

# Effects of land use change on belowground biodiversity

Kurniatun Hairiah, Sandy E Williams, David Bignell,  
Mike Swift and Meine van Noordwijk



# **Effects of land use change on belowground biodiversity**

Kurniatun Hairiah, Sandy E Williams, David Bignell,  
Mike Swift and Meine van Noordwijk

December 2001

Bogor, Indonesia

Published in December 2001

Published by:  
International Centre for Research in Agroforestry  
Southeast Asian Regional Research Programme  
PO Box 161, Bogor, Indonesia  
Tel: +62 251 625415; fax: +62 251 625416; email: [icraf-indonesia@cgiar.org](mailto:icraf-indonesia@cgiar.org)  
Web site: <http://www.icraf.cgiar.org/sea>

© copyright ICRAF Southeast Asia

Cover illustration: Wiyono

Layout: T Atikah & DN Rini

# Towards integrated natural resource management in forest margins of the humid tropics: local action and global concerns

Meine van Noordwijk, Sandy Williams and Bruno Verbist (Editors)

Humanity stands at a defining moment in history. We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, ill health and illiteracy, and the continuing deterioration of the ecosystems on which we depend for our well-being. However, integration of environment and development concerns and greater attention to them will lead to the fulfilment of basic needs, improved living standards for all, better protected and managed ecosystems and a safer, more prosperous future. No nation can achieve this on its own; but together we can - in a global partnership for sustainable development. (Preamble to the United Nations' Agenda21 on Sustainable Development; <http://www.un.org/esa/sustdev/agenda21chapter1.htm>).

## Background to this series of lecture notes

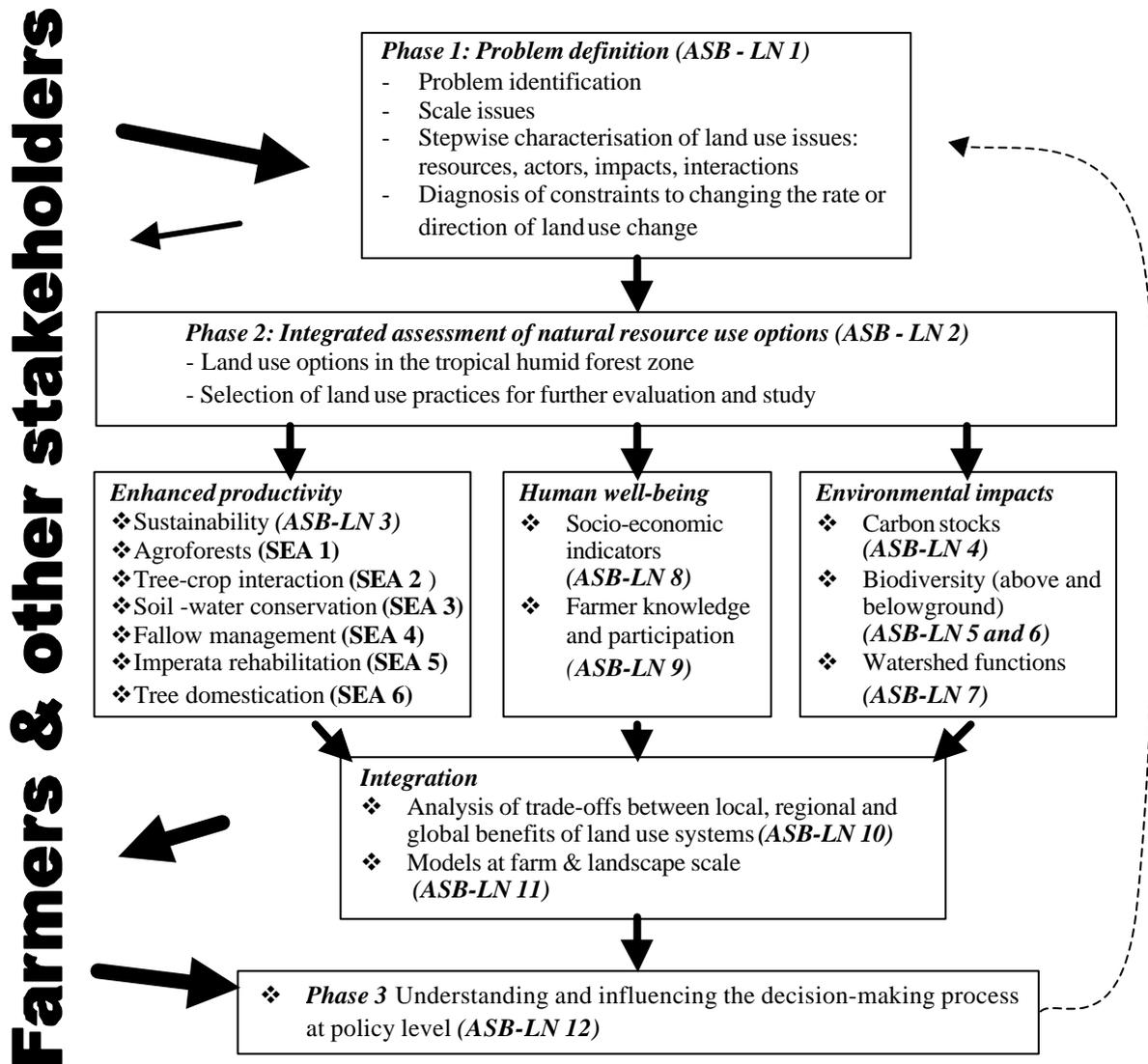
Much of the international debate on natural resource management in the humid tropics revolves around forests, deforestation or forest conversion, the consequences it has and the way the process of change can be managed. These issues involve many actors and aspects, and thus can benefit from many disciplinary perspectives. Yet, no single discipline can provide all the insights necessary to fully understand the problem as a first step towards finding solutions that can work in the real world. Professional and academic education is still largely based on disciplines – and a solid background in the intellectual capital accumulated in any of the disciplines is of great value. If one wants to make a real contribution to natural resource management issues, however, one should at least have some basic understanding of the contributions other disciplines can make as well. Increasingly, universities are recognising the need for the next generation of scientists and policymakers to be prepared for interdisciplinary approaches. Thus, this series of lecture notes on integrated natural resource management in the humid tropics was developed.

