33.9	11.0	223.0	256.0
Diversity	1.23	0.32	1.39	0.43	1.69	0.60	1.42	0.21
	April							
Mesofauna	0.4 **a**	0.1	5.6 **b**	7.5	4.7 **a**	1.9	2.9 **a**	1.7
Macrofauna	11.8 **a**	6.5	28.6 **a**	11.0	37.9 **a**	23.9	66.2 **a**	56.9
Oligochaeta	0.0 **a**	0.0	0.0 **a**	0.0	855.0 **a**	611.0	1000.0 **a**	730.0
Total	12.2	6.5	34.2	14.0	891.0	594.0	1070.0	698.0
Diversity	0.72	0.37	1.48	0.40	0.37	0.22	0.40	0.36
	May							
Mesofauna	9.3 **a**	7.5	4.2 **a**	0.9	8.7 **a**	5.7	8.4 **a**	5.5
Macrofauna	126.0 **a**	39.0	52.0 **b**	21.5	183.0 **a**	22.8	120.0 **a**	36.0
Oligochaeta	55.7 **a**	96.5	55.7 **a**	96.5	0.0 **a**	0.0	0.0 **a**	0.0
Total	191.0	52.5	112.0	78.1	191.0	28.5	128.0	37.0
Diversity	2.06	0.63	1.43	0.57	2.21	0.11	2.06	0.37

In a row under each sampling sites (field and bund), means followed by a common letter are not significantly different at the 5% level (ANOVA on log-transformed fauna data).

Early fallow. In the early fallow (one month after the field had been drained), soil fauna abundance and biomass tended to be higher in 4-m plots than in 8-m plots. In contrast, mesofauna abundance and biomass in the 8-m plots were more than double that in the 4-m plots, i.e., 3230 ind. m^{-2} (abundance) and 15.0 mg m^{-2} (biomass) in 8-m plots and 1330 ind. m^{-2} and 7.0 mg m^{-2} in 4-m plots (Table 3.11). Mesofauna reached the highest abundance and biomass in this phase, especially in the 8-m plots. On average, their abundance and biomass was more than four times that of the flooded phases (dry-seeded rice and transplanted rice) (Figure 3.7A). The most numerous taxa were Collembola (Isotomidae and Entomobryidae), and Acari, namely oribatid and spider mites, irrespective of bund distance.

After the macrofauna population had been suppressed during the rice field phases, they reached the highest number and biomass in the early fallow phase. Numbers and biomass were more than four times those observed during the rice field phases (Figure 3.8 B). Macrofauna numbers in 4-m plots were almost three times higher than those in 8-m plots, and their biomass was almost doubled (Table 3.11). Formicidae (ants) and Coleoptera were the most numerous taxa among the macrofauna in the 4-m plots. In the 8-m plots, Formicidae and Coleoptera also occurred, but their numbers were not as high as in the 4-m plots.

Table 3.11:. Average soil fauna abundance, biomass and diversity for two different bund distances (4m and 8m) in early fallow (soil depth of 0-15 cm).

	Abundance (Individual/m^2)				Biomass (mg/m^2)			
	4m		8m		4m		8m	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	June							
Mesofauna	1330 **a**	453	3230 **a**	1943	7.1 **a**	2.2	14.8 **a**	9.4
Macrofauna	816 **a**	1200	296 **a**	229	424.0 **a**	601.0	188.0 **a**	126.0
Oligochaeta	11 **a**	5	9 **a**	3	37.4 **a**	64.4	0.3 **a**	0.1
Total	2160	920	3530	2170	469.0	572.0	203.0	135.0
Diversity	1.90	0.42	1.95	0.20	1.66	0.28	1.95	0.39

In a row under each abundance and biomass, means followed by a common letter are not significantly different at the 5% level (ANOVA on log-transformed data).

As in the rice field periods, the Oligochaeta population in the dry phase did not exhibit any special pattern; however, their numbers and biomass in 4-m plots tended to be higher than in 8-m plots. During the early fallow, only enchytraeids occurred in the soil samples, whereas earthworms did not. Since enchytraeids are the small Oligochaeta with an average individual body weight approx. 0.03 mg, the biomass of the Oligochaeta was also low in this phase (Table 3.11).

Although the differences in soil fauna abundance and biomass between 4-m and 8-m plots were high in the early fallow, the Anova test on log-transformed fauna data showed no overall significant difference between these plots. The non-significant results may be caused by the high variance of the fauna data. Soil fauna abundance-based diversity in the early fallow period did not show any differences between 4-m plots and 8-m plots, but their biomass-based diversity was higher in 8-m plots (1.95) than in 4-m plots (1.66) (Table 3.11).

Crop-planted bund

During the rice phases, both in dry-seeded and transplanted rice, soil fauna abundance and biomass were significantly higher in the bunds than in the fields (Table 3.12). The higher number of soil fauna populations in the bunds was attributed to the aerobic soil condition in the bund, which is more appropriate for soil fauna than the anaerobic soil condition in the field. This section discusses whether crops planted on the bunds would affect the soil fauna population, and whether different crops would have different effects on soil fauna abundance and biomass. The study was conducted during the rice seasons (dry-seeded rice and transplanted rice) and early fallow, shortly after the field had been drained.

Dry-seeded rice. The average soil fauna abundance and biomass in plots without crops on the bund (control plots), plots with cassava planted on the bund (cassava plots) and plots with mungbean planted on the bund (mungbean plots) during the dry-seeded rice season is presented in Tables 3.13 and 3.14. The Anova test on log-transformed fauna data showed that the total soil fauna abundance and biomass was significantly higher in the bunds than in the fields (Table 3.12).

Table 3.12: Soil fauna abundance and biomass at two different sampling sites (field and bund) with different crop-planted bunds (ANOVA on log-transformed fauna data; F mean of field, B mean of bund, ns= non significant).

	Sampling Site (S)	**Crop-planted Bund (C)**
Dry-Seeded Rice		
Abundance	<0.01 B>F	ns
Biomass	<0.01 B>F	ns
Transplanted Rice		
Abundance	<0.01 B>F	ns
Biomass	<0.01 B>F	ns

Although crops (cassava and mungbean) cultivated on the bund did not significantly influence soil fauna abundance and biomass, in most months soil fauna abundance and biomass tended to be higher in plots with crops planted on the bund than in plots without (Tables 3.13 and 3.14).

Macrofauna and Oligochaeta dynamics did not exhibit a particular pattern; at some sampling dates macrofauna abundance and biomass were higher in control plots than in plots with crops on the bund. This is presumably due to the Coleoptera and Diptera larvae, which dominated the macrofauna population during the rice seasons and appeared to live equally well both in the field and in the bunds with and without crops. Oligochaeta occasionally occurred in the control, cassava and mungbean plots. However, when earthworms occurred in the samples, the Oligochaeta biomass made up approx. 90% of the total biomass as observed in November and December. In January, Oligochaeta only appeared in the mungbean plots with a very low number and biomass (Table 3.14).

The higher number and biomass of soil fauna on the crop-planted bund were accompanied by a higher soil fauna diversity on the bund compared to the field. The abundance-based diversity was higher in the control bund (1.83) than in the cassava bund (1.77) and the mungbean bund (1.57), whereas the biomass-based diversity indices were 0.91 (control bund), 1.02 (cassava bund), and 0.82 (mungbean bund). The most numerous taxa in the control bund were groups of collembolans, i.e., Sminthuridae and Isotomidae, whereas in the cassava bund, Sminthuridae and Hypogastruridae (Collembola) and a group of Acari, i.e., spider mites (Tetranychidae), dominated. In mungbean bunds, the most numerous animal groups were Collembola, i.e., Sminthuridae and Isotomidae. In terms of biomass, the dominant animals in the control bund were earthworms and ants, in the cassava bund earthworms, Coleoptera (adults and larvae) and ants, and in the mungbean bund adults and larvae of Diptera and Coleoptera.

Transplanted rice. Tables 3.15 and 3.16 show the average soil fauna abundance and biomass in plots without crop on the bund (control plots), plots with cassava planted on the bund (cassava plots) and plots with mungbean planted on the bund (mungbean plots) during the transplanted rice season. The soil fauna population in this subsystem indicated a pattern similar to the dry-seeded rice season, with total soil fauna abundance and biomass being significantly higher in the bunds than in the fields. Although the crops planted on the bund did not significantly influence the soil fauna population, there was a tendency of meso- and macrofauna abundance and biomass in cassava and mungbean bunds to be higher than that in the control bund, especially in April and May. This may indicate that bunds with cassava and mungbean are more favorable for soil fauna during the flooding of the field. As with dry-seeded rice, the Oligochaeta population did not indicate a particular pattern; they occurred occasionally in control, cassava and mungbean plots.

Soil fauna abundance-based diversity in all treatment plots was higher in the bund than in the field. Except for mungbean plots, animal biomass-based diversity was also higher in the bund than in the field. In the control bund, the most numerous soil fauna group were Collembola (Sminthuridae, Entomobryidae and Hypogastruridae). In bunds with crops, the dominant animal groups were found to be more diverse, i.e., Collembola (Sminthuridae, Entomobryidae and Hypogastruridae) and Acari (oribatid mites and spotted acari) in cassava bunds, and Collembola (Sminthuridae, Entomobryidae and Hypogastruridae), Acari, and Orthoptera in mungbean bunds. In terms of biomass, the dominant soil fauna groups in control bunds were earthworms, adults and larvae of Coleoptera and Diptera; in cassava bunds they were earthworms and larvae and adults of Coleoptera ; and in mungbean bunds they were Coleoptera and Formicidae.

Early fallow. Crops planted on the bund tended to influence the population of meso- and macrofauna in the early fallow (Table 3.17), an effect not observed during the rice field phases. The abundance and biomass of the mesofauna were higher in plots with crops planted on the bund than in the control plot. In mungbean plots, their abundance and biomass were approx. twice as high as in control plots (Figure 3.9A). Macrofauna abundance and biomass were also higher in plots with crops on the bund, especially in cassava plots (Figure 3.9B). However, due to the high standard deviation of the data, the Anova test on log-transformed fauna data showed no significant differences between the soil fauna population in the control plot and plots with cassava and mungbean on the bund.

As in the rice seasons, the Oligochaeta population dynamics did not exhibit any particular pattern. They occurred in all treatment plots of crop-planted bunds, but with a very low number and biomass. During the early fallow, only enchytraeids occurred in the soil samples, while earthworms did not. Since enchytraeids are small animals with a low body weight, the Oligochaeta biomass in this phase was also low (Figure 3.9C).

The soil animal taxa richness was higher in plots with crops on the bunds than in plots without crops. In control plots, the most numerous taxa were Collembola (Hypogastruridae and Entomobryidae), and Acari (Oribatid and spider mites). Plots with cassava on the bund were dominated by Collembola (Hypogastruridae and Entomobryidae), Acari (Oribatid and spider mites), and Formicidae (ants). Mungbean plots were dominated by Collembola (Hypogastruridae and Entomobryidae), Acari (Oribatid and spider mites), ants and Coleoptera.

The results indicate that although no significant differences existed between the soil fauna population in the control plots and in the plots with cassava and mungbean on the bunds, the increase in the mesofauna and macrofauna population after the flooding period was faster in plots with crop-planted bunds. The increase of soil fauna abundance and diversity in the terrestrial phase after the flooding period is important, because soil animals may intensify organic matter decomposition and nitrogen mineralization. The fallow period is therefore expected to be better able to enhance the productivity of the entire rainfed paddy production phase.

Table 3.13: The effect of crop-planted bunds on soil fauna abundance (Individual/m^2) and diversity in dry-seeded rice (soil depth 0-15 cm).

	Control				Cassava				Mungbean			
	Field		Bund		Field		Bund		Field		Bund	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	November											
Mesofauna	494	574	1090	261	207	158	1100	332	2330	2530	454	45
Macrofauna	207	293	76	73	48	34	64	56	32	1	24	11
Oligochaeta	4	6	8	11	163	231	4	6	0	0	4	6
Total	705	873	1170	346	418	355	1170	383	2360	2530	482	28
Diversity	0.85	0.31	1.58	0.25	1.42	0.20	1.34	0.12	0.87	0.62	1.72	0.25
	December											
Mesofauna	96	23	203	73	143	79	88	23	299	231	446	394
Macrofauna	28	6	12	6	8	11	32	0	8	11	20	28
Oligochaeta	24	23	4	6	4	6	12	6	0	0	4	6
Total	147	51	219	84	155	84	131	17	307	220	470	360
Diversity	2.09	0.01	1.94	0.04	1.68	0.41	2.12	0.06	1.11	0.88	1.35	0.76
	January											
Mesofauna	88	79	124	63	191	146	231	124	139	28	243	73
Macrofauna	12	6	28	17	4	6	16	11	72	101	48	45
Oligochaeta	0	0	0	0	0	0	0	0	0	0	8	11
Total	100	84	152	46	195	152	247	113	211	130	299	17
Diversity	1.53	0.20	2.0	0.12	1.48	0.18	1.86	0.42	1.43	0.26	1.66	0.19

Table 3.14**:** The effect of crop-planted bunds on soil fauna biomass (mg/m^2) and diversity in dry-seeded rice (soil depth 0-15 cm).

	Control				Cassava				Mungbean			
	Field		Bund		Field		Bund		Field		Bund	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	November											
Mesofauna	1.2	1.3	3.7	0.4	0.6	0.3	3.1	1.0	6.1	6.3	1.4	0.2
Macrofauna	164.0	232.0	48.7	42.9	28.0	11.9	48.0	45.5	9.8	13.0	17.1	14.2
Oligochaeta	0.1	0.2	167.0	237.0	1260.0	1780.0	0.1	0.2	0.0	0.0	0.1	0.2
Total	166.0	234	220.0	280.0	1290.0	1770.0	51.2	46.3	16.0	6.7	18.7	14.2
Diversity	0.51	0.25	1.20	0.45	0.49	0.57	1.60	0.15	1.02	0.42	1.16	0.56
	December											
Mesofauna	0.3	0.0	0.7	0.2	0.5	0.3	0.4	0.1	0.8	0.5	1.4	1.3
Macrofauna	19.8	6.2	8.9	3.6	3.5	4.9	19.8	5.5	4.3	6.0	12.8	18.0
Oligochaeta	418.0	355.0	83.6	118.0	83.6	118.0	251.0	118.0	0.0	0.0	83.6	118.0
Total	438.0	361.0	93.3	122.0	87.6	113.0	271.0	113.0	5.1	5.6	97.7	135.0
Diversity	0.30	0.13	0.37	0.08	0.24	0.33	0.35	0.23	0.72	0.27	0.70	0.16
	January											
Mesofauna	0.3	0.2	0.5	0.4	0.9	0.8	1.1	0.6	0.6	0.2	0.8	0.1
Macrofauna	4.4	0.6	22.7	17.5	1.8	2.5	12.2	12.1	55.9	79.1	21.6	19.3
Oligochaeta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.4
Total	4.7	4.8	23.3	17.1	2.7	3.3	13.3	11.5	56.5	79.2	22.7	19.6
Diversity	0.52	0.54	1.16	0.23	1.11	0.36	1.10	0.21	0.49	0.42	0.61	0.24

Table 3.15: The effect of crop-planted bunds on soil fauna abundance (Individual/m^2) and diversity in transplanted rice (soil depth 0-15 cm).