The lecture notes were developed on the basis of the experiences of the Alternatives to Slash and Burn (ASB) consortium. This consortium was set up to gain a better understanding of the current land use decisions that lead to *rapid* conversion of tropical forests, shifting the forest margin, and of the *slow* process of rehabilitation and development of sustainable land use practices on lands deforested in the past. The consortium aims to relate local activities as they currently exist to the global concerns that they raise, and to explore ways by which these global concerns can be more effectively reflected in attempts to modify local activities that stabilise forest margins.

The Rio de Janeiro Environment Conference of 1992 identified deforestation, desertification, ozone depletion, atmospheric CO<sub>2</sub> emissions and biodiversity as the major global environmental issues of concern. In response to these concerns, the ASB consortium was formed as a system-wide initiative of the Consultative Group on International Agricultural Research (CGIAR), involving national and international research institutes. ASB's objectives are the development of improved land-use systems and policy recommendations capable of alleviating the pressures on forest resources that are associated with slash-and-burn agricultural techniques. Research has been mainly concentrated on the western Amazon (Brazil and Peru), the humid dipterocarp forests of Sumatra in Indonesia, the drier dipterocarp forests of northern Thailand in mainland

Southeast Asia, the formerly forested island of Mindanao (the Philippines) and the Atlantic Congolese forests of southern Cameroon.

The general structure of this series is



This latest series of ASB Lecture Notes (**ASB-LN 1 to 12**) enlarges the scope and embeds the earlier developed ICRAF-SEA lecture notes (**SEA 1-6**) in a larger framework. These lecture notes are already accessible on the website of ICRAF in Southeast Asia: <http://www.icraf.cgiar.org/sea>

In this series of lecture notes we want to help young researchers and students, via the lecturers and professors that facilitate their education and training, to grasp natural resource management issues as complex as that of land use change in the margins of tropical forests. We believe that the issues, approaches, concepts and methods of the ASB program will be relevant to a wider audience. We have tried to repackage our research results in the form of these lecture notes, including non-ASB material where we thought this might be relevant. The series of lecture notes can be used as a basis for a full course, but the various parts can also 'stand alone' in the context of more specialised courses.

## **Acknowledgements**

A range of investors (or ‘donors’) have made the work of the ASB consortium possible over the past years, some by supporting specific parts of the program, others by providing core support to the program as a whole. These lecture notes build on all these investments, but were specifically supported by the ASB Global Steering Group, with funds provided by the Asian Development Bank, the World Bank via the CGIAR, by ICRAF core funds, by the Netherlands' Government through the Direct Support to Training Institutions in Developing Countries Programme (DSO)-project and by the Flemish Office for Development Cooperation and Technical Assistance (VVOB). Both biophysical and policy research was supported by a Regional Technical Assistance Grant from the Asian Development Bank. Many researchers and organisations have contributed to the development of ideas, collection and synthesis of data, and otherwise making the program what it is today. A team at the International Centre for Research in Agroforestry (ICRAF), consisting of Kurniatun Hairiah, Pendo Maro Susswein, Sandy Williams, SM Sitompul, Marieke Kragten, Bruno Verbist and Meine van Noordwijk developed these lecture notes. A first test of their suitability was provided by a course on ‘Ecology for Economists’ organised by the Economy and Environment Program for Southeast Asia (EEPSEA) program – we thank David Glover, Hermi Francisco and all participants to that course for their suggestions. Key researchers within the consortium provided support and agreed to act as co-authors on the various chapters. Editorial comments on draft forms of the various lecture notes were obtained from Fahmuddin Agus, Georg Cadisch, Min Ha Fagerström, Merle Faminow, Roeland Kindt, Chun Lai, Ard Lengkeek, Jessa Lewis, Chin Ong, Per Rudebjer, Goetz Schroth, Douglas Sheil, Fergus Sinclair, Sven Wunder and others. Overall responsibility for any shortcomings in the lecture notes remains with the editorial team.

### **ASB-consortium members**

Details of the ASB consortium members and partner organisations can be found at:  
<http://www.asb.cgiar.org/>

### **Copyright**

This material is considered to be an international public good that can be freely copied for use in an educational, non-commercial context, provided that the source is acknowledged.



## Lecture Note 6A

# EFFECTS OF LAND USE CHANGE ON BELOWGROUND BIODIVERSITY

By Kurniatun Hairiah, Sandy E. Williams, David Bignell, Mike Swift and Meine van Noordwijk

## Contents

I. OBJECTIVES	2
II. LECTURE	2
1. INTRODUCTION	2
2. MAIN GROUPS OF BELOWGROUND ORGANISMS AND THEIR ROLES IN ECOSYSTEMS	3
3. RELEVANCE OF BELOWGROUND ORGANISMS FOR ECOSYSTEM FUNCTION AND FOR FARMING	9
3.1. Links between above- and belowground diversity	9
3.2 Farmers and belowground biodiversity	11
3.3 Impacts of agriculture and land use change on belowground biodiversity	13
3.4 Values and perceptions of soil biodiversity	15
4. METHODS FOR ASSESSING IMPACTS OF FOREST CONVERSION AND AGRICULTURAL INTENSIFICATION ON BELOWGROUND BIODIVERSITY	16
4.1 How to measure belowground biodiversity?	16
4.2. System of classification	17
4.3. What measure of diversity should be related to ecosystem function?	18
4.4. Which groups should we study and why-what do they tell us?	21
4.4. Restoration of biodiversity and functions	22
5. RESULTS OBTAINED SO FAR ON TROPICAL LAND USE CHANGE	22
5.1 Belowground biodiversity in forest and agricultural land cover types	22
5.2 Effects of burning on belowground biodiversity	26
5.3 Effect of fallow-type on belowground crop parasites	28
6. HYPOTHESES AND CONCLUSIONS	29
III. READING MATERIALS	31

## I. Objectives

- To discuss the importance of belowground biodiversity (BGBD) for ecosystem functions and for farming
- To discuss the impacts of land use change on BGBD
- To illustrate how effects of land use change on BGBD can be assessed and which problems exist in the interpretation of data from such studies

## II. Lecture

### 1. Introduction

Although not apparent to the naked eye, soil is actually one of the most diverse habitats on earth! It contains one of the most diverse assemblages of living organisms known to us, and the issues relating to belowground biodiversity (BGBD) are the same as those related to its more visible counterpart aboveground. Its lower visibility, however, has led to less attention being paid to it in the past, especially as there is an absence of 'charismatic' species that attract attention. Yet, belowground biodiversity may be of direct relevance to the health of crops, trees and other plants that are desirable to man. So, special attention to the belowground parts of biodiversity may be justified.

Giller et al. (1997) reported that a single gram of soil is estimated to contain several thousand species of bacteria alone. Of the 1 500 000 species of fungi estimated to exist worldwide remarkably little is known about soil fungi, apart from the common fungal pathogens and the useful mycorrhizal species which improve crops' efficiency in taking up nutrients. Among the soil fauna some 100 000 species of protozoa (Box 1, Table 1) 500 000 species of nematodes and 3 000 species of earthworms are estimated to exist, not to mention the other invertebrate groups. These other groups include animals classified as mesofauna ('middle-sized' ones between 0.1 and 2 mm in length) like springtails and mites and macrofauna ('larger-sized' ones between 2 and 20 mm) like ants, termites, beetles and spiders.

What exactly is Biodiversity then? The basic concepts can be found in lecture note 5. In this lecture note we will focus on:

- the main groups of belowground organisms and their role in the ecosystem,
- the relevance of belowground organisms for ecosystem function and for farming,
- how the impacts of forest conversion and agricultural intensification on belowground biodiversity can be assessed,
- results obtained so far for tropical land use change and the hypotheses and conclusions to which this gives rise.

But first, we need a look at the belowground zoo – take a handful of forest litter and soil, spread it out and look with the naked eye, with a magnifying glass, with a microscope....

**Box 1. A look in the belowground zoo – a refresher course in 5 minutes**

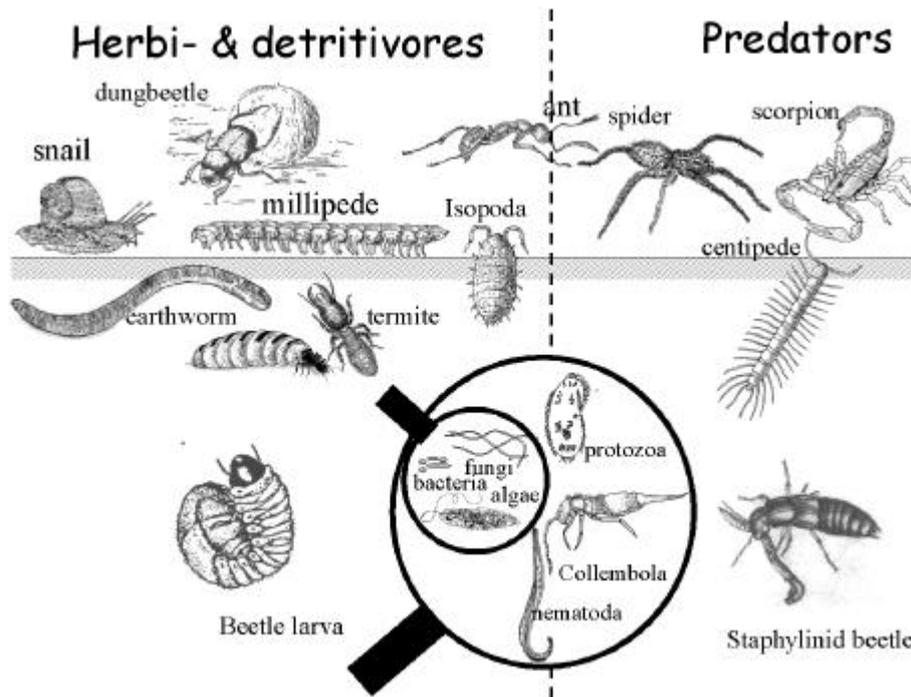


Figure 1. Litter layer and soil with some of its inhabitants (see Table 1 for more details).

**Technical terms we may encounter...**

Based on body size: micro-, meso- and macro-.

Based on food: rhizovores eat roots, bacterivores eat bacteria, fungivores eat fungi, methanotroph bacteria ingest methane.

Symbionts: different types of organisms that live together in a mutually beneficial relationship (symbiosis).

Obligate symbionts: symbionts that can't survive without each other.

Antagonist: an organism that has a negative effect on the survival, growth or reproduction of another type of organism.

## 2. Main groups of belowground organisms and their roles in ecosystems

As the total diversity of organisms is too large to quantify or classify, ecologists often use the concept of 'functional groups'. This does not mean that there also are non-functional (or 'redundant') groups, but merely introduces a term for groups of soil organisms that contribute to ecosystem functioning in a similar way (Brussaard, 1998). Swift and Bignell (1999) classified soil invertebrates according to their feeding habits and distribution in the soil profile as follows:

Table 1. Examples of groups of soil biota, their habitats and food preferences.