	Control				Cassava				Mungbean			
	Field		Bund		Field		Bund		Field		Bund	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	March											
Mesofauna	255	113	2130	1310	370	298	928	963	1200	1530	406	101
Macrofauna	32	11	207	203	32	23	127	135	68	96	56	0
Oligochaeta	0	0	8	11	4	6	0	0	0	0	0	0
Total	287	101	2350	1520	406	327	1060	1100	1270	1620	462	101
Diversity	1.69	0.65	1.07	0.08	1.93	0.36	2.04	0.04	1.35	0.15	1.89	0.01
	April											
Mesofauna	104	22	498	332	131	73	637	113	323	321	673	366
Macrofauna	32	34	68	6	48	45	151	34	28	6	88	68
Oligochaeta	0	0	56	45	0	0	24	0	0	0	44	17
Total	135	56	621	293	179	118	812	146	350	315	804	450
Diversity	2.00	0.30	2,27	0.01	2.09	0.01	2.18	0.23	1.89	0.03	1.81	0.41
	May											
Mesofauna	1350	766	597	79	677	214	1620	456	1110	124	1790	698
Macrofauna	179	174	195	73	131	17	326	23	255	11	263	68
Oligochaeta	4	6	0	0	4	6	0	0	0	0	0	0
Total	1540	935	792	6	812	191	1947	479	1360	113	2050	631
Diversity	2.11	0.16	2.68	0.18	2.28	0.41	2.19	0.27	2.29	0.29	2.18	0.63

Table 3.16: The effect of crop-planted bunds on soil fauna biomass (mg/m^2) and diversity in transplanted rice (soil depth 0-15 cm).

	Control				Cassava				Mungbean			
	Field		Bund		Field		Bund		Field		Bund	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	March											
Mesofauna	0.9	0.0	5.8	3.4	1.6	1.4	4.0	4.1	4.5	5.8	1.8	0.2
Macrofauna	12.6	1.3	101.0	105.0	12.3	3.3	73.7	81.8	35.9	50.8	32.8	13.9
Oligochaeta	0.0	0.0	167.0	237.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Total	13.6	1.3	274.0	338.0	14.0	2.0	77.6	77.7	40.5	45.0	34.7	14.1
Diversity	1.28	0.47	1.40	0.33	1.24	0.48	1.79	0.80	1.42	0.35	1.48	0.11
	April											
Mesofauna	0.5	0.1	2.6	1.9	7.2	9.7	3.9	1.0	1.3	1.3	4.9	2.8
Macrofauna	22.3	21.8	35.9	1.1	20.4	15.9	97.4	48.7	17.8	2.0	22.9	10.4
Oligochaeta	0.0	0.0	1170.0	946.0	0.0	0.0	502.0	0.0	0.0	0.0	1120.0	631.0
Total	22.8	21.7	1210.0	945.0	27.6	25.7	603.0	49.7	19.1	0.7	1140.0	623.0
Diversity	1.13	1.11	0.28	0.21	0.93	0.25	0.68	0.18	1.25	0.25	0.19	0.10
	May											
Mesofauna	10.0	9.3	2.9	0.9	3.5	2.5	10.1	4.1	6.7	4.1	12.6	2.4
Macrofauna	84.7	76.4	124.0	46.5	67.2	22.0	180.0	27.8	116.0	59.3	15.0	58.4
Oligochaeta	83.6	118.0	0.0	0.0	83.6	118.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	178.0	32.5	127.0	45.6	154.0	138.0	190.0	31.9	122.0	63.4	163	56.0
Diversity	1.51	1.04	2.68	0.18	1.59	0.33	2.19	0.27	2.13	0.62	2.18	0.63

Table 3.17: The effect of crop-planted bunds on soil animal abundance, biomass and diversity in early fallow (soil depth 0-15 cm).

	Control		Cassava		Mungbean	
	Mean	SD	Mean	SD	Mean	SD
	Abundance (Individual/m^2)					
Mesofauna	1470	525	2330	1930	3050	2610
Macrofauna	80	0	1240	1370	350	263
Oligochaeta	5	0	11	0	13	4
Total	1550	525	3580	567	3410	2870
Diversity	1.93	0.11	2.02	0.27	1.79	0.55
	Biomass (mg/m^2)					
Mesofauna	8.2	2.0	9.0	4.9	15.7	13.4
Macrofauna	53.9	2.0	660.0	647.0	205.0	145.0
Oligochaeta	0.2	0.0	0.3	0.0	56.1	78.8
Total	62.3	0.0	669.0	642.0	276.0	79.0
Diversity	1.74	0.34	1.81	0.50	1.87	0.44

Interaction between two main factors (bund distance and crop-planted bund) did not show any significant difference regarding soil fauna abundance and biomass, although the short bund distance with crop on the bund tended to have a higher soil fauna abundance and biomass compared to the longer-bund distance without crop on the bund. During the dry-seeded rice period, the short-bund distance with mungbean planted on the bund even significantly increased the macrofauna biomass (Table 3.18).

Table 3.18: The effect of bund distance and crops planted on the bund on macrofauna biomass during the dry-seeded rice season.

Crop-planted bund	Bund Distance	
	4m	8m
Control	0.71 a1	0.68 a1
Cassava	0.61 a1	0.52 a1
Mungbean	0.81 a1	0.29 a2

In a column, means followed by a common letter and in a row means followed by a common number are not significantly different at the 5% level by Duncan's Multiple Range Test (ANOVA on log-transformed data).

The short-bund distance, particularly with mungbean planted on the bund, seemed to provide favorable conditions for macrofauna. They could easily move to the bund when the conditions in the field became unfavorable (flooding) and mungbean on the bund presumably provided good litter for their consumption.

Resume

During the rice field phases, in general, meso-, macrofauna and Oligochaeta abundance and biomass in fields with a short bund distance (4m) did not significantly differ from those with a long bund distance (8m). Nevertheless, data indicate that their abundance and biomass tended to be higher in 4-m plots than 8-m plots. Approximately 60% of the individual results for the different months indicate that soil fauna abundance and biomass was higher in 4-m plots than 8-m plots. In November, macrofauna abundance and biomass in 4-m plots were even significantly higher, both in the field and in the bund. This is also supported by the results from March and May, when macrofauna abundance and biomass (only May) in the 4-m plots were significantly higher. In early fallow, with the exception of mesofauna, soil fauna abundance and biomass tended to be higher in 4-m than in 8-m plots.

In the dry-seeded rice period, soil fauna was more diverse in 4-m plots than in 8-m plots. In 4-m plots, Collembola, Diptera, Coleoptera, Enchytraeidea, and earthworms were dominant, whereas 8-m plots were mainly occupied by mesofauna, particularly Collembola. In transplanted rice fields, the soil fauna diversity in 4-m plots was equal to that of the 8-m plots and mainly contained Sminthuridae (Collembola) and oribatid mites. In terms of biomass, the larvae of Coleoptera and Diptera were the dominant groups both in 4-m and 8-m plots.

Although crops (cassava and mungbean) cultivated on the bund did not significantly influence soil fauna abundance and biomass, this tended to be higher in plots with crops planted on the bund than in plots without. In the dry-seeded rice period, in more than 60% of the sampled months, the mean soil fauna abundance and biomass were higher in plots with crops on the bund than in plots without. During the transplanted rice period, this was less frequently the case. The diversity of soil fauna taxa during the rice field phases was higher in bunds than in fields. Sminthuridae was the most numerous animal group in the bund, while in terms of biomass, larvae and adults of Coleoptera and Diptera were the dominant animal taxa. Interaction between bund distance and crop-planted bund only influenced the macrofauna. Here, biomass in the 4-m plots with mungbean planted on the bund was significantly increased.

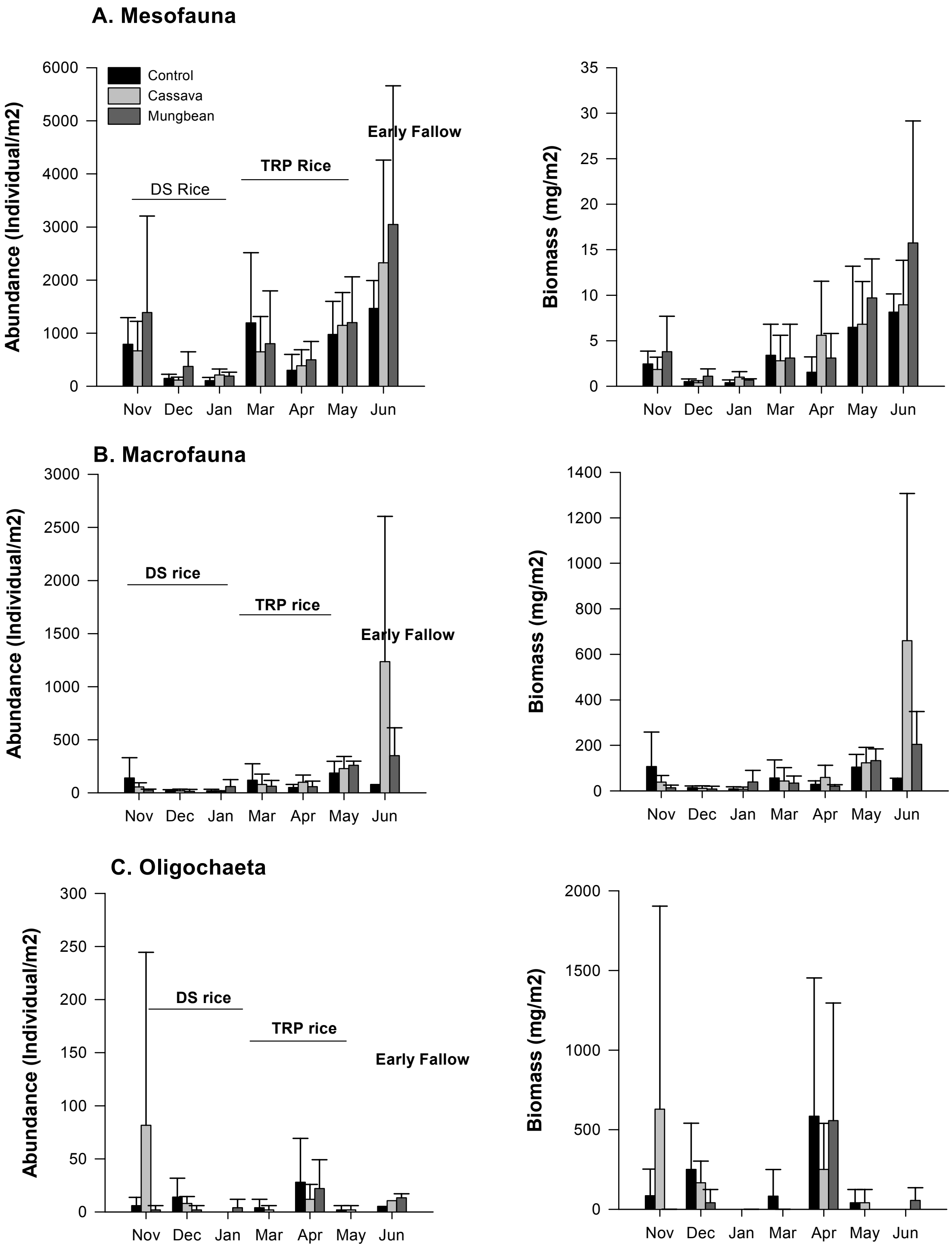


Figure 3.9: The effect of crop-planted bunds on soil animal abundance and biomass in dry-seeded rice (DS rice), transplanted rice (TRP rice) and early fallow (soil depth 0-15 cm)

3.3 Litter decomposition in the fallow and rice seasons

The role of soil fauna in rice straw litter decomposition was evaluated using different mesh-sized litterbags, i.e. coarse mesh (10 mm) permitting access of all organisms, medium mesh (0.25 mm) excluding macro-organisms, and fine mesh (0.038 mm) permitting access only of microorganisms. The enclosed rice-straw litter (7 g per bag) in the different litterbags was then buried at approximately 5 to 7 cm depth in the field of each treatment plot and retrieved after 30, 60 and 90 days of exposure, during the fallow and rice (dry-seeded rice and transplanted rice) periods, respectively.

3.3.1 Effects of mesh size on litter decomposition

On average, the rice straw litter-weight loss during the dry season (fallow) was low, especially in the medium-mesh litterbags. After 90 days of exposure in the field, the rice straw had lost 34%, 18% and 46% of the original weight from the coarse-, medium- and fine-mesh bags, respectively. The litter weight loss was significantly higher in the fine-mesh bags than in the medium- and coarse-mesh bags (Table 3.19). The higher litter-weight loss in fine-mesh bags, where only microorganisms were involved in the decomposition process was probably due to the more humid conditions in the bag. We suppose that enclosing litter in these bags created a condition more favorable for microorganisms than outside (however, moisture data are not available to confirm this idea). Also, during the dry season, the activity of microorganisms was presumably hampered by the hot and dry soil conditions in the better-aerated medium- and coarse-mesh bags, or the soil fauna may have moved to a deeper soil layer to avoid the heat, so that they could not play their role in the decomposition process on the soil surface.

During the rice seasons, the weight loss of rice-straw litter was faster than that during the fallow, especially in the coarse-mesh bags. In dry-seeded rice, after 90 days, approximately 65% of the original material had disappeared from the coarse-mesh bags, i.e. more than double that lost in the fallow. In the transplanted rice, the rice-straw litter-weight loss from all mesh sizes was faster by approx. 25% than that in the dry-seeded rice. Both in the dry-seeded rice and transplanted rice, the litter-weight losses from coarse-mesh litterbags were significantly higher than those from medium- and fine-mesh litterbags, particularly after 90 days (Table 3.19). The higher litter-weight loss in coarse-mesh bags indicates the importance of macrofauna in the decomposition process.

Thus, the macrofauna seemed to enhance litter decomposition during the rice seasons. After the fallow, when the meso- and macrofauna presumably stayed deeper underground, they may have moved up in the rainy season when environmental factors such as temperature and moisture became favorable.

Table 3.19: Remaining weight of rice-straw litter (% of initial weight) with litterbags of different mesh sizes after 30, 60 and 90 days of exposure time during the fallow, dry-seeded rice and transplanted rice.

Mesh size	**Exposure Times (Day)**		
	30	**60**	**90**
Fallow			
Coarse	97.5 **b1**	85.7 **ab2**	66.0 **b3**
Medium	105.9 **a1**	93.0 **a2**	81.5 **a3**
Fine	89.8 **b1**	79.1 **b2**	53.5 **c3**
Dry-Seeded Rice			
Coarse	57.6 **c1**	37.2 **c2**	35.6 **c2**
Medium	69.0 **b1**	50.5 **b2**	46.2 **b3**
Fine	73.3 **a1**	56.6 **a2**	52.2 **a3**
Transplanted Rice			
Coarse	52.4 **a1**	34.6 **b2**	25.9 **b3**
Medium	54.9 **a1**	43.9 **a2**	39.2 **a3**
Fine	54.2 **a1**	43.2 **a2**	38.4 **a3**

For each season in a column, means followed by a common letter and in a row, and means followed by a common number are not significantly different at the 5% level by Duncan's Multiple Range Test.

During the fallow, the decomposition rate was faster in fine-mesh bags than in medium- and coarse-mesh bags (Figure 3.10). In fine-mesh bags, the time needed for 50% loss of the initial litter dry weight (t_{50}) was 167 days, less than half the time needed in medium mesh-bags (435 days). The t_{50} in coarse-mesh bags was intermediate (238 days) between fine-mesh and medium-mesh bags. In contrast, the decomposition rates (calculated by a negative exponential regression, Anderson and Ingram 1993) in the rice seasons were faster in coarse-mesh bags than in medium- and fine-mesh bags. The t_{50} in coarse-mesh litterbags ranged between 54 days and 83 days, while t_{50} in medium-mesh litterbags ranged from 88 days to 124 days and from 69 days to 135 days in fine-mesh litterbags. In all treatment plots, decomposition rates in coarse-mesh litterbags were about 50% higher than the rates in fine-mesh litterbags. Decomposition rates in medium-mesh bags were intermediate. The high decomposition rates in the coarse-mesh litterbags and the lower rates in medium- and fine-mesh litterbags indicate that macrofauna played an important role in the decomposition process.

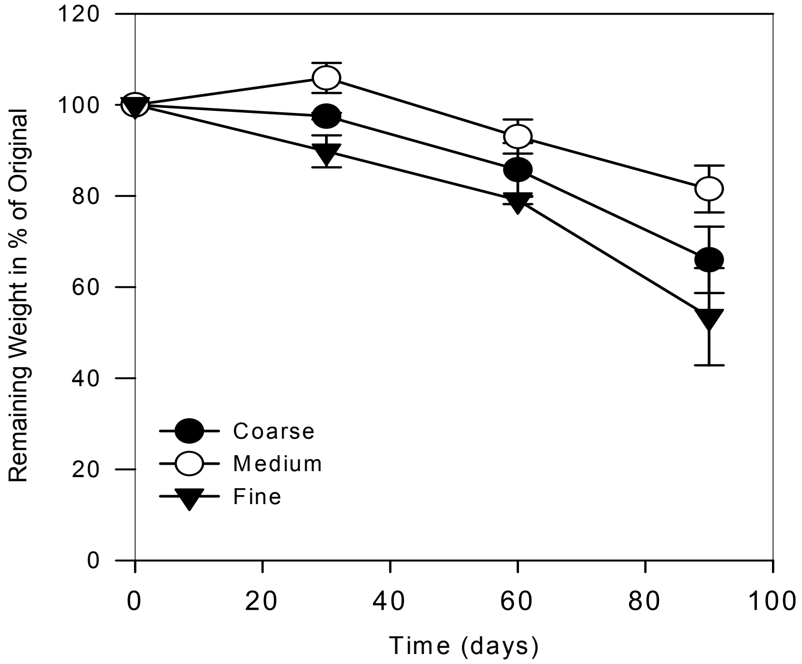


Figure 3.10: Pattern of weight loss of rice straw from three different mesh-sized litterbags calculated as percentage of remaining ash-free dry weight during the fallow period.

In the rice seasons, the litter weight loss was generally more pronounced during the first 30 days, particularly in coarse-mesh litterbags, with about 40% to 45% of the original material disappearing from the litterbags. In medium- and fine-mesh litterbags, the initial weight loss was lower than in coarse mesh bags, i.e. about 30% of the original weight. After 60 and 90 days exposure in the field, the weight loss became slower (Figure 3.11 and 3.12). The rapid initial litter-weight loss in the coarse-mesh litterbags was presumably due to the fragmentation of the litter into small particles by the soil fauna, and by leaching of water-soluble component through rainfall. Also, small fragments of litter may have been lost from the bags.

3.3.2 Effects of different bund distances and crop-planted bunds in litter decomposition

In the rice seasons, the effect of different bund distances (4m and 8m) and crop-planted bund (control, cassava and mungbean) on the rice-straw litter decomposition in the field was evaluated using different mesh-sized litterbags. Both in the 4m- and 8-m plots, the litter-weight loss from coarse-mesh bags was significantly higher than that from medium- and fine-mesh litterbags (Table 3.20). This indicates the important role of macrofauna in litter decomposition. During dry-seeded rice, on average, the different bund distances did not influence soil fauna; their activity was equally high both in the 4-m and 8-m plots. In contrast, when the macrofauna activity was restricted in fine-mesh bags, the litter-weight loss was significantly higher in the 4-m plots than in the 8-m plots (Table 3.20). In other words, microbial decay of the rice straw was positively affected by the 4-m bund distance treatment.

During the transplanted rice, the effect of different bund distances on litter decomposition was particularly clear in medium- and fine-mesh bags, when the litter-weight loss in the 4-m plots was significantly higher than in the 8-m plots. In coarse-mesh bags the difference was insignificant (Table 3.20). The higher litter-weight loss in 4-m plots indicates that these plots might have a better soil fauna population than the 8-m plots during the transplanted rice phase. In fact, the soil fauna population tended to be higher in 4-m plots than in 8-m plots, both in the field and in the bund during this phase (see Section 3.2.2).

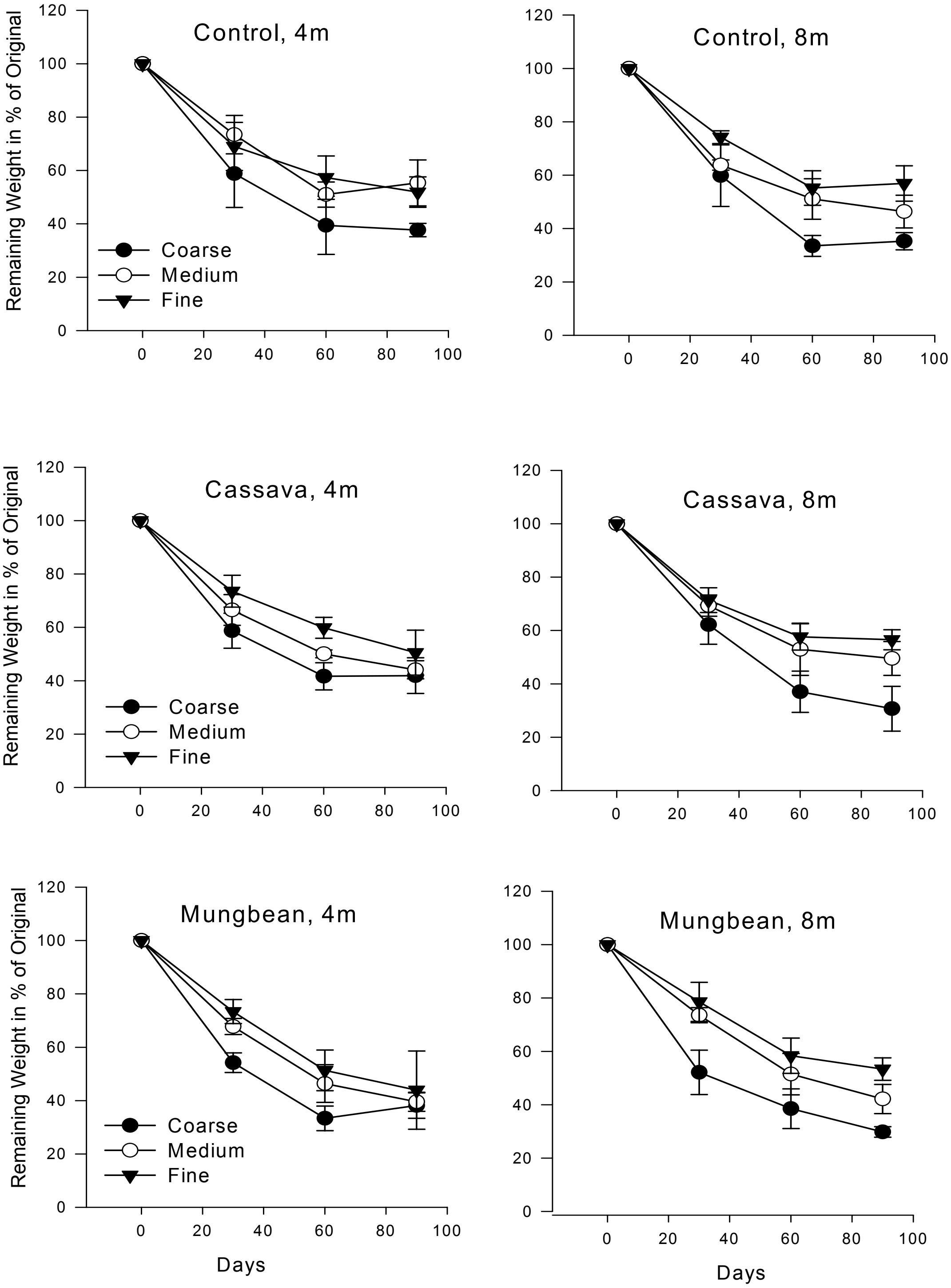


Figure 3.11: Patterns of weight loss of rice-straw litter from litterbags of different mesh-sizes exposed to different treatment plots in the dry-seeded rice season.

Table 3.20: Anova of the litter-weight loss calculated as percentage remaining ash-free dry weight in the treatment plots of 4-m and 8-m bund distance in the dry-seeded rice and transplanted rice.

Mesh Sizes	Bund Distance	
	4m	8m
Dry-Seeded Rice		
Coarse	44.8 **c1**	42.1 **c1**
Medium	54.8 **b1**	55.6 **b1**
Fine	59.0 **a1**	62.4 **a2**
Transplanted Rice		
Coarse	36.5 **b1**	38.8 **b1**
Medium	43.8 **a1**	48.3 **a2**
Fine	43.7 **a1**	46.7 **a2**

For each season, in a column, means followed by a common letter and in a row, means followed by a common number are not significantly different at the 5% level by Duncan's Multiple Range Test.

Crops cultivated on the bunds enhanced the soil-fauna activity and thus the litter decomposition in the field during the dry-seeded rice seasons. When the whole decomposer community participated in the decomposition process (coarse-mesh bags), the litter-weight loss in plots with mungbean planted on the bunds was significantly higher than in control and cassava plots (Table 3.21). This corresponds with the soil fauna population, which had a tendency to be higher in plots with crops (cassava and mungbean) on the bund, both in the field and the bund than in control plots (see Section 3.2.3). Mungbean-cultivated bunds presumably offered a better protection for soil fauna living on the bunds through their leaves, which shaded the soil surface from direct sunshine. Maybe the mungbeans also provided the better litter for soil fauna consumption. In the transplanted rice, in general, crops cultivated on the bund did not influence the litter decomposition in coarse- and fine-mesh bags, whereas in the medium-mesh bags, the litter-weight loss in the mungbean plots was significantly slower than in the cassava or control plots (Table 3.21).

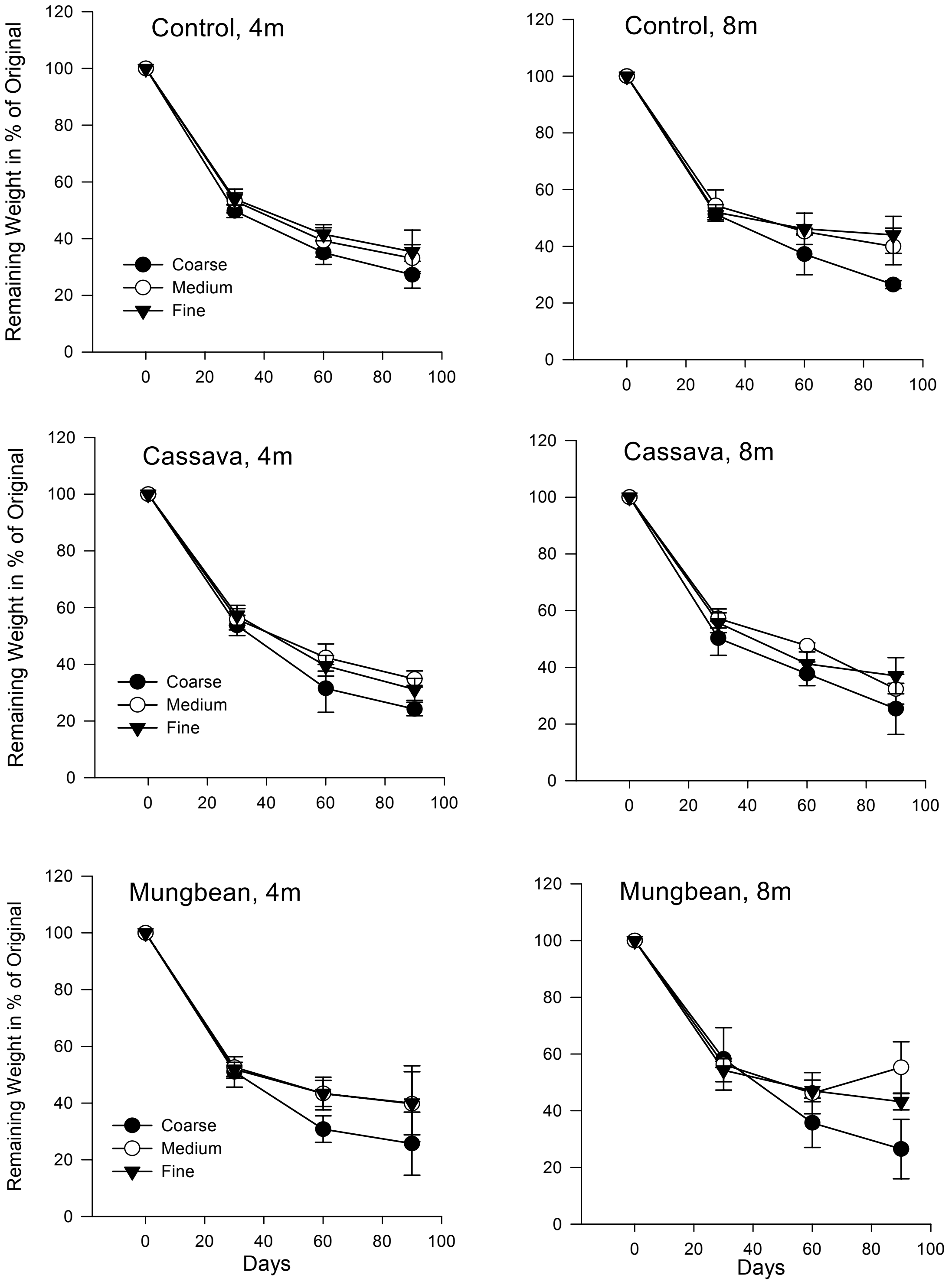


Figure 3.12: Patterns of weight loss of rice straw litter from litterbags of different mesh-sizes exposed to different treatment plots in transplanted rice season.

Table 3.21: Anova of the litter-weight loss calculated as percentage remaining ash-free dry weight in the treatment plots of control, cassava- and mungbean-planted bunds, during the dry-seeded rice.

Mesh Sizes	**Crop-planted bund**		
	Control	**Cassava**	**Mungbean**
Dry-Seeded Rice			
Coarse	44.1 **c2**	45.3 **c2**	41.0 **c1**
Medium	56.8 **b1**	55.4 **b1**	53.4 **b1**
Fine	60.7 **a1**	61.5 **a1**	59.8 **a1**
Transplanted Rice			
Coarse	37.8 **b1**	37.1 **b1**	37.9 **b1**
Medium	44.2 **a1**	45.0 **a1**	48.9 **a2**
Fine	45.5 **a1**	43.6 **a1**	46.5 **a1**

For each season, in a column, means followed by a common letter and in a row, means followed by a common number are not significantly different at the 5% level by Duncan's Multiple Range Test.

In the dry-seeded rice, the different bund distances did not influence the litter decomposition in the plots with cassava on the bund or in the control plots (Table 3.22). However, litter decomposition (litter weight loss) in the short-bund distance (4m) was most marked when the bunds were cultivated with mungbean. This coincides with the macrofauna population, whose biomass was significantly higher in the 4-m plots with mungbean on the bund than in control and cassava plots (Table 3.18).

During the transplanted rice, the litter-weight loss did not differ among control, cassava and mungbean plots in the 4-m plots, whereas in the 8-m plots, the litter-weight loss in the mungbean plots was slower than in the control- and cassava-plots. The effect of the 4-m bund distance was more clearly shown in plots with mungbean on the bund and in control plots (Table 3.22). With the exception of the control plots, the higher litter decomposition in the 4-m plots with mungbean on the bund corresponds with the litter-decomposition results during the dry-seeded rice, again indicating that the short bund distance, particularly with mungbean planted on the bund, was able to enhance the soil fauna population living both in the field and in the bund and thus their role in the decomposition process.