Name: English/ scientific; please add your local names...	Size: approximate body length	Where do they live?			What do they eat?
		Litter layer?	Soil?	Rhizosphere (around plant roots)?	
Bacteria	<1-5 $\mu\text{m}$ - visible only under micro- scope (x 1000)	X	x	X	<ul style="list-style-type: none"> <li>• organic substrates (some groups of bacteria called organotrophs)</li> <li>• inorganic substrates like <math>\text{CO}_2</math> from the air, <math>\text{NH}_4^+</math>, <math>\text{NO}_2^-</math>, <math>\text{Fe}^{2+}</math>, <math>\text{S}^-</math> and <math>\text{S}_2\text{O}_3^{2-}</math> (some groups of bacteria called lithotrophs)</li> </ul>
Actinomycetes (filamentous bacteria)	“				Carbon-based substrates. Actinomycetes play an important role in the early stages of decomposition, by mineralising C and N.
Fungi	Some microscopic, but some aboveground parts can reach up to 40 cm!	X	x	x	Carbon and other nutrients from organic matter in the external environment. Fungi can decompose cellulose, hemicellulose and pectin in plant cell walls and also lignin.
Protozoa (single celled organisms)	0.002 mm – 2 mm	X	x	X	Bacteria, yeasts and algae and sometimes other small protozoa too. They feed by engulfing the other organisms.
Nematodes (roundworms)	250-5500 $\mu\text{m}$	X	x	X	Bacteria, fungi (including yeasts) protozoa and other small nematodes. Some nematodes are parasites of invertebrates, vertebrates (including humans), and plants, affecting roots and all aboveground parts too. Nematodes are just like ‘vacuum cleaners of the soil’!
Springtails (Collembola)	1 – 10 mm	X	x		Decaying vegetation and associated microbes, but they are also fungivores. Some feed on live plants or their roots. One family (Onychiuridae) may feed in the rhizosphere and ingest mycorrhizae. Springtails are also effective in the biological control of a pathogen of cotton plant roots.

Name: English/ Scientific; please add your local names...	Body length (mm)	Where do they live?			What do they eat?
		Litter layer?	Soil?	Rhizo-sphere?	
Mites (Acarina)	0.1 – 6 mm	X	X		Fungi , decomposing vegetable matter, or both
Wood lice (Isopoda)	5 – 20 mm		Under rocks		Roots and foliage of seedlings.
Millipedes (Diplopoda)	2 – 250 mm	X	X		Organic debris, but they avoid leaf litter in that has a high content of polyphenols and favour litter with a high calcium (Ca) content.
Centipedes (Chilopoda)	25 – 280 mm		X		Leaf litter, predator of collembolans.
Scorpions (Scorpionidae)	Average 6 cm, min. 12 mm, max. 18 cm!	X	Under rocks or logs		Carnivores. Predator of other arthropods, lizards, mice and birds, they are also cannibalistic.
Spiders (Arachnida)	0.5 – 90 mm	X			Carnivores. Aboveground predators.
Ants (Formicidae)	1 – 25 mm	X	X		Wood that has come into contact with soil.
Termites (Isoptera)	0.5 – 20 mm	X	x		Wood, plants, humus.
Beetles (Coleoptera)	0.5 mm – 200 mm	X	X		Animal dung and carcasses, predator of ground surface beetles, predator of millipedes.
Earthworms (Oligochaeta)	5 - 25 cm	X	x		Organic litter, soil.

- (a) Epigeic species are biota which live and feed on the soil surface. These invertebrates effect litter comminution (reduction in litter size) and mineralisation (nutrient release), but do not actively redistribute plant materials. They are mainly arthropods e.g. ants, beetles, cockroaches, centipedes, millipedes, woodlice, orthopterans (grasshopper-type insects), together with gastropods (snails) and small, entirely pigmented (dark colored) earthworms. These ‘surface-active’ macrofauna can be sampled using pitfall traps (water-filled containers sunk into the ground where the animals tumble over the edge and get caught).
- (b) Anecic species are biota which eat litter from the soil surface and transport it to the deeper soil layers. Through their feeding activities, a considerable amount of topsoil, minerals and organic materials become distributed through the soil profile; this is also accompanied by channel or structure formation and an increase in soil porosity. Fauna included in this group are earthworms, non-soil-feeding termites and arachnids (spiders).
- (c) Endogeic species are biota which live in the soil and feed on organic matter and dead roots, also ingesting large quantities of mineral materials. Fauna included in this group are non-pigmented earthworms and soil-feeding termites.

A different way of classifying organisms into functional groups distinguishes four groups: rhizosphere biota, decomposers, ecosystem engineers and micropredators.

**Rhizosphere biota** are organisms that directly influence plant performance in a positive or negative way and *vice versa*. This group includes mycorrhiza, symbiotic N<sub>2</sub>-fixing bacteria, plant-pathogenic fungi, plant-parasitic nematodes, rhizovorous (‘root herbivorous’) insects and so on.

Growing roots release an appreciable amount of organic carbon into the rhizosphere, and this provides a source of food for soil organisms. Three major components of this organic carbon are:

- Free exudates (substances exuded from roots: low-molecular-weight organic compounds)
- Mucilage (high-molecular-weight gelatinous (‘slimy’) materials which are produced by root tips)
- Sloughed-off cells and tissues and their decomposition products (‘lysates’).

The amount of organic C released into the rhizosphere expressed as a fraction of the total dry matter production of young plants varies over a wide range from less than 1 % to more than 30 %. It is very much determined by age of the plants, environmental stress e.g. drought, mechanical impedance, nutrient deficiency and toxicity. The availability of C in the rhizosphere is mostly higher than in the non-rhizosphere zone, leading to high population densities of microbes (see example in Box 2).

A second important group are the **decomposers** or **litter transformers**; they are organisms that decompose plant residues, and produce purely organic structures that persist for only a short time. Who are they? This group includes:

- (a) the vastly diverse fauna of micro- and macroarthropods which feed on and live in litter systems; this group also includes enzymatic groups of soil microorganisms, detrital food web groups, macro-invertebrate decomposers and groups of macro-invertebrate predators.
- (b) some of the earthworms (the epigeic type, living in the litter layer on top of the mineral soil)

- (c) termites (wood eating = ‘xylophagous’)
- (d) potworms (the small Enchytraeidae, within the Class Oligochaeta).