Table 3.22:. Anova of the litter-weight loss calculated as percentage remaining ash-free dry weight in the different bund distance and crop-planted bund during the dry-seeded rice and transplanted rice.

Crop-planted bund	Bund Distance	
	4m	**8m**
Dry-Seeded Rice		
Control	54.8 **a1**	52.9 **a1**
Cassava	54.1 **a1**	54.1 **a1**
Mungbean	49.7 **b1**	53.1 **a2**
Transplanted Rice		
Control	40.9 **a1**	44.1 **b2**
Cassava	41.2 **a1**	42.7 **b1**
Mungbean	42.0 **a1**	47.0 **a2**

For each season, in a column, means followed by a common letter and in a row, means followed by a common number are not significantly different at the 5% level by Duncan's Multiple Range Test.

Resume

In general, the rice-straw litter-weight loss during the dry season was lower compared to that in the flooded rice period (dry-seeded rice and transplanted rice). After 90 days of fallow, approx. 34%, 18% and 46% of the original weight had disappeared from coarse-, medium- and fine-mesh bags, respectively. In dry-seeded rice, the litter-weight losses from coarse-, medium- and fine-mesh bags were 65%, 54%, 48% of the original weight, respectively. Only for the coarse and medium mesh-size was this two- and three-fold higher compared to that in the dry season. The litter-weight losses from coarse-, medium- and fine-mesh bags in the transplanted rice were 74%, 61% and 62% of the original material, respectively, or higher compared to that in the dry season for all litterbags.

In dry-seeded rice, the synergistic effect of short bund distance and crops cultivated on the bund was clearly shown. In the 4-m plots with mungbean planted on the bund, the litter decomposition was highest, coinciding with the macrofauna biomass, which was highest in the 4-m plots with mungbean on the bund. Similar results were obtained during the transplanted rice season, in which the litter decomposition was significantly higher in the 4-m plots, particularly with mungbean planted on the bund. This result corresponds with the soil fauna, with abundance and biomass higher in the 4-m plots with crops on the bunds than in the 8-m plots without crops on the bund.

3.4 Nitrogen mineralization in rainfed paddy fields: relationship with soil fauna

3.4.1 Nitrogen mineralization in fallow and rice fields

In general, net nitrogen (N) mineralization during the fallow period was slower than during the rice field period (Table 3.23). The average nitrogen mineralization during the fallow (the soil samples were taken from 8 randomized points) was 76 kg N/ha. The lower N mineralization was presumably due to the dry soil condition and suppressed soil fauna (see Section 3.2). Verhoef and Brussaard (1990) reported on the importance of soil fauna, which they held responsible for about 30% of total net nitrogen mineralization in forest and grassland ecosystems. During the fallow period, the monthly rainfall ranged between 0 to 79 mm (Figure 3.1), while the temperature reached the highest level, ranging from 32.0 to 36.6 ^{o}C (Figure 3.2). Crops cannot grow under this condition, and soil processes, such as mineralization are also inhibited.

Table 3.23: Mean nitrogen mineralization (n=4) in kg per hectare in the different treatment plots during fallow and rice seasons.

Treatment Plots	**Fallow ^{a})**		**Dry-Seeded Rice**		**Transplanted Rice**		**Early Fallow**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Control, 4m	76	10	141	16	106	25	79	13
Cassava, 4m			192	19	101	26	65	13
Mungbean, 4m			87	18	100	8	76	27
Control, 8m			76	19	96	7	57	11
Cassava, 8m			86	9	74	12	49	20
Mungbean, 8m			65	24	79	12	60	24

^{a}) No treatment plots during fallow period; soil samples were taken from 8 randomized points.

When the field was flooded in the rice seasons (dry-seeded rice and transplanted rice), N mineralization was stimulated. In dry-seeded rice, particularly in plots with 4-m bund distance, N mineralization was almost double that observed in the fallow period (140 kg N/ha). This mineralization rate is relatively high compared to other studies. The N mineralization capacity of some paddy soils in China, for example, ranges between 8-160 kg N/ha and averages 80 kg N/ha (Zhu *et al.* 1984). In transplanted rice, the nitrogen mineralization was still high, especially in plots with 4-m bund distance (Table

3.23). When the flooded fields dried in early fallow (June), the nitrogen mineralization significantly decreased by approx. 30% (Table 3.24).

Table 3.24: ANOVA of nitrogen mineralization (kg/ha) in dry-seeded rice, transplanted rice and early fallow.

Seasons	**Means**
Dry-Seeded Rice	108.03 b
Transplanted Rice	92.49 b
Early Fallow	64.29 a

Means followed by a common letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

The decrease in net nitrogen mineralization in the early fallow, shortly after the field had been drained, was opposite to what one would expect. The net mineralization of nitrogen under upland conditions is expected to increase because the soil then turns from anaerobic to aerobic conditions. Under aerobic conditions, the oxygen needed to decompose the organic matter used by aerobic bacteria as their terminal electron acceptor to convert organic molecules to carbon dioxide and ammonia to nitrate is available. Since oxygen is the most effective oxidizing agent, the decomposition under aerobic conditions is more efficient than in an anaerobic environment (Erickson and Tyler 2000).

The soil incubation method (PVC tubes; Chapter 2: Materials and Methods) could be one reason for the N-mineralization increase in the rice season. During the exposure time, the upper part of the PVC tubes was kept open, which allowed water to enter the tubes during flooding, which stimulated anaerobic conditions in the tubes. Thus, decomposition of organic matter was suppressed, so that mineralizable nitrogen was accumulated in the incubation tubes. When, upon extraction of the tubes, the soil slowly desiccated, conditions changed from anaerobic to aerobic, and this could have positively influenced nitrogen mineralization. However, we assume this error to be small.

We therefore attribute the high nitrogen mineralization in the field during the rice phases to microorganisms that were stimulated by the improved physical environmental conditions, such as the higher soil moisture and lower air temperatures than those in the fallow period. Such conditions are essential for most microorganisms and other soil fauna, which are the real mineralizers (Kolberg *et al*. 1999, Swift 1995).

3.4.2 The effect of bund distance and crop-planted bund on net nitrogen mineralization

In all seasons, the 4-m bund distance seemed to exert a positive effect on nitrogen mineralization. In dry-seeded rice, the 4-m bund distance significantly increased the nitrogen mineralization in the field compared to the 8-m bund distance. In transplanted rice and early fallow, the higher N-mineralization in the 4-m plots was not significantly different (Figure 3.13). The higher net nitrogen mineralization with 4-m bund distance, especially in dry-seeded rice, corresponds to the higher soil fauna population, particularly of macrofauna in the 4-m plots (see Section 3.2.2). Since interactions of soil fauna with microorganisms may influence the mineralization processes (Lavelle and Spain 2001), the density of soil fauna will also determine the rate of mineralization.

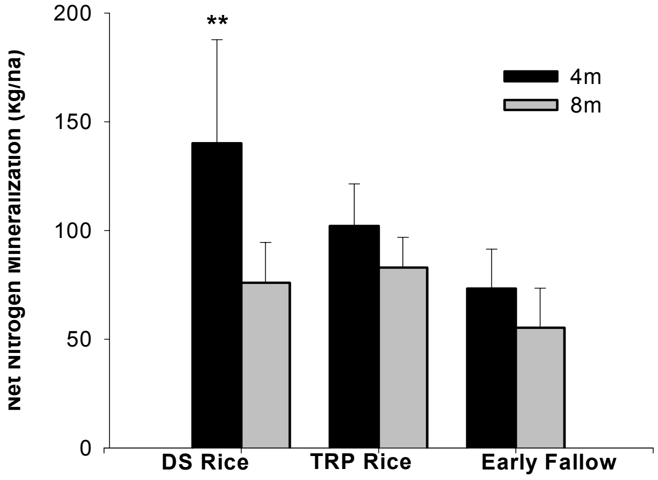


Figure 3.13: Nitrogen mineralization in plots with bund distance of 4m and 8m, during dry-seeded rice (DS Rice), transplanted rice (TRP Rice) and early fallow. Under each season, bars marked ** mean significant at the 5% level by LSD.

Crops planted on the bund significantly enhanced the N-mineralization only in dry-seeded rice. Here, cassava planted on the bund significantly increased the net nitrogen mineralization. In transplanted rice and early fallow, the nitrogen mineralization was not significantly influenced by different crops cultivated on the bunds (Figure 3.14).

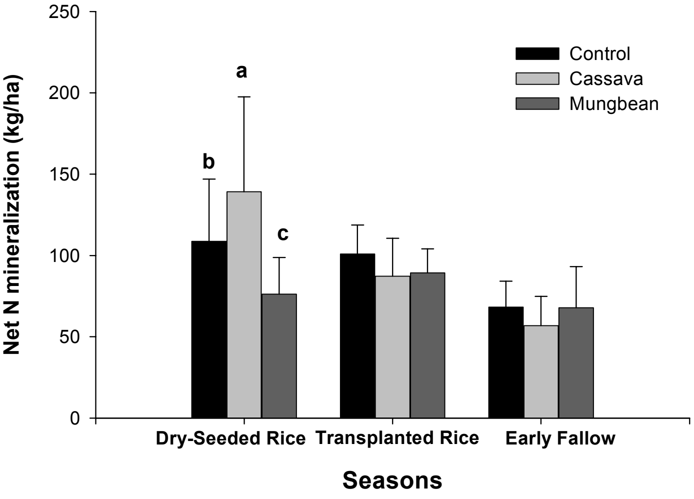


Figure 3.14: Nitrogen mineralization in plots with crop-planted bunds (control, cassava and mungbean) during dry-seeded rice, transplanted rice and early fallow. Bars marked a,b,c, are significantly different at the 5% level by Duncan's Multiple Range Test.

In the dry-seeded rice season, the effect of crop-planting of bunds on N mineralization was shown only in the plots with a short bund distance (4m), whereas planting did not change the mineralization rate in those with the wider bund distance (8m) (Table 3.25). The effect of short bund distance on the N mineralization was most marked when the bunds were cultivated with cassava (N mineralization = 192 kg N/ha), suggesting that the narrow bund distance with cassava on the bund provided a better condition for soil fauna living both in the field and in the bund, so that their abundance and biomass could be enhanced (see Section 3.2.2). Enhancement of the soil fauna population can increase the litter decomposition and nitrogen mineralization (Carcamo *et al*. 2001).

In the transplanted rice season, no effect of crop-planting of bunds on N mineralization was observed, neither in the 4-m plots nor in the 8-m plots. However, as in the dry-seeded rice, a combined effect of short bund distance and crop-planted bund was observed in the 4-m plots with cassava planted on the bund. The N mineralization in the 4-m plots was significantly higher than that in the 8-m plots. In early fallow, differences in N mineralization between the treatment plots were no longer observed. This is presumably due to the fact that in the early fallow the bunds were destroyed, so that bund distance and crop-planting of bunds had no effect on N mineralization.

Table 3.25**:** ANOVA of nitrogen mineralization (kg/ha) in treatment plots of crop-planted bund and bund distances during dry-seeded rice, transplanted rice and early fallow.

Crops	**Bund Distances**	
	4m	**8m**
Dry-Seeded Rice		
Control	141 b1	76 a2
Cassava	192 a1	86 a2
Mungbean	87 c1	65 a1
Transplanted Rice		
Control	106 a1	96 a1
Cassava	101 a1	74 a2
Mungbean	100 a1	79 a1
Early Fallow		
Control	79 a1	57 a1
Cassava	65 a1	49 a1
Mungbean	76 a1	60 a1

For each season, in a column, means followed by a common letter and in a row means followed by a common number are not significantly different at the 5% level by Duncan's Multiple Range Test.

3.4.3 Nitrifiers and denitrifiers

In general, the nitrifier population during the fallow period was high, reflecting the high rate of nitrification that occurred under the aerobic conditions (Table 3.26). Although the field was flooded during the dry-seeded rice season, and the soil conditions changed from aerobic to anaerobic, the nitrifier population remained high, consistent with the N mineralization observed. However, during the transplanted rice season, the nitrifier population drastically decreased to approx. 1.3 x 10^5 cfu/g soil, whereas N mineralization remained high (Table 3.24). Possibly, an aerobic soil surface layer or rhizosphere-fed oxygen through the rice aerenchym provided sites where nitrification continued to take place.

Table 3.26: Population of nitrifiers and denitrifiers as most probable number (MPN) in different treatment plots during fallow, dry-seeded rice (DS Rice), transplanted rice (TRP Rice) and early fallow.

Treatment Plots	**Fallow[a)]**	**DS Rice**	**TRP. Rice**	**Early Fallow**
Nitrifiers (10^5 cfu /g soil)				
Control, 4m	98	136.4	1.0	6.9
Cassava, 4m		143.1	1.0	3.3
Mungbean, 4m		135.3	1.6	12.6
Control, 8m		71.7	1.8	13.8
Cassava, 8m		37.9	1.5	7.5
Mungbean, 8m		76.2	0.7	3.0
Denitrifiers (10^5 cfu /g soil)				
Control, 4m	1.8	0.5	0.7	0.1
Cassava, 4m		0.2	0.2	0.1
Mungbean, 4m		0.3	7.9	0.2
Control, 8m		0.3	8.2	1.4
Cassava, 8m		0.3	5.7	0.7
Mungbean, 8m		0.5	7.4	0.4

[a)] No treatment plots during fallow subsystem; soil samples were taken from 6 randomized points.

The population of denitrifiers stayed low in the dry-seeded season, suggesting a slow reduction of the soil despite flooding. The effect of flooding on the denitrifier population was evident in the transplanted rice season, when their population clearly increased. The increase in denitrifiers is presumably because they are the group of facultative anaerobic microorganisms that are engaged in reduction of nitrate (NO_3^-) to nitrogen gas or to organic nitrogen compounds when O_2 is limited under anaerobic conditions (Geng 2000; Schimel and Gulledge 1998). The high amount of nitrate produced by nitrifiers during the dry-seeded rice could also stimulate the denitrifier population in transplanted rice, since denitrifiers utilize nitrate as the terminal electron acceptor in converting nitrate to nitrogen gas or to organic compounds (Potter 2001).

After the field desiccated in early fallow, the population of nitrifiers slightly increased, conversely, the population of denitrifiers declined and as a consequence the rate of denitrification was low (Aulakh *et al*. 2000). This was probably due to the soil then returning from anaerobic to aerobic conditions. In general, the bund distance (4m and 8m) and crop planting on the bund (control, cassava and mungbean) did not influence the population of nitrifiers and denitrifiers. Their populations in the field plots were almost always the same, except for the nitrifier population in dry-seeded rice.

Here, their population in 4-m plots was higher than in 8-m plots, as expected from the N mineralization in 4-m plots.

Resume

Nitrogen mineralization during the fallow period was lower than that during rice growth, both in dry-seeded rice and transplanted rice. After the field had been drained, in early fallow the nitrogen mineralization again was significantly lower than in the rice field seasons. The plot with 4-m bund distance showed a positive effect on nitrogen mineralization, particularly in dry-seeded rice. Crops planted on the bund influenced nitrogen mineralization only in dry-seeded rice, with the N mineralization in the cassava plot significantly higher than that in control and mungbean plots.

In the dry-seeded rice season, the combined effect of bund distance and crop-planted bund on N mineralization was very marked in the 4-m plots with cassava planted on the bund. Here, nitrogen mineralization was significantly higher than in other treatments. In transplanted rice, the higher N-mineralization in 4-m plots also was particularly pronounced in the cassava plots. In general, the nitrifier population was high in dry-seeded rice, in accordance with the N mineralization. However, the nitrifier population drastically declined in transplanted rice, which was not in line with N mineralization.

4 GENERAL DISCUSSION AND CONCLUSIONS

4.1 Screening of soil fauna in different ecosystems in the study area

Land use can alter soil conditions and the soil community of meso- and macro-organisms (Lavelle *et al.* 1997; UNEP 2001). For example, in the ecosystem comparison, the teak forest and home garden had a higher soil fauna abundance and biomass than the fallow paddy field. The teak forest and home garden had also a greater soil fauna variety, with at least three taxa dominating the soil fauna biomass in the teak forest, namely ants, termites and earthworms. Ants were also a dominant group in the home garden, whereas termites and earthworms did not occur in the soil samples of the fallow paddy field.

Poor vegetation cover and lack of plant litter covering the soil surface tend to reduce the abundance of soil fauna in the fallow paddy field, whereas some crops, like cassava, papaya and sweet potatoes, still found in the home garden during the dry season, protected the soil surface from direct sunshine. Likewise, in the teak forest, teak trees, shrubs and grasses as well as litter on the forest floor shaded the soil surface from direct sun and maintained soil moisture. This condition presumably provided a more favorable habitat for soil fauna (Saetre *et al.* 1999), and accounted for the higher numbers of their population and diversity in the home garden and teak forest than in the fallow paddy field. Thus, vegetation cover appears important to maintain soil moisture and soil living-organisms.

The screening confirmed the data from soil fauna studies in other regions: management of the rainfed paddy field should mimic the structure of the teak forest and home garden, possibly through cultivation of the bunds with crops to provide a safe haven for the soil fauna population and promote their activity, as rice fields are inhospitable for soil fauna. Besides providing a good litter for soil fauna consumption, planting crops such as legumes along the bund could conserve soil moisture. These plants not only do not compete with the rice crop (Eagleton *et al.* 1991), but they also provide additional food (or income) to the farmers.

4.2 Soil fauna population dynamics in rainfed paddy ecosystem

The dynamics of soil fauna in the rainfed paddy field appeared to fluctuate following the seasonal changes. During the dry season or fallow period, the soil fauna population decreased from August to October and stayed low during the flooded periods, when the rainfall was high at around 200-300 mm per month. In May, when rainfall started to decrease, the soil fauna abundance increased and reached its peak in June, one month after the field had been drained (Figure 4.1).

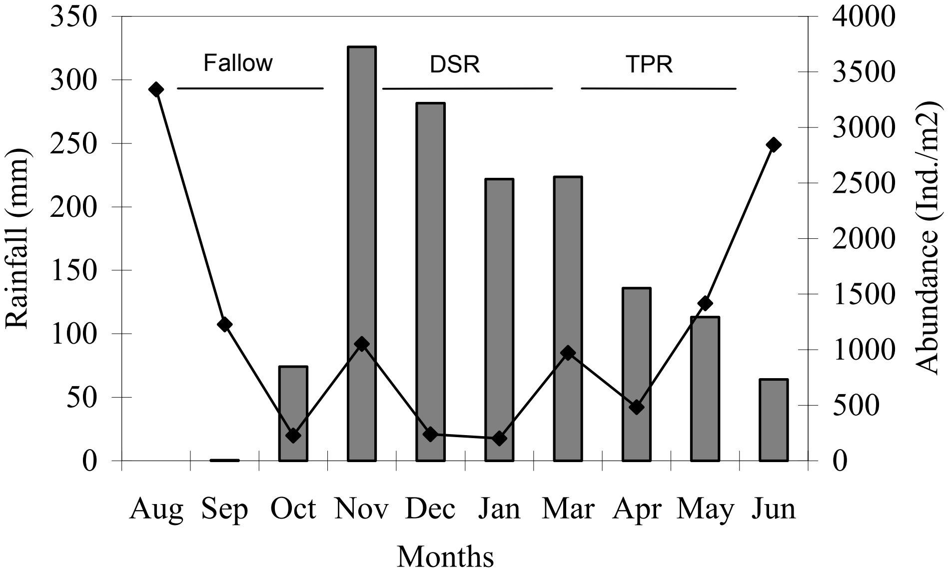


Figure 4.1: Soil Fauna abundance and rainfall pattern during fallow, dry-seeded rice (DSR), transplanted rice (TPR) and early fallow (Jun) (Lines = Abundance; Bars = Rainfall).

The soil fauna biomass exhibited a pattern similar to that of the abundance, except in April, when the soil fauna biomass reached the highest value due to earthworms in the samples (Figure 4.2). The results also indicate that the temporary drainage of rice fields and land preparation prior to the new cropping season are important, since the soil fauna population consistently increased at the onset of each new cropping season, i.e. in November and March (Figure 4.1). This boost in soil fauna population may in part be due to the effect of land preparation, as the land was drained, hoed and turned over before planting, thus aerating the soil. In addition, in transplanted rice, the remaining rice straw from the previous cropping was used as an organic input. Both, better soil aeration and organic input, probably accounted for the increase in the soil fauna population at the beginning of each cropping system. Incorporating remaining rice straw into the soil is also important since it returns most of the nutrients and helps to conserve soil nutrient reserves in the long-term (Dobermann and Fairhurst 2002). Additionally, the temporary drainage of rice fields has an additional benefit, since it can reduce water consumption and methane emissions (Wassmann 2002).

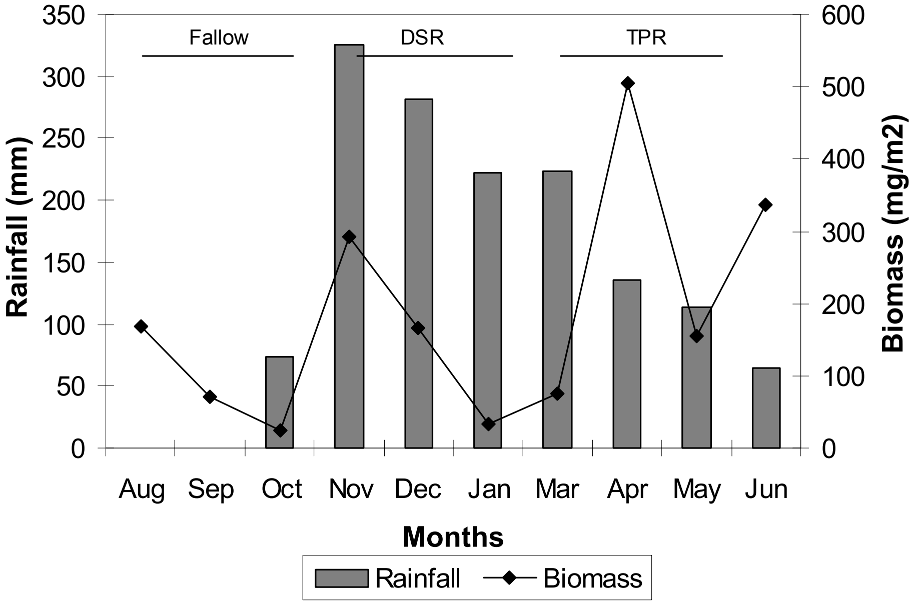


Figure 4.2: Soil fauna biomass and rainfall pattern during fallow, dry-seeded rice (DSR), transplanted rice (TPR) and early fallow (Jun).

Collembola and Acari were the most numerous taxa in the rainfed paddy field, as they always occurred under both fallow and flooded conditions. However, Acari seem to be more tolerant of the dry conditions than Collembola, as they occurred in high numbers during the fallow period. According to Lavelle and Spain (2001), the resistance of Acari to water and temperature stress is high; they can withstand desiccation up to –6.0 Mpa (pF 5). This may have influenced their population densities during the dry and hot seasons. In terms of biomass, Coleoptera was the most dominant taxa group in the dry fallow phase. However, their larvae together with Diptera larvae were the most dominant taxa under flooded conditions. These results corroborate the findings of the ecosystem screening, in which Coleoptera was found to be the dominant soil fauna biomass in the fallow paddy field. The presence of Acari, Collembola, Coleoptera and the larvae of Coleoptera and Diptera, both under flooded and non-flooded conditions was important, since most of them are important decomposers (Raw 1967; Borror *et al.* 1989; Daly *et al.* 1998 and Lavelle and Spain 2001). In Amazon forest ecosystems, the decomposers dominated the Coleoptera population, attaining 62% of the total number of families, followed by predators (13%) and herbivores (2%) (Hanagarth and Brändle 2001). Thus, it is expected that they can play an important role in the soil processes in rainfed paddy fields, as their activity is critical to the maintenance of a favorable soil structure and mineral cycling (Lal 1995).

4.3 Effect of bund distance and crop-planted bund on soil fauna, litter decomposition and nitrogen mineralization

4.3.1 Soil fauna population

During the rice phases (dry-seeded rice and transplanted rice), plots with a short bund distance (4m) tended to have a higher soil fauna abundance, biomass and diversity, both in the field and in the bund, than the 8-m plots. The larger soil fauna population in the 4-m plots was more pronounced when the bunds were cultivated with crops, such as mungbean. In the 4-m mungbean-plot, the macrofauna biomass showed the greatest increase during the dry-seeded rice period. Coleoptera larvae and the bigger animals, such as earthworms, occurred in the field and in the bund of this plot**,** contributing to the high macrofauna biomass. In the 4-m plots, the soil fauna, particularly macrofauna, could presumably easily escape to the bunds when the conditions in the field became unfavorable (flooding), and mungbean on the bund provided good litter for their consumption. Thus, the 4-m plots with mungbean on the bund seemed to be more favorable for soil fauna, especially macrofauna, than the plots with a longer bund distance (8m) without crops on the bunds.

This study also revealed that the soil fauna on the bund was found to be more abundant and diverse than in the field. Way *et al*. (1998) also found that ant communities were more abundant and sometimes very diverse on the bunds around tropical irrigated rice fields. The abundance of soil fauna on the bunds was particularly high when these were cultivated with crops, because the crops on the bunds could maintain the soil moisture (Eagleton *et al.* 1991), providing favorable conditions for soil fauna. The higher soil fauna abundance and diversity on the bund is important because soil fauna can easily move from the bund to the field and participate in the soil processes in the field, such as litter decomposition and nitrogen mineralization, particularly if the bund distances are shorter.

Farmers can also benefit from the crops planted on the bund, since the crops on the bund did not negatively influence the rice (Eagleton *et al.* 1991). The soil fauna abundance was lower on the new bunds, which are regularly constructed before the new cropping period. The new bunds provided an unstable habitat for soil fauna and decreased their population as compared to the undisturbed bund. Widyastuti and Martius (unpublished work) found that the soil fauna population, especially ants, was more abundant in the old than in the new bunds of a rainfed paddy field in Pati. Thus, it is proposed to maintain the bunds after the final rice harvest.

4.3.2 Litter decomposition and nitrogen mineralization

The decomposition rate under rice field conditions was generally higher than that in the dry season. When the activity of macrofauna was not restricted (coarse bags), the litter-weight loss was more than twice that in dry season. The role of macrofauna in litter decomposition was clearly exhibited during the rice seasons. In the coarse-mesh bags, which permitted access to the whole decomposer community, the litter-weight loss was significantly higher than in fine- and medium-mesh bags, where macrofauna activity was restricted (Table 3.19). This result corresponds with the findings of Höfer and Luizäo (1999) in different areas of primary and secondary forest and polyculture systems in Amazonia. When the activity of macrofauna was restricted in medium- and fine-mesh bags, they found the decomposition rates also to decrease to about 50% of the rates in the coarse-mesh bags. They also reported that the role of macrofauna was more pronounced during the rainy season, when the macrofauna enhanced decomposition.

In the dry season or fallow phase, the role of meso- and macrofauna in litter decomposition was not readily explained. This is presumably due to the reduction of the soil fauna population by the hot and dry conditions in the coarser-meshed bags during the dry season (Section 3.2). In the fine-mesh bags, which permit access only to microorganisms, the rate of decomposition was faster than that in medium- and coarse-mesh bags. The enclosure of the litter in a fine-mesh bag presumably created hotter and more humid conditions in the bag, making it more favorable for microorganisms. Unfortunately, no moisture measurements were taken. It can thus be concluded that the litterbag experiments show that the soil fauna activity in the fallow season is strongly reduced.

Although the soil-fauna population was suppressed in the field during the (flooded) rice season (Section 3.2), the environmental conditions like warm air temperature and high soil moisture seemed to promote the activity of soil fauna in their role in organic matter decomposition. This has also been reported by others (Swift 1995; Seneviratne *et al*. 1998; Lavelle and Spain 2001). In contrast, the low temperature and extreme desiccation prevalent in cold desert soil severely limit decomposition processes and the activity and abundance of soil organisms (Treonis *et al*. 2002). Water content of decomposing materials can also influence the decay rate. Martius (1997) reported that the woody material of two varzea tree species decomposed faster if it was previously submersed in river water for periods of 1-4 weeks. In our study, during the rice seasons, the high water content of rice-straw litter also contributed to the litter decomposition rate.

Litter decomposition in the rice season was fastest in plots with short-bund distance (4m), particularly when the bund was cultivated with mungbean, indicating the importance of bund distance to facilitate soil fauna movement across the bunds and the importance of vegetation on the bunds to maintain soil moisture and provide favorable conditions for soil fauna. This result coincides with the macrofauna biomass that significantly increased in these plots during the dry-seeded rice period (Table 3.19). The occurrence of earthworms and some families of beetle larvae, such as Scarabidae and Erotylidae that are known as decomposers (Alford 1999; Borror *et al.* 1989; Daly *et al.* 1998), both in the field and the bund of the 4-m plots with mungbean on the bund explain the higher litter decomposition rate in this plot.

The short bund distance (4m) also had a positive effect on nitrogen mineralization, particularly in the dry-seeded rice. The nitrogen mineralization in the field significantly increased, coinciding with the higher soil fauna population both in the field and in the bund of the 4-m plots. In the dry-seeded rice, the increase of N mineralization in the 4-m plots was more clearly exhibited when the bund was planted with cassava. This result again indicates the importance of vegetation planted on the bund to conserve the soil moisture and provide a good litter for the soil fauna living on it. The higher numbers of soil fauna in the 4-m plots with cassava on the bund suggest a close positive relationship between the soil fauna population and nitrogen mineralization. The role of soil fauna in litter decomposition and nitrogen mineralization has been reported by some researchers, for example, Verhoef and Brussaard (1990) reported that soil fauna contributed about 30% of the total net nitrogen mineralization in forest and grassland ecosystems.

4.4 Concluding remarks

1. The soil fauna studies in other regions (ecosystem screening) confirmed the important of vegetation cover to maintain soil moisture and soil-living organisms. Since rainfed paddy field has less vegetation cover and thus a lower soil fauna population, its management should, therefore, mimic the structure of the teak forest and home garden, possibly through cultivation of the bunds with crops. These plants not only do not compete with the staple (rice) crop, but they also provide additional food (or income) to the farmers.
2. It is suggested to maintain the bunds after the final rice harvest, as the soil fauna abundance was lower on the new bunds, which are regularly constructed before the new cropping period. The new bunds provided an unstable habitat for soil fauna and decreased their population, as compared to the undisturbed bund.
3. The temporary drainage of rice fields and land preparation before the new cropping season are important, since the soil fauna population consistently increased at the beginning of each new cropping season.
4. Collembola and Acari were the most numerous taxa in the rainfed paddy field, as they always occurred under both fallow and flooded conditions. Acari seem to be more tolerant of the dry conditions than Collembola, as they occurred in high numbers during the fallow period. In terms of biomass, Coleoptera was the most dominant taxon in the dry fallow phase. However, their larvae along with the Diptera larvae were the most dominant taxa under flooded conditions. Earthworms sporadically occurred both in the fallow and the rice seasons, without any particular pattern. Once they occurred in the soil samples, their biomass could make up for more than 60% of the total.
5. In the dry season or fallow phase, the role of meso- and macrofauna in litter decomposition was not clearly shown. This is presumably due to the reduction of

the soil fauna population and to their activities being hampered by the hot and dry conditions in the coarser-meshed bags.