**Box 2. Populations of microorganisms in the rhizosphere**

Table 2. Numbers of bacteria, actinomycetes and fungi in the rhizosphere compared with non-rhizosphere of the legume *Dolichos lablab* at different observation times. (Rao, 1977)

		Plant age (days)				
		1	5	10	15	20
Bacteria (x10 <sup>6</sup> )	Rhizosphere	15.0	95.5	260.0	310.8	677.8
	Non-rhizosphere	2.0	2.0	1.1	2.0	2.5
Actinomy cetes (x10 <sup>6</sup> )	Rhizosphere	5.5	3.5	34.5	95.8	83.3
	Non-rhizosphere	4.5	6.0	1.3	1.0	1.0
Fungi (x10 <sup>4</sup> )	Rhizosphere	3.3	2.0	26.0	68.0	91.8
	Non-rhizosphere	0.9	1.6	1.5	1.7	6.8

For all observation times the population densities of bacteria, actinomycetes and fungi are higher in the rhizosphere than in non-rhizosphere, and the bacteria population density was the highest of the three groups studied.

These organisms are active comminutors, breaking up the plant residues into smaller pieces that are accessible to the microflora, as well as grazing directly on the fungal biomass.

**Ecosystem engineers** have a major influence on the structure of a soil, creating a network of pores and contributing to aggregation, or the way elementary soil particles (clay, silt and/or sand) stick together. Earthworms, termites and some ants can create macropores by pushing their bodies into the soil (and thus compacting a zone of soil around the channel that can persist for some time), or by eating their way through the soil and removing soil particles. Earthworms and other animals that feed on soil produce excrement that contains resistant organo-mineral structures that may persist for long periods of time (from months to years) and which profoundly affect the environment for smaller organisms. Earthworms and termites can do this because they have a gut flora of bacteria. These activities of soil biota, which include moving particles from one horizon to another, and which affect and determine the soil’s physical structure and the distribution of organic material in the soil profile, are termed ‘bioturbation’. This in turn can have an effect on plant growth.

Examples of ecosystem engineers are earthworms of the ‘anecic’ group (species that live in the litter layer) and of the endogeic group (species that live and feed in the subsoil).

The relationships among these groups are presented in Figure 2.

**Micropredators** are small invertebrates, mainly protozoa and nematodes, that feed on microorganisms. These micropredators live free in the soil and do not develop mutualistic relationships with microflora. Predation of microorganisms, particularly by nematodes and protozoa, plays an important role in regulating the biomass of

microorganisms and is likely to assist in maintaining diversity by preventing dominance of particular groups. This is arguably more important for bacteria, which tend to be strongly regulated by predation, than for fungi which are less susceptible to grazing, as they are more complex both chemically and structurally (Wardle and Lavelle, 1997, cited in Giller *et al.*, 1997).

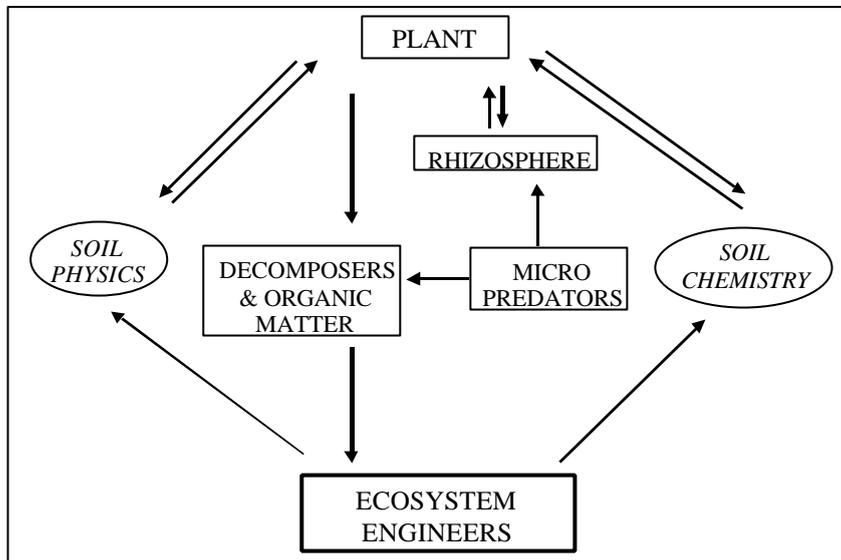


Figure 2. The relationships among the main groups of soil biota and plants (modified from Brussaard, 1998).

Predation of the bacteria and fungi that are involved in decomposition can actually control the rate of this important process. Current models of belowground food-webs are reasonably successful in predicting the time pattern of N mineralisation for a given structure of the foodweb and abundance of functional groups, but even in the most intensively managed and simplified agro-ecosystems, mineralisation of organic residues still occurs (De Ruiter *et al.*, 1995). Application of such models to tropical ecosystems, however, is still very limited. Box 3 illustrates the components of the basic food webs that can develop around roots as they grow.

### Box 3. Interactions between roots and biota: rhizosphere flora and fauna

Along the length of a root a snap-shot of the development in time can be obtained, with a succession of organisms, building up a food chain. Root tips growing into the soil have three choices:

- (A) they can penetrate into mineral soil (if the bulk density and soil moisture content allow...),
- (B) grow over the surface of a soil ped, or
- (C) grow into an existing macro-pore or crack.

Root hairs are the main way for roots in situations B and C to come into contact with the water in the soil matrix and the nutrients it contains. The first tissue to be pushed into the soil is the *root cap* (Figure 3) consisting of cells that can be *sloughed off* to lubricate the penetration by the root of mineral soil. The root cap protects the root meristem (growing point), or the zone with active cell division.

### Box 3. (Continued) Interactions between roots and biota: rhizosphere flora and fauna

The young cells behind the root cap leak out a lot of soluble substances – both organic and inorganic. Some of the organic substances are considered to be *exudates* (Figure 3) and their leakage into soil may actually serve a function for the plant, as they help to break down organic substrates, mobilize plant nutrients, detoxify ions such as aluminium ( $Al^{3+}$ ) or stimulate the development of a specific rhizosphere flora, consisting of bacteria and fungi. Close to the root tip we mainly find bacteria that are able to respond quickly to the sudden supply of organic substrate (the “fast” flora), further from the tip we also find the organisms that need more time to respond (the “slow” flora) and the protozoa and other *microfauna* that live on the rhizosphere bacteria.

*Mycorrhiza*, the symbiosis of fungi and roots, may develop right at the root tip, when the root tip carries the fungi along, or it may develop at some distance behind the root tip, if it starts with spores or mycelium of the fungus that ‘wake up’ when they get the right exudate signal passing by, and actively grow towards the root.

Further from the root tip, the belowground foodweb may be fully developed with *mesofauna* feeding on the soil micro-fauna and various groups of *rhizovores* (root feeders) that have had a chance to discover the root. The chance that they actually find the root probably depends on the size of the macro-pore gaps around the root, but our understanding of the detailed dynamics of soil structure, roots and soil biota is still rather cursory.

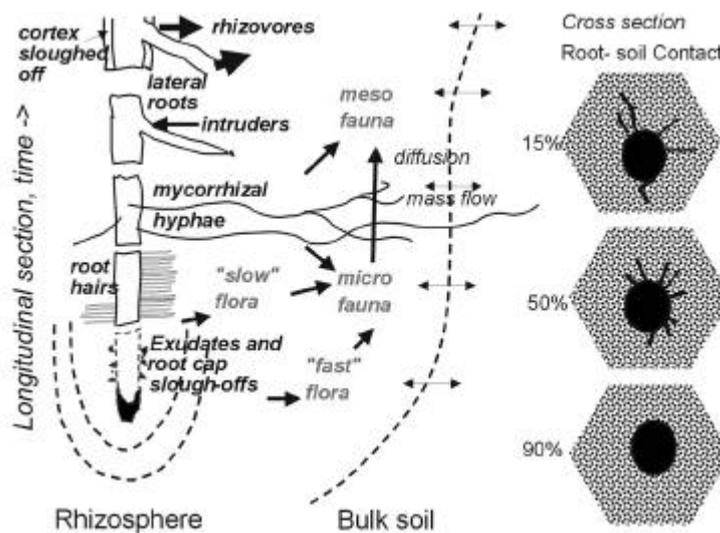


Figure 3. Schematic view of interactions between roots and biotic factors in the rhizosphere, along a longitudinal section of the root, representing changes in time (left side of the figure), and a cross section (right) highlighting the range of root-soil contact situations which is likely to exist in structured soils (Van Noordwijk *et al.*, 1993).

## 3. Relevance of belowground organisms for ecosystem function and for farming

### 3.1. Links between above- and belowground diversity

Aboveground diversity consists of plants and nearly all animal groups, but plants play a dominant role in providing the ‘infrastructure’ of the vegetation, as well as providing the foundations of the foodweb by capturing energy from sunlight and sequestering  $CO_2$  into energy-rich carbohydrates, proteins and other organic substrates. Most plants, however, live only partly aboveground – their belowground organs (roots) are essential

for survival and functioning. We may expect a strong linkage between above- and belowground diversity, primarily because plants and plant diversity determine the functioning of the belowground ecosystem via factors such as:

- plant litter quality, quantity and timing,
- the soil water balance and microclimate in the surface layer, and
- root activity that may change the rhizosphere (the area around the roots) by exudation of soluble organics and decay of structural material

(van Noordwijk and Swift, 1999).

The directly soluble leachates affect the microflora and the more structural components provide substrate for 'comminutors', organisms that chew up organic substrates into smaller ('minute') pieces and thus make them more accessible for attack by micro-organisms.

Plant diversity can, in theory, lead to a wider array and/or a more continuous supply of substrates for the belowground system. In return, the belowground community provides a number of '*environmental services*' for the plants; but the processes involved in mineralisation and decomposition are broad-based and there is little evidence that specific groups of belowground organisms are needed, or that more diverse systems function better from a plant's perspective. However, specific relations occur between the symbionts, diseases and their antagonists and it is here that belowground diversity may facilitate aboveground diversity.

Causal links between aboveground (plant) diversity and belowground biodiversity are likely to exist (Table 3), but probably involve considerable time lags. Little is known about how long it takes for the belowground ecosystem to respond to even such drastic changes as a conversion of forest to crops or grassland. For re-introducing aboveground diversity (rehabilitation of degraded lands) the lack of specific groups of soil organisms may limit potential aboveground (plant) diversity (Table 4), but little hard data exist so far.

Table 3. Effects ( $\Rightarrow$ ) of plant diversity on belowground biodiversity (van Noordwijk and Swift, 1999).

Aspect	Effect	Soil organisms	
<b>PLANT DIVERSITY</b>	Litter quality & timing	Leachates	Microflora
		Structural material	Comminutors, Engineers
	Root Quality & timing	Rhizosphere effects: C-supply, enzymes pH, aeration, N-mineralisation	Rhizosphere microflora + related mesofauna
		Food source	Rhizovores
		Symbionts	Symbionts
		Soil structure	Microflora
Water Balance	Drying cycles $\Rightarrow$ structure	All	
Micro-Climature	Temperature in top soil	All	

**BELOW-GROUND DIVERSITY**

Table 4. Effects ( $\Leftrightarrow$ ) of belowground biodiversity on plant growth (van Noordwijk and Swift, 1999).