6. Although the soil-fauna population was suppressed in the field during the (flooded) rice season, the environmental conditions like warm air temperature and high soil moisture seemed to promote the activity of soil fauna to play their role in organic matter decomposition and nitrogen mineralization.
7. In the rice seasons, the short bund distance (4m) tended to increase soil fauna abundance, biomass and diversity both in the field and the bund. The effect of the short bund distance was more pronounced when crops were cultivated on the bund. Here, the crops enhanced macrofauna biomass (only in dry-seeded rice), litter decomposition and nitrogen mineralization in the field. Mungbean on the bund increased the litter decomposition, whereas cassava increased nitrogen mineralization, suggesting that both mungbean and cassava are appropriate for bund crops. Nevertheless, similar studies with other crops planted on the bund should be done to achieve a better understanding of bund crops and how they influence soil fauna population and their role in the soil processes. Thus, fields with the short-bund distance with crops planted on the bund seem to be a favorable habitat for the soil fauna population, enhancing their role in soil processes and supporting the management of crop residues.
8. An additional aspect is that crop residues are sometimes a burden in intensive farming by small-scale farmers, particularly in wetland rice. Farmers lack the equipment to incorporate large amounts of straw, which often leads to burning of this valuable material. Large quantities of CO_2 and nutrients may end up being lost from the system into the atmosphere (Dobermann and Fairhurst 2002). Not only does this negatively affect soil productivity, but it also adds to the build-up of greenhouse gasses (GHG) into the atmosphere. Proper management of residues was identified as one of the most important means of mitigating GHG emissions and restoring soil productivity (Wassmann *et al*. 2000). Finding management options that will help the breaking down residues and mineralizing the stored nutrients by promoting soil biological activity might help farmers. With regard to this aspect, the present study can contribute by showing that an improvement of soil biological activity in rice fields can accelerate organic matter decomposition on the spot.

5 SUMMARY

Sustainable agriculture can be improved through soil-biological management of cropping systems that favor an enhancement of soil-organism populations and their ecological services, such as organic matter decomposition and nutrient mineralization (Lavelle *et al* 2002). The rainfed lowland paddy fields found widespread in Indonesia have great potential to be used to increase the productive area, which has become limited in Indonesia, especially in Java. Rainfed paddy fields are not irrigated and depend, therefore, totally on rainfall. Due to the lack of irrigation infrastructure, water resources and low soil fertility, the productivity of rainfed paddy fields is lower compared to that of irrigated rice-field systems. The low productivity of rainfed paddy fields calls for alternative management options to increase rice yields.

In this study, crop management systems to improve the soil fauna population and its role in ecosystem processes has been studied in a rainfed paddy field in Pati, Indonesia, by modifying the bund distance (4m and 8m) and by cultivating the bund with crops (cassava or mungbean). The short bund distance (4m) might facilitate the movement of the soil fauna from the field (during flooding) to the bund. Cultivation of crops on the bund would increase the soil-surface cover, thus protecting the soil fauna living on the bund from direct sunshine. It was expected that this would enhance the soil fauna population and its ecological services. The cropping systems used by local farmers are (1) dry-seeded rice planted at the beginning of the rainy season, and (2) transplanted rice planted at the end of rainy season, followed by (3) a short fallow during the dry season. The objective of this study was to evaluate the dynamics of the soil fauna population and the function of soil fauna in soil processes during the fallow and rice phases, and to evaluate the influence of two different bund distances (4m and 8m) and crop-planted bunds (control, cassava and mungbean) on the soil fauna population, and on the function of soil fauna in litter decomposition and N-mineralization.

First, a screening of the different ecosystems in the region (teak forest, home garden and rainfed paddy field) was conducted to obtain a general overview of the soil fauna. The main study was then conducted in a rainfed paddy field. The experiment was carried out in plots of 12 x 16 m each, with factorial treatments of bund distance (4m and 8m) and crops cultivated on the bund (control, cassava and mungbean). The soil

fauna population was sampled using a soil corer of 20 cm diameter at a depth of 0-15 cm, and extracted in a Berlese funnel extractor. The collected animals were stored in ethanol 70% and determined under a stereomicroscope. The soil fauna population was evaluated in all treatment plots during each season after 30, 60 and 90 days. The litter decomposition was studied using stainless steel litterbags measuring 20 x 20 cm with the three different mesh sizes 0.038, 0.25, and 10 mm. Rice straw was used as standard litter, and the litter decomposition was evaluated in all treatment plots during each season 30, 60 and 90 days after onset. Nitrogen mineralization was also assessed each season in all treatment plots at the peak of the season using undisturbed soil confined in PVC tubes containing anion exchanged resins.

In the ecosystem comparison, the fallow paddy field had the lowest soil fauna abundance, biomass and diversity compared to its surrounding ecosystems, e.g. the vegetation-covered home garden and the teak forest, suggesting the importance of vegetation to maintain soil moisture and soil-living organisms. Soil-fauna feeding activity was also low in the rainfed paddy field and high in the home garden. However, although soil fauna abundance and biomass were high in the teak forest, their feeding activity was low at this site, due possibly to the abundance of alternative feed sources.

The soil fauna dynamics in the rainfed paddy field fluctuated following seasonal changes. Soil fauna abundance, biomass and diversity decreased at the peak of the dry season and stayed low during the rice seasons (dry-seeded rice and transplanted rice). It again increased at the end of the transplanted rice season when the rainfall started to decrease, and reached the high numbers in early fallow, shortly after the field had been drained. Acari and Collembola were the most numerous taxa in the paddy field, both in the fallow and rice seasons. However, they were dominated by different groups; oribatid mites (Acari) in the fallow period, and Sminthuridae (Collembola) during the rice seasons. In terms of biomass, Coleoptera was the dominant taxon, both in the fallow and rice seasons. In the rice seasons, Coleoptera larvae, along with Diptera larvae, were more dominant than the adults. Actually, Oligochaeta occasionally had a high biomass in all seasons, but not with any special pattern.

Although the soil-fauna population was suppressed in the field during the (flooded) rice seasons, the environmental conditions like warm air temperature and high soil moisture seemed to promote the activity of soil fauna to play their role in organic matter decomposition and nitrogen mineralization. During the rice seasons, the short bund distance (4m) tended to increase soil fauna abundance, biomass and diversity in the field and in the bund as well. The higher soil fauna population in the 4-m plots was most strongly shown when the bunds were cultivated with mungbean. Here, the macrofauna biomass significantly increased during the dry-seeded rice.

The combined effect of short bund distance (4m) and crops on the bund also seemed to stimulate the soil fauna in promoting litter decomposition and N mineralization in the field during the rice seasons. In dry-seeded rice, litter-weight loss was most strongly shown in the 4-m plots with mungbean planted on the bund, whereas in transplanted rice, the higher litter-weight loss in the 4-m bund distance was more pronounced in the control plots and the plots with mungbean on the bund. Nitrogen mineralization was also strongly marked in 4-m plots, particularly during the dry-seeded rice season in the plots with cassava planted on the bund. In transplanted rice, the higher N mineralization in the 4-m bund distance was only observed when the bund was cultivated with cassava, whereas in early fallow, differences in the N mineralization between the treatment plots were no longer observed. Thus, mungbean on the bund increased the litter decomposition, whereas cassava increased N-mineralization, suggesting that both mungbean and cassava are appropriate for bund crops. In conclusions, the short bund distance with crops planted on the bund seemed to be favorable habitat for soil fauna population, so that they can enhance their role in soil processes and help in the management of crop residues.

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7 APPENDICES

Appendix 1: Soil fauna in the field during the fallow (averages over 3 months).

No.	Taxa	Number of individuals m^{-2}
	Mesofauna	
1	Acari/Oribatida (Oribatid mites)	1270
2	Acari/Tetranychidae (Spider mites)	171
3	Acari/others	50
4	Collembola/Hypogastruridae	297
5	Collembola/Onychiuridae	21
6	Collembola/Isotomidae	213
7	Collembola/Poduridae	10
8	Collembola/Neelidae	5
9	Collembola/Entomobryidae	12
10	Collembola/Sminthuridae	1
11	Copepoda	2
	Macrofauna	
12	Aranae (Spiders)	5
13	Coleoptera/Pselaphidae (Short-winged mold beetles)	32
14	Coleoptera/Erotylidae la.	15
15	Coleoptera/Tenebrionidae	2
16	Coleoptera/Salpingidae (Narrow-waisted bark beetles)	3
17	Coleoptera/Dermestida (Dermestid beetles) la.	1
18	Coleoptera/Lathridiidae (Minute Scavenger beetles)	2
19	Coleoptera/Scydmaenidae (Antlike stone beetles)	16
20	Coleoptera/Staphylinidae (Rove beetles)	1
21	Coleoptera/Ptiliidae	1
22	Coleoptera/Carabidae (Ground beetles)	3
23	Coleoptera/others	27
24	Diplopoda (Millipedes) ad	3
25	Diplura/Anajapygidae	1
26	Diplura/Japygidae	16
27	Diptera/Ceratopogonidae (Punkies) la.	1
28	Diptera/Mydaidae la.	2
29	Diptera/ others ad.	6
30	Hemiptera/Cydnidae (Burrower bugs)	4
31	Hemiptera/ Pentatomidae (Stink bugs)	1
32	Hemiptera/others	4
33	Homoptera/ others	1
34	Hymenoptera/Formicidae (Ants)	12
35	Hymenoptera/others	5
36	Isopoda	3
37	Orthoptera/Phaneropterinae (Katydids)	1
	Oligochaeta	
38	Oligochaeta/Enchytraeids	20
39	Oligochaeta/Earthworms	6
	Total	**2240**

Appendix 2: Soil fauna in the field with two different bund distances (4m and 8m) in dry-seeded rice season.

No.	Taxa	Number of individuals m^{-2}			
		4 m		8 m	
		Field	Bund	Field	Bund
	Mesofauna				
1	Acari/Oribatida (Oribatid mites)	25	14	11	25
2	Acari/Tetranychidae (Spider mites)	11	32	4	53
3	Acari/others la.	4	11	11	7
4	Collembola/Isotomidae	71	106	88	103
5	Collembola/Sminthuridae	163	265	510	276
6	Collembola/Hypogastruridae	40	60	0	28
7	Collembola/Entomobryidae	7	7	7	11
8	Collembola/Poduridae	0	4	0	0
9	Collembola/Onychiuridae	0	4	0	0
10	Copepoda	4	4	4	0
11	Pseudoscorpiones Immature	4	0	0	0
	Macrofauna				
12	Aranae (Spiders)	11	4	0	7
13	Coleoptera/Platypsyllidae	0	7	0	0
14	Coleoptera/Scarabidae la	0	7	0	0
15	Coleoptera/Erotylidae la.	0	4	0	0
16	Coleoptera/Scydmaenidae (Antlike stone beetles) la.	4	0	4	4
17	Coleoptera/Scydmaenidae (Antlike stone beetles) ad.	0	0	0	7
18	Coleoptera/Hylobiinae	3	0	0	0
19	Coleoptera/Pselaphidae (Short-winged mold beetles)	0	4	4	4
20	Coleoptera/Carabidae (Ground beetles) ad.	0	4	0	0
21	Coleoptera/Carabidae (Ground beetles) la.	0	4	0	7
22	Coleoptera/Monommidae (Monommids)	0	4	0	4
23	Coleoptera/Platypodidae	0	0	0	4
24	Coleoptera/others la.	4	7	0	7
25	Coleoptera/ others ad.	4	4	0	11
26	Diplura/Japygidae	0	4	4	4
27	Diptera/Culicidae (Mosquitoes) Immature	7	18	0	4
28	Diptera/Sciaridae (Dark-winged fungus gnat)	4	4	0	4
29	Diptera/Mydaidae la.	4	0	7	0
30	Diptera/Ceratopogonidae la.	0	0	4	0
31	Diptera/Tephritidae (Apple maggot)	0	0	0	4
32	Diptera/Sepsidae (Black scavenger flies)	0	0	4	0
33	Diptera/others la.	50	18	7	4
34	Hymenoptera/Formicidae (Ants)	14	18	14	7
35	Hymenoptera/Chalcidoidea	0	0	4	0
36	Hymenoptera/others	0	4	0	0
37	Hemiptera/Miridae	0	7	0	0
38	Orthoptera/Acrididae (Grasshoppers) Immature	4	4	0	0
	Oligochaeta				
39	Oligochaeta/Enchytraeids	4	7	28	4
40	Oligochaeta/Earthworms	4	11	21	7
	Total	**439**	**644**	**732**	**591**

Appendix 3: Soil fauna in the field with two different bund distances (4m and 8m) in transplanted rice season.

No.	Taxa	Number of individuals m^{-2}			
		4m		8m	
		Field	Bund	Field	Bund
	Mesofauna				
1	Acari/Oribatida (Oribatid mites)	131	71	103	74
2	Acari/Tetranychidae (Spider mites)	32	81	67	135
3	Acari/others la.	14	60	50	21
4	Acari (spotted acari)	7	184	0.0	11
5	Collembola/Sminthuridae	195	439	255	195
6	Collembola/Hypogastruridae	71	170	134	92
7	Collembola/Entomobryidae	113	227	124	326
8	Collembola/Isotomidae	11	35	11	32
9	Collembola/Poduridae	4	0	0	4
10	Psocoptera (Psocids) ad.	4	0	0	0
11	Psocoptera (Psocids) Instar	14	11	4	4
12	Thysanoptera/Thripidae (Thrips) la.	0	0	0	4
	Macrofauna				
13	Aranae (Spiders)	7	14	4	0
14	Coleoptera/Alleculidae (Comb-claw beetles)	11	11	7	7
15	Coleoptera/Staphylinidae (Rove beetles)	18	18	35	28
16	Coleoptera/Staphylinidae (Rove beetles) la.	7	3.5	3.5	11
17	Coleoptera/Lathridiidae (Minute scavenger beetles)	11	28	11	32
18	Coleoptera/Carabidae (Ground beetles) ad.	11	12	0	4
19	Coleoptera/Carabidae (Ground beetles) la.	0	4	4	7
20	Coleoptera/Heteroceridae (Variegated mud-loving b.)	7	11	7	0
21	Coleoptera/Heteroceridae (Variegated mud-loving b.) la.	0	0	0	4
22	Coleoptera/Dytiscidae la.	4	4	4	0
23	Coleoptera/Cucujidae (Flat bark beetles)	0	4	0	0
24	Coleoptera/Mycetophagidae	4	4	0	0
25	Coleoptera/Scydmaenidae (Antlike stone beetles)	0	4	4	0
26	Coleoptera/Pselaphidae (Short-winged mold beetles)	0	7	7	7
27	Coleoptera/Tenebrionidae (Darkling beetles)	4	0	4	0
28	Coleoptera/Rhysodidae (Wrinkled bark beetles)	0	4	0	4
29	Coleoptera/others la.	7	4	0	4
30	Coleoptera/others ad.	4	0	4	0
31	Diptera/Tipulidae la.	0	4	4	0
32	Diptera/Cecidomyiidae (Gall midges) ad.	0	7	0.0	3.5
33	Diptera/Otitidae	0	4	0	0
34	Diptera/Culicidae (Mosquitoes) la.	0	4	0	7
35	Diptera/Ceratopogonidae (Little gray punkie) la.	0	4	0	4
36	Diptera/Mydaidae la.	0	4	0	0
37	Diptera/Asilidae la.	0	4	0	0
38	Diptera/Chironomidae (Midges) la.	0	0	4	0
39	Diptera/Bombyliidae	0	0	0	4
40	Diptera/others la.	0	0	4	0
41	Diptera/others ad.	14	57	14	21
42	Grylloblattaria (Rock crawlers)	0	0	0	4

Continued

No.	Taxa	Number of individuals m^{-2}			
		4m		8m	
		Field	Bund	Field	Bund
43	Hemiptera/Miridae (Immature)	4	0	0	0
44	Hemiptera/Cydnidae (Burrower bugs)	0	4	0	0
45	Hemiptera/Pyrrhocoridae	0	4	0	0
46	Hemiptera/others	8	0	0	0
47	Homoptera/Aphididae (Instar)	7	14	4	4
48	Homoptera/Deltocephalinae (Leafhoppers)	4	0	0	0
49	Homoptera/others ad.	4	25	0	0
50	Hymenoptera/Formicidae (Ants)	11	25	4	18
51	Hymenoptera/Tiphiinae (Tiphiid wasps)	0	0	4	0
52	Hymenoptera/others ad.	0	7	0	0
53	Lepidoptera ad.	0	0	0	7
54	Orthoptera/Tettigoniidae (Grasshoppers)	0	4	0	0
55	Orthoptera/Conocephalinae (Meadow grasshopp.)	0	7	0	0
56	Orthoptera/Gryllidae (Mole crickets) Immature	0	14	0	7
57	Orthoptera/ Phaneropterinae (Bush Katydids)	4	0	0	0
58	Orthoptera/Others	0	0	0	4
59	Plecoptera (Stoneflies) Nymphs	0	0	18	4
60	Trichoptera (Caddisflies) la.	28	25	21	35
	Oligochaeta				
61	Oligochaeta/Earthworms	0	18	4	18
62	Oligochaeta/Enchytraeids	7	0	0	0
	Total	**775**	**1634**	**916**	**1139**

Appendix 4: Soil fauna in the field with two different bund distances (4m and 8m) in the early fallow.

No.	Taxa	Number of individuals m^{-2}			
		4m		8m	
		Field	Bund	Field	Bund
	Mesofauna				
1	Acari/Oribatida (Oribatid mites)	64	159	372	1465
2	Acari/Tetranychidae (Spider mites)	127	191	149	531
3	Acari/Others la.	11	0	96	21
4	Acari (Spotted acari)	85	21	0	21
5	Collembola/Sminthuridae	0	11	510	32
6	Collembola/Hypogastruridae	435	96	754	403
7	Collembola/Entomobryidae	234	425	478	1221
8	Collembola/Isotomidae	234	595	202	202
9	Collembola/Poduridae	0	0	0	11
	Macrofauna				
10	Aranae (Spiders)	0	0	0	11
11	Coleoptera/Pselaphidae (Short-winged mold beetles)	21	0	32	21
12	Coleoptera/Pselaphidae (Short-winged mold beetles) la.	0	0	21	0
13	Coleoptera/ Cucujidae la.	11	0	0	0
14	Coleoptera/Lathridiidae (Minute scavenger beetles)	21	21	32	85
15	Coleoptera/Lathridiidae (Minute scavenger beetles) la.	0	0	11	0
16	Coleoptera/Staphylinidae (Rove beetles) ad.	11	11	74	21
17	Coleoptera/Staphylinidae (Rove beetles) la.	11	11	11	2
18	Coleoptera/Scydmaenidae (Antlike stone beetles)	0	11	21	21
19	Coleoptera /Elateridae (Click beetles)	0	0	0	11
20	Coleoptera/Phalacridae (Shining flower beetles)	0	0	11	0
21	Coleoptera/Salpingidae (Narrow-waisted bark beetles)	0	0	11	0
22	Coleoptera/Erotylidae la.	0	0	0	43
23	Coleoptera/Alleculidae (Comb-clawed beetles) la.	0	0	0	11
24	Coleoptera/ others la.	11	11	11	21
25	Diplura/ Japygidae	0	0	11	0
26	Diptera/ Asilidae la.	0	0	0	11
27	Diptera/ Cecidomydae la.	0	0	0	11
28	Diptera/ others ad.	0	0	21	21
29	Hemiptera/others	0	0	0	11
30	Homoptera/Aphididae (Aphids) Instar	11	11	11	11
31	Homoptera/Deltocephalinae (Leafhoppers) Immature	0	0	11	0
32	Hymenoptera/Formicidae (Ants)	21	1507	0	96
33	Hymenoptera/others	0	11	0	0
	Oligochaeta				
34	Oligochaeta/Enchytraeids	21	11	74	21
35	Oligochaeta/Earthworms	0	11	21	43
	Total	**1327**	**3110**	**2941**	**4406**

Appendix 5: Soil fauna in the fields surrounded by different crop-planted bunds in the dry- seeded rice season.

No.	Taxa	Number of individuals m^{-2}					
		Control		Cassava		Mungbean	
		Field	Bund	Field	Bund	Field	Bund
	Mesofauna						
1	Acari/Oribatida (Oribatid mites)	16	21	32	21	5	16
2	Acari/Tetranychidae (Spider mites)	11	69	5	42	5	16
3	Acari/others la.	5	5	11	16	16	5
4	Collembola/Isotomidae	27	112	42	69	170	133
5	Collembola/Sminthuridae	202	281	64	308	743	223
6	Collembola/Hypogastruridae	5	32	43	74	11	27
7	Collembola/Entomobryidae	5	11	11	11	5	5
8	Collembola/Poduridae	0	5	0	0	0	0
9	Collembola/Onychiuridae	0	5	0	0	0	0
10	Copepoda	0	0	5	5	5	0
11	Pseudoscorpiones Immature	5	0	0	0	0	0
	Macrofauna						
12	Aranae (Spiders)	0	5	5	11	0	0
13	Coleoptera/Hylobiinae	0	0	5	0	0	0
14	Coleoptera/Pselaphidae (Short-winged mold)	0	5	5	5	0	0
15	Coleoptera/Carabidae (Ground beetles) la.	0	5	0	11	0	5
16	Coleoptera/Platypsyllidae	0	5	0	0	0	5
17	Coleoptera/Scarabidae la	0	5	0	0	0	5
18	Coleoptera/Erotylidae la.	0	5	0	0	0	0
19	Coleoptera/Scydmaenidae (Antlike stone) la.	5	5	0	0	0	0
20	Coleoptera/Scydmaenidae (Antlike stone) ad.	5	5	0	5	0	0
21	Coleoptera/(Monommidae)	0	0	0	5	0	5
22	Coleoptera/Platypodidae	0	0	0	0	0	5
23	Coleoptera/ others ad.	0	11	5	11	0	0
24	Coleoptera / others la.	0	11	0	5	5	5
25	Diplura/Japygidae	0	5	0	0	5	5
26	Diptera/Culicidae (Mosquitoes) Immature	5	11	0	5	5	16
27	Diptera/Sciaridae (Dark-winged fungus gnat)	5	0	0	0	0	11
28	Diptera/Ceratopogonidae la.	5	0	0	0	0	0
29	Diptera/Tephritidae (Apple maggot)	0	5	0	0	0	0
30	Diptera/Sepsidae (Black scavenger flies)	5	0	0	0	0	0
31	Diptera/Mydaidae la.	11	0	5	0	0	0
32	Diptera/others la.	64	16	16	11	5	5
33	Hymenoptera/Formicidae (Ants)	11	16	0	21	32	0
34	Hymenoptera/Chalcidoidea	5	0	0	0	0	0
35	Hymenoptera/others	0	0	0	0	0	5
36	Hemiptera/Miridae	0	0	0	0	0	5
37	Orthoptera/Acrididae (Grasshoppers) Immature	0	0	5	0	0	0
	Oligochaeta						
38	Oligochaeta/Enchytraeids	11	0	37	5	0	11
39	Oligochaeta/Earthworms	11	11	27	11	0	5
	Total	**419**	**669**	**324**	**653**	**1014**	**520**

Appendix 6: Soil fauna in fields surrounded by different crop-planted bunds during transplanted rice

No.	Taxa	Number of individuals m^{-2}					
		Control		Cassava		Mungbean	
		Field	Bund	Field	Bund	Field	Bund
	Mesofauna						
1	Acari/Oribatida (Oribatid mites)	106	42	90	90	154	85
2	Acari/Tetranychidae (Spider mites)	27	90	42	117	80	117
3	Acari/others la.	27	69	27	37	43	16
4	Acari (Spotted acari)	0	0	5	212	5	80
5	Collembola/Sminthuridae	265	669	85	202	324	80
6	Collembola/Hypogastruridae	106	117	53	138	149	138
7	Collembola/Entomobryidae	64	106	138	287	154	435
8	Collembola/Isotomidae	11	11	5	32	16	59
9	Collembola/Poduridae	0	5	5	0	0	0
10	Psocoptera (Psocids) ad.	5	0	0	0	0	0
11	Psocoptera (Psocids) Instar	5	5	11	5	11	11
12	Thysanoptera/Thripidae (Thrips) la.	0	5	0	0	0	0
	Macrofauna						
13	Aranae (Spiders)	5	5	0	11	11	5
14	Coleoptera/Alleculidae (Comb-claw beetles)	5	11	0	5	16	5
15	Coleoptera/Staphylinidae (Rove beetles) ad.	24	21	21	16	27	27
16	Coleoptera/Staphylinidae (Rove beetles) la.	0	11	5	11	5	0
17	Coleoptera/Lathridiidae (Minute scavenger)	11	27	11	42	11	21
18	Coleoptera/Carabidae (Ground beetles) ad.	5	5	5	5	5	11
19	Coleoptera/Carabidae (Ground beetles) la.	5	11	0	0	0	5
20	Coleoptera/Rhysodidae (Wrinkled bark)	0	5	0	0	0	5
21	Coleoptera/Pselaphidae (Short-winged mold)	5	0	0	11	5	11
22	Coleoptera/Heteroceridae	11	5	0	11	11	5
23	Coleoptera/Dytiscidae la.	5	5	0	0	5	0
24	Coleoptera/Cucujidae (Flat bark beetles)	0	5	0	0	0	0
25	Coleoptera/Mycetophagidae	5	0	0	5	0	0
26	Coleoptera/Scydmaenidae (Antlike stone b.)	0	0	5	5	0	0
27	Coleoptera/Tenebrionidae (Darkling beetles)	0	0	11	0	0	0
28	Coleoptera/others la.	0	5	5	0	5	5
29	Coleoptera/others ad.	0	0	0	0	11	0
30	Diptera/Tipulidae la.	0	5	5	0	0	0
31	Diptera/Cecidomyiidae (Gall midges) ad.	0	11	0	5	0	0
32	Diptera/Otitidae	0	5	0	0	0	0
33	Diptera/Chironomidae (Midges) la.	5	0	0	0	0	0
34	Diptera/Bombyliidae	0	5	0	0	0	0
35	Diptera/ Culicidae (Mosquitoes) la.	0	5	0	10	0	0
36	Diptera/Ceratopogonidae la.	0	0	0	5	0	5
37	Diptera/Mydaidae la.	0	0	0	5	0	0
38	Diptera/Asilidae la.	0	0	0	0	0	5
39	Diptera/others la.	5	0	0	0	0	0
40	Diptera/others ad.	11	64	21	37	11	16
41	Grylloblattaria (Rock crawlers)	0	0	0	0	0	5
42	Hemiptera/Pyrrhocoridae (Red bugs)	0	0	0	0	0	5

Continued

No.	Taxa	Number of individuals m^{-2}					
		Control		Cassava		Mungbean	
		Field	Bund	Field	Bund	Field	Bund
43	Hemiptera/Miridae (Immature)	5	0	0	0	0	0
44	Hemiptera/Cydnidae (Burrower bugs)	0	0	0	5	0	0
45	Hemiptera/others	0	0	5	0	5	0
46	Homoptera/Aphididae (Instar)	5	5	5	11	5	11
47	Homoptera/Deltocephalinae (Leafhoppers)	0	0	0	0	5	0
48	Homoptera/others ad.	0	5	0	0	0	0
49	Hymenoptera/Formicidae (Ants)	11	16	5	43	5	32
50	Hymenoptera/Tiphiinae (Tiphiid wasps)	0	0	5	0	0	0
51	Hymenoptera/others ad.	0	5	5	5	0	5
52	Lepidoptera ad.	0	5	0	0	0	5
53	Orthoptera/Gryllidae (Crickets) Immature	0	5	0	0	0	27
54	Orthoptera/ Phaneropterinae (Bush Katydids)	5	0	0	0	0	0
55	Orthoptera/Tettigoniidae (Grasshoppers)	0	0	0	5	0	0
56	Orthoptera/Conocephalinae Imm.	0	0	0	5	0	5
57	Orthoptera/Others	0	0	0	0	0	5
58	Plecoptera (Stoneflies) Nymphs	0	0	5	5	21	0
59	Trichoptera (Caddisflies) la.	27	21	16	37	32	32
	Oligochaeta						
60	Oligochaeta/Enchytraeids	0	0	11	0	0	0
61	Oligochaeta/Earthworms	5	27	0	11	0	16
	Total	**777**	**1422**	**610**	**1433**	**1130**	**1295**

Appendix 7: Soil fauna in fields surrounded by different crop-planted bunds in the early fallow.

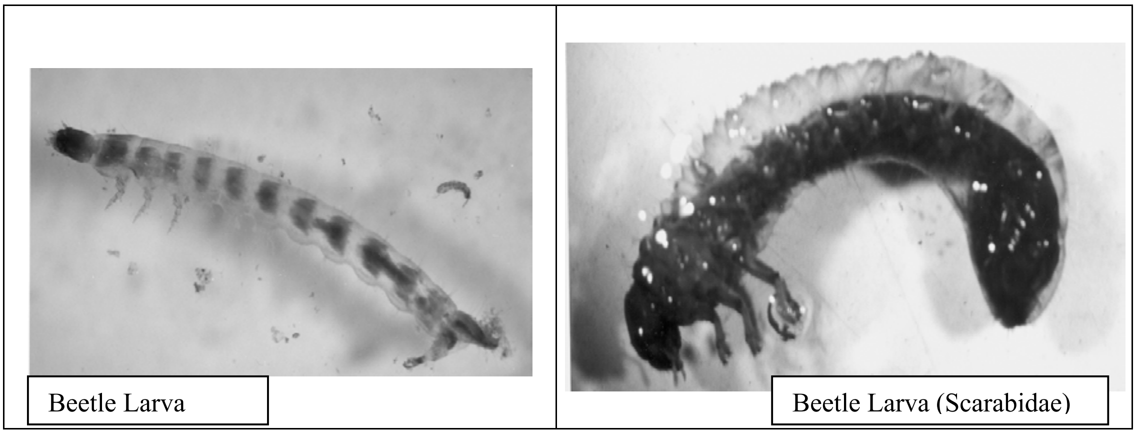
No.	Taxa	Number of individuals m^{-2}					
		Control		Cassava		Mungbean	
		Field	Bund	Field	Bund	Field	Bund
	Mesofauna						
1	Acari/Oribatida (Oribatid mites)	64	175	239	1147	350	1115
2	Acari/Tetranychidae (Spider mites)	159	96	127	637	127	350
3	Acari/Others la.	0	0	16	16	143	16
4	Acari (Spotted acari)	16	0	64	48	48	16
5	Collembola/Sminthuridae	16	32	733	16	16	16
6	Collembola/Hypogastruridae	382	255	446	255	955	239
7	Collembola/Entomobryidae	398	478	287	398	382	1592
8	Collembola/Isotomidae	207	637	111	143	334	414
9	Collembola/Poduridae	0	0	0	0	0	16
	Macrofauna						
10	Aranae (Spiders)	0	0	0	0	0	16
11	Coleoptera/Pselaphidae (Short-winged mold)	32	16	16	0	32	16
12	Coleoptera/Pselaphidae la.	0	0	32	0	0	0
13	Coleoptera/ Cucujidae la.	16	0	0	0	0	0
14	Coleoptera/Lathridiidae (Minute scavenger)	32	16	32	48	16	96
15	Coleoptera/Lathridiidae la.	0	0	0	0	16	0
16	Coleoptera/Staphylinidae (Rove beetles) ad.	16	0	32	16	80	32
17	Coleoptera/Staphylinidae (Rove beetles) la.	16	16	0	16	16	32
18	Coleoptera/Scydmaenidae (Antlike stone)	0	0	16	16	16	32
19	Coleoptera/Phalacridae (Shining flower)	0	0	16	0	0	0
20	Coleoptera/Salpingidae (Narrow-waisted)	0	0	16	0	0	0
21	Coleoptera/Erotylidae la.	0	0	0	16	0	48
22	Coleoptera/Alleculidae (Comb-clawed) la.	0	0	0	16	0	0
23	Coleoptera /Elateridae (Click beetles)	0	0	0	0	0	16
24	Coleoptera/ others la.	16	16	0	16	16	16
25	Diplura/ Japygidae	0	0	0	0	16	0
26	Diptera/ Asilidae la.	0	0	0	0	0	16
27	Diptera/ Cecidomydae la.	0	0	0	0	0	16
28	Diptera/others ad.	0	0	16	0	32	16
29	Diptera/others la.	0	0	16	16	0	0
30	Hemiptera/others	0	16	0	0	0	0
31	Homoptera/Aphididae (Aphids) Instar	0	0	16	16	16	16
32	Homoptera/Deltocephalinae (Leafhoppers)	0	0	16	0	0	0
33	Hymenoptera/Formicidae (Ants)	16	32	16	2166	0	207
34	Hymenoptera/others	0	16	0	0	0	0
35	Trichoptera (Caddisflies)	32	32	0	0	16	48
	Oligochaeta						
36	Oligochaeta/Enchytraeids	32	16	16	16	96	16
37	Oligochaeta/Earthworms	0	0	0	0	0	16
	Total	**1449**	**1847**	**2277**	**5016**	**2723**	**4427**

Appendix 8**:** The average values of feeding activity of the soil animals in various depth of soil in ecosystem of teak forest, home garden and rainfed paddy field.