	Effects	Functions	Groups	
PLANT GROWTH	Resources	N, P mineralisation	Comminutors, microbes, mesofauna	BELOWGROUND DIVERSITY
		N <sub>2</sub> fixation	<i>Rhizobia</i> , <i>Azospirillum</i> , etc. (bacteria)	
	Uptake efficiency	Mycorrhiza formation	Mycorrhizal Fungi	
		Soil structure => Root growth	Ecosystem engineers	
	Biotic relations	Root turnover, plant death	Rhizovores	
		Protection against diseases and rhizovores	Antagonists	

Functional relations between above- and belowground biodiversity, mediated by roots, are likely to involve time-lags and may be poorly reversible. Soil organisms tend to have less effective means of dispersal than most aboveground organisms and may thus become a rate-limiting step for ecosystem adjustment in as far as they are critical for the functioning of aboveground vegetation. This is most likely to be the case for specialised obligate symbionts such as mycorrhizal fungi and specific rhizosphere organisms. In fact, the rate of establishment of plant-parasitic nematodes was recently shown to be a major determinant of primary succession in sand dunes in the Netherlands (Van der Putten *et al.*, 1993), yet previously it was believed that succession in the area was mainly influenced by nutrient availability!

### 3.2 Farmers and belowground biodiversity

Human interest in belowground biodiversity may be grouped under 7 headings (Table 5). The ranking 1...7 reflects our rough assessment of the likely interest of society at large in soil biota, but we are not aware of more formal valuation efforts.

Table 5. Seven direct and indirect reasons for human interest in maintaining belowground biodiversity, and related questions on natural resource management (Van Noordwijk and Swift, 1999)

1. Soil biota as contributors to <b>soil fertility</b> , maintenance of nutrient cycles and soil structure:
1.1 Are basic processes of decomposition and mineralisation affected by agricultural management practices?
1.2 Does N <sub>2</sub> -fixation and/or mycorrhizal infection contribute significantly to the N and P economy of the system and increase economic return on a sustainable basis?
1.3 Is the economic efficiency of the system increased by maintaining an organically and biologically driven component to the nutrient cycles (as compared with reliance on inorganics alone)?
1.4 Are negative impacts on the surrounding environment, e.g. by pollution of ground- and surface water and by emission of greenhouse gases, reduced or elevated in systems with organically and biologically driven nutrient cycles?
1.5 What contribution is made by soil macrofauna to soil conservation by increasing water infiltration and reducing surface run-off (deep-burrowing (non-

---

pigmented) earthworms are the prime example) and how can this contribution be increased?

- 1.6 What contribution is made by maintaining soil structure as a favourable environment for (tree) crop roots and thus reducing the need for soil tillage, and how can this be further increased?

---

2. Soil as a source of **genes**, microbes and other soil biota for (*ex situ*) use in pharmaceutical industry or other biotechnology applications (this may represent the highest direct market value, but probably depends on soils in 'extreme environments' rather than 'normal' soils in agricultural use):

- 2.1 Are current regulations of access to the belowground gene resource adequate?

- 2.2 Are current activities in line with reasonable expectations of the real value?

---

3. Soil biota as producers of **edible products** (e.g. mushrooms), either *in situ* or *ex situ*:

- 3.1 Are current harvest levels sustainable under current *in situ* management?

- 3.2 Can soil biota be 'domesticated' for increased production in semi-natural or man-made environments?

---

4. **Soil biological capital**, concerns on overall land degradation and global homeostasis:

- 4.1 Is there a 'soil biological capital' which is lost due to specific land use types and which restricts potential future usage of this land?

- 4.2 Which aspects of land use are largely responsible for loss (or maintenance) of soil biological capital: conversion of forests, slash-and-burn and other techniques for land clearing, amount and quality of organic inputs, use of agro-chemicals?

- 4.3 What is the role of soil biota and their diversity in global homeostasis by maintaining balance in the global C and N cycles and dissipating carbon sequestered in photosynthesis and nitrogen fixed by microorganisms or industries? Specific attention may be needed for the greenhouse gases methane and nitrous oxide, which can be oxidised in soils in the neighbourhood of production sites, before they reach the lower atmosphere.

---

5. Benefits and risks of **(re-)introduction** of soil biota,

- 5.1 Can symbiotic inoculants (Rhizobium, mycorrhizal fungi) be targeted to those soils and crops/ trees where a real response can be expected?

- 5.2 How can quality control be provided for the considerable number of inoculants available commercially?

- 5.3 Can we assist farmers and land managers in a better judgement of whether and where the use of general microbial inoculants ('biofertilizer') is worth the money spent on it?

- 5.4 What are risks and benefits of (re-)introduction of soil meso- or macrofauna (e.g. earthworms, dungbeetles)?

- 5.5 How can we assess the risks of releasing genetically modified soil (micro)organisms?

---

6. Soil biota as **antagonists** and **suppressants** of 'soil borne diseases', reducing the need for agrochemicals,

- 6.1 Which soil-borne diseases are directly influenced by land use practices, including organic matter management?

- 6.2 Can generalisations be made on antagonism and suppression beyond the specifics of well-known diseases?

---

---

7. Soil biota as a valuable component of the biosphere **in their own right**, reflecting an important part of the evolutionary history of the biosphere,

7.1 How important is this 'intrinsic value' argument relative to the more direct values presented by 1...6?

7.2 Does the 'intrinsic value' argument lead to specific conservation efforts beyond points 1...6?

---

### 3.3 Impacts of agriculture and land use change on belowground biodiversity

Although our knowledge of the biodiversity of organisms in all soils is still very poor, soils in the tropics deserve particular attention for a number of reasons. The rate of agricultural intensification in the tropics is greater than in other regions of the world, so that some ecosystems are under particular threat of major changes or loss of biodiversity. The conversion from natural to managed ecosystems generally induces a substantial decrease in soil C-stock and leads to modified belowground biodiversity (Figure 4). In many regions of the tropics, the reliance of cropping systems on organic inputs for management of soil fertility implies that farmers there rely more upon the biological functioning of the soil. Agricultural productivity of farmers may therefore be affected if losses of biodiversity lead to changes in ecosystem functioning.