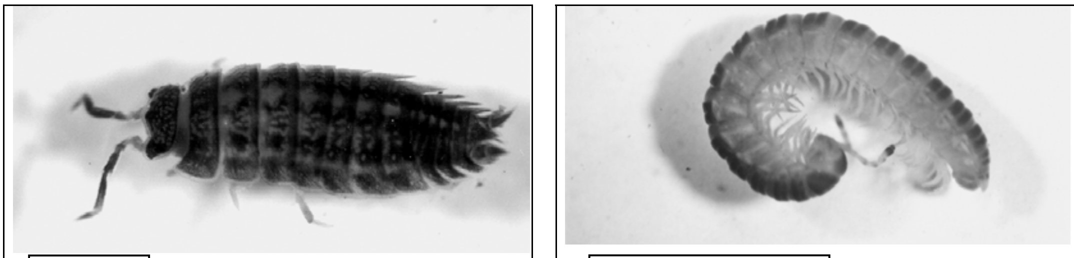
Depth		**% holes fed per depth**				
Holes	**cm**	**Teak Forest**	**Home Garden**	**Rice Field**	**Old Bund**	**New Bund**
1	0.00	0.26	0.44	0.21	0.77	0.17
2	0.55	0.24	0.45	0.17	0.83	0.15
3	1.10	0.24	0.44	0.15	0.75	0.10
4	1.65	0.20	0.39	0.17	0.60	0.13
5	2.20	0.17	0.38	0.18	0.54	0.06
6	2.75	0.18	0.38	0.17	0.56	0.06
7	3.30	0.14	0.38	0.18	0.54	0.08
8	3.85	0.15	0.40	0.19	0.54	0.02
9	4.40	0.14	0.39	0.18	0.48	0.04
10	4.95	0.12	0.36	0.18	0.52	0.06
11	5.50	0.10	0.39	0.16	0.48	0.06
12	6.05	0.10	0.38	0.16	0.48	0.04
13	6.60	0.13	0.40	0.16	0.50	0.04
14	7.15	0.12	0.39	0.15	0.40	0.10
15	7.70	0.11	0.38	0.15	0.42	0.04
16	8.25	0.11	0.35	0.13	0.42	0.08

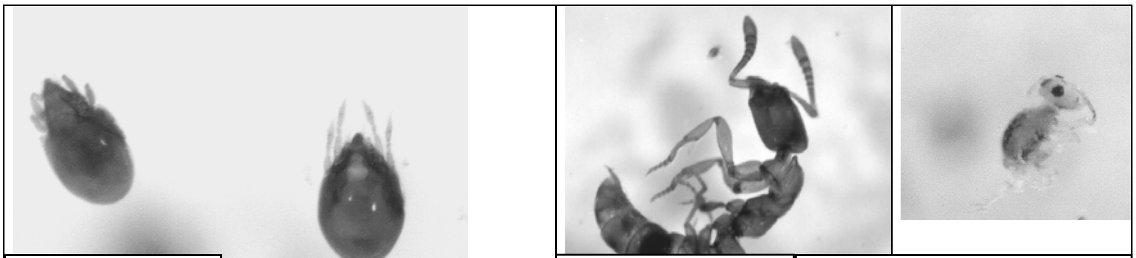
Appendix 9: The decomposition rates of litter in bags with different mesh sizes calculated with a negative exponential regression in the fallow phase.

Mesh Sizes	**k/day**	**R^2**	**k/year**	**t_{50} (days)**
Coarse	0.0042	0.8602	1.5330	238
Medium	0.0023	0.6826	0.8365	435
Fine	0.0060	0.9022	2.1900	167


Beetle Larva
Beetle Larva (Scarabidae)


Beetle (Heteroceridae)
Beetle (Staphylinidae)
Beetles (Pselaphidae)


Isopod
Diplopoda Larva


Oribatid Mites
Ant (Formicidae)
Collembola (Sminthuridae)

Appendix 10: Some soil animals found in rainfed paddy in Jakenan, Pati.

Appendix 11: The decomposition rates of litter in different mesh-sized litterbags during the dry-seeded rice season calculated with a negative exponential regression.

Treatment Plots	**Mesh Sizes**	**k/day**	**R^2**	**k/year**	**t_{50} (days)**
Control, 4m	Coarse	0.0133	0.9461	4.8545	75
	Medium	0.0081	0.8895	2.9565	124
	Fine	0.0080	0.9359	2.9200	125
Control, 8m	Coarse	0.0148	0.9487	5.4020	68
	Medium	0.0098	0.9294	3.5770	102
	Fine	0.0074	0.9076	2.7010	135
Cassava, 4m	Coarse	0.0121	0.9132	4.4165	83
	Medium	0.0102	0.9638	3.7230	98
	Fine	0.0080	0.9818	2.9200	125
Cassava, 8m	Coarse	0.0149	0.9875	5.4385	67
	Medium	0.0089	0.9469	3.2485	112
	Fine	0.0073	0.9075	2.6645	137
Mungbean, 4m	Coarse	0.0147	0.9017	5.3655	68
	Medium	0.0114	0.9837	4.1610	88
	Fine	0.0099	0.9880	3.6135	101
Mungbean, 8m	Coarse	0.0157	0.9597	5.7305	64
	Medium	0.0102	0.9939	3.7230	98
	Fine	0.0077	0.9766	2.8105	130

Appendix 12: The decomposition rates of rice straw in different mesh-sized litterbags during the transplanted rice season calculated with a negative exponential regression.

Treatment Plots	**Mesh Sizes**	**k/day**	**R^2**	**k/year**	**t_{50} (days)**
Control, 4m	Coarse	0.0173	0.9626	6.3145	57.8
	Medium	0.0147	0.9473	5.3655	68.0
	Fine	0.0138	0.9361	5.0370	72.5
Control, 8m	Coarse	0.0168	0.9711	6.1320	59.5
	Medium	0.0122	0.8999	4.4530	82.0
	Fine	0.0113	0.8296	4.1245	88.5
Cassava, 4m	Coarse	0.0182	0.9880	6.6430	54.9
	Medium	0.0136	0.9520	4.9640	73.5
	Fine	0.0147	0.9775	5.3655	68.8
Cassava, 8m	Coarse	0.0170	0.9691	6.2050	58.8
	Medium	0.0131	0.9623	4.7815	76.3
	Fine	0.0134	0.9356	4.8910	74.6
Mungbean, 4m	Coarse	0.0185	0.9753	6.7525	54.1
	Medium	0.0126	0.8866	4.5990	79.4
	Fine	0.0126	0.8774	4.5990	79.4
Mungbean, 8m	Coarse	0.0163	0.9931	5.9495	61.3
	Medium	0.0089	0.7037	3.2485	112.4
	Fine	0.0112	0.8646	4.0880	89.3

Appendix 13: The weight loss of rice-straw litter from different mesh-sized litterbags in the dry-seeded rice season, calculated as percentage of remaining ash-free dry weight (average over 4 reps ± SD).

Exposure Times	Mesh Sizes	Treatment Plots					
		Control		Cassava		Mungbean	
		4m	8m	4m	8m	4m	8m
30 days	Coarse	58.8±12.7	59.8±11.5	58.7±6.6	62.2±7.4	54.2±3.7	52.1±8.3
	Medium	73.4±7.2	63.9±1.9	66.5±5.8	69.3±4.0	67.7±3.0	73.5±2.8
	Fine	69.0±9.0	74.2±2.4	73.5±6.0	71.3±4.6	73.3±4.5	78.5±7.3
60 days	Coarse	39.4±39.4	33.5±3.9	41.7±5.1	37.0±7.7	33.3±4.6	38.5±7.5
	Medium	50.9±4.7	51.1±7.6	50.1±1.5	52.9±9.7	46.4±7.1	51.5±7.8
	Fine	57.3±8.1	55.2±6.5	59.8±3.9	57.6±4.9	51.3±7.6	58.4±6.6
90 days	Coarse	37.6±2.5	35.2±3.2	41.9±6.7	30.7±8.4	38.1±4.8	29.8±2.0
	Medium	55.3±8.6	46.3±6.2	44.1±3.4	49.5±6.3	39.5±3.6	42.1±5.5
	Fine	51.9±5.7	56.9±6.7	50.5±8.4	56.5±3.7	43.9±15.0	53.4±4.2

Appendix 14: The weight loss of rice-straw litter from different mesh-sized litterbags in the transplanted rice season, calculated as percentage of remaining ash-free dry weight (average over 4 reps ± SD).

Exposure Times	Mesh Sizes	Treatment Plots					
		Control		Cassava		Mungbean	
		4m	8m	4m	8m	4m	8m
30 days	Coarse	49.7±2.3	51.3±1.2	53.7±3.6	50.3±6.0	51.0±5.4	58.3±10.9
	Medium	53.3±4.2	54.4±5.5	55.9±3.8	57.2±3.4	52.6±3.8	56.3±1.2
	Fine	54.0±2.1	52.0±2.6	57.3±3.5	55.7±3.5	51.9±2.4	54.3±4.1
60 days	Coarse	35.0±4.2	37.2±7.2	31.5±8.4	37.7±4.2	30.8±4.7	35.7±8.7
	Medium	39.2±5.7	45.1±1.2	42.4±4.8	47.6±1.0	43.4±4.6	46.2±7.3
	Fine	41.5±2.3	46.1±5.5	39.5±3.7	41.2±4.2	43.3±5.7	47.0±3.8
90 days	Coarse	27.2±4.7	26.5±1.4	24.2±2.4	25.4±9.1	25.7±11.1	26.5±10.5
	Medium	33.1±4.8	39.9±6.5	34.8±2.8	32.3±5.3	39.7±13.4	55.3±9.0
	Fine	35.3±7.7	44.0±6.5	31.1±3.9	37.0±6.4	39.9±11.1	43.2±2.9

Appendix 15: ANOVA of nitrogen mineralization (kg N/ha) in treatment plots of crop-planted bund during dry-seeded rice, transplanted rice and early fallow.

Crops	**Seasons**		
	Dry Seeded Rice	**Transplanted Rice**	**Early Fallow**
Control	108.71 b	100.96 a	68.16 a
Cassava	139.15 a	87.21 a	56.91 a
Mungbean	76.22 c	89.29 a	67.79 a

In a column, means followed by a common letter are not significantly different at the 5% level by Duncan's Multiple Range Test.

Appendix 16: ANOVA of nitrogen mineralization (kg N/ha) for two different bund distances during dry-seeded rice, transplanted rice and early fallow.

Seasons	**Bund Distance**	
	4m	**8m**
Dry-Seeded Rice	140.12 a1	75.94 ab2
Transplanted Rice	102.04 b1	82.94 a1
Early Fallow	73.32 c1	55.25 b1

In a column, means followed by a common letter and in a row means followed by a common number are not significantly different at the 5% level by Duncan's Multiple Range Test.

Appendix 17: Chemical and physical properties of Pati's Soil.

Soil Properties		**Soil Properties**	
pH H2O	5.60	H (me 100 g^{-1})	0.16
KCl	4.20	Fe (μ g^{-1})	50.1
C organic (%)	0.58	Cu (μ g^{-1})	0.88
N total (%)	0.05	Zn (μ g^{-1})	0.48
Available P $Bray^{-1}$ (μg P g^{-1})	3.30	Mn (μ g^{-1})	8.32
Ca (me 100 g^{-1})	2.64		
Mg (me 100 g^{-1})	0.38	**Physical properties**	
K (me 100 g^{-1})	0.08	Sand (%)	46.0
Na (me 100 g^{-1})	0.16	Silt (%)	49.5
CEC (me 100 g^{-1})	5.06	Clay (%)	4.5

Acknowledgments

My study was made possible through the financial support of the Center for Wetland Studies (CWS), Bogor Agricultural University (IPB).
I would like to express my deepest thanks to Prof. Paul L.G. Vlek, my first supervisor, for his guidance, support and encouragement during my study, particularly his critical and valuable comments on the manuscript. I could not have completed this thesis without the generous help of Dr. Christopher Martius, who provided guidance during my field research in Indonesia and support, suggestions and constructive comments on the manuscript. For this, I will be forever grateful. I would also like to thank Prof. Matthias Schaefer and Prof. Dr. D. Wittmann, my second and third supervisors for their evaluation.

My thanks also go to Dr. Astiana Sastiono, Head of the Soil Science Department and Dr. Iswandi Anas, Head of the Soil Biology Laboratory, IPB, who allowed me to pursue my study. I am grateful to the Central Research Institute for Food Crops, Jakenan, Pati, who allowed me to conduct my field research in their experimental station.
I thank Dr. Günther Manske, Ms. Hanna Peters, Ms. Sabine Aengenendt-Baer, and Ms. Sina Bremer of the Center for Development Research (ZEF), Bonn University, for their support and help. I also thank Mrs. Margaret Jend for proofreading the manuscript.
I thank my colleagues Dr. Abay Asfaw, Mr. Arief Sabdo Yuwono, Dr. Dougbedji Fatonji, Mr. Li Zhaohua, Dr. Maria Andrea de Macale, Ms. Mercy Gichora, Mr. Mohsin Hafeez, Ms. Nermin El-Halawany, Mr. Tadesse Gole who created a great atmosphere during my studies at ZEF. To a number of people and institutions, who contributed to my study and who cannot all be named here, I express my thanks.

My special thanks to Dr. M. Edi Premono for his company during my hard time, his encouragement and help. Finally, my sincerely thanks to all my family, especially my parents, Mr. and Mrs. Soedaryadi, for their moral support and prayers. I dedicate this thesis to them.