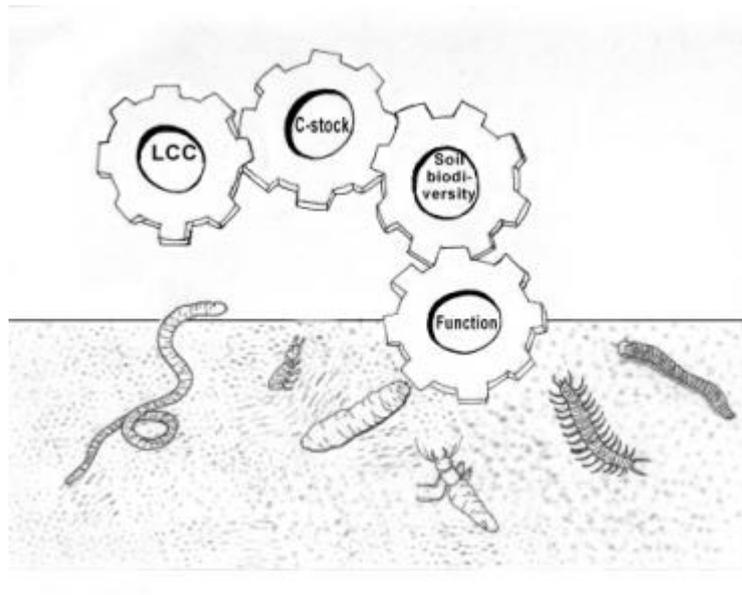


Figure 4. Schematic link between land cover change (LCC), C-stock, soil biodiversity and its functions in soil fertility: a change in one induces changes in the other wheels.

When forests are converted into agricultural use, either temporarily or permanently, the forest soil provides a rich heritage for the new crops or trees, from its structure (including old tree root channels, Van Noordwijk *et al.*, 1991), chemical content (especially when the litter layer and biomass were turned into ash), organic matter content and scarcity of weed seeds. In traditional agricultural systems, plots are cleared of their natural vegetation, then burnt and cropped for a few years only. Crop yields

usually decline rapidly, because of a combination of decreased nutrient supply, increased soil acidity (decreasing 'lime' effect of the burnt forest biomass), physical degradation of soil and increased infestation of weeds. Within this complex of factors, decline of soil organic matter (SOM) content is widely seen as a major factor in the decrease of soil fertility and crop yields after forests are converted for agricultural use. A rapid initial decline of SOM after secondary rainforest clearing has been observed by Sanchez *et al.* (1983) with 25% lost in the first year in Brazil. Preliminary observations in Lampung (Hairiah *et al.*, 1995) confirm this trend.

Mineralisation of SOM is a major source of plant nutrients, but the stock can run out quickly, unless sufficient organic inputs are used. Intensive agricultural systems often involve activities such as ploughing, drainage/irrigation and liming, which may increase the rate of mineralisation and thus promote crop growth in the short term, but speed up soil fertility depletion due to decline of soil organic matter content. Retaining crop residues in the field (and not burning them or using them as fodder) may help, but additional inputs from cover crops and/or tree prunings may be needed as part of the cropping system.

It is generally expected that soil biota are very responsive to human-induced disturbance e.g. intensive agricultural practices, but there is remarkably little data to support this expectation. As intensification proceeds, aboveground biodiversity is reduced and the biological regulation of soil processes is altered and often substituted by the use of mechanical tillage, chemical fertilizers and pesticides. The key biological functions in tropical agricultural soils, the principal groups of organisms responsible for them, and the effects on these of various agricultural management practices are presented in Table 6. The agricultural management involves mainly the burning activity during land clearing, applying fertilizer and liming, irrigating and spraying of herbicide, insecticide and pesticide.

Table 6. Key biological functions, the groups of soil biota principally responsible for these functions and management practices most likely to affect them (Giller *et al.*, 1997).

<b>Biological function</b>	<b>Biological/functional group</b>	<b>Management practices</b>
Decomposition	Residue-borne microorganisms,	Burning, soil tillage, pesticide applications
C-sequestration	Microbial biomass (especially fungi), macrofauna building compact structures	Burning, shortening of fallow in slash and burn, soil tillage
N-fixation	Free and symbiotic N-fixers	Reduction in crop diversity, fertilization
Organic matter/ nutrient redistribution	Roots, mycorrhizas, soil macrofauna	Reduction in crop diversity, fertilization, soil tillage
Nutrient cycling, mineralisation/ immobilisation	Soil microorganisms, soil microfauna	Soil tillage, irrigation, fertilization, pesticide applications, burning
Bioturbation*	Roots, soil macrofauna	Soil tillage, irrigation, pesticide applications
Soil aggregation	Roots, fungal hyphae, soil macrofauna, soil mesofauna	Burning, soil tillage, reduction in crop diversity, irrigation
Population control	Predators/grazers, parasites, pathogens	Fertilization, pesticide application, reduction in crop diversity, soil tillage

\*Redistribution of soil and organic particles within the soil profile.

Burning is a central component of shifting cultivation or slash and burn agriculture due to its mobilisation of nutrients. Burning may also influence the biological functions of organic matter decomposition, carbon sequestration and soil aggregation both directly through loss of organic matter inputs, and indirectly through a change in the size and structure of biological communities.

Soil tillage has some of the most far-reaching effects on biological processes. It strongly influences the placement and distribution of crop residues, resulting in differences in the composition and activity of microbial and faunal communities, which can markedly affect rates of residue decomposition, C-sequestration, mineralisation and immobilisation. The intensity of soil tillage may also indirectly impact physical processes in soils e.g. bioturbation and soil aggregation, through changes in the diversity and composition of biological communities. Additionally, soil tillage can directly disrupt earthworm populations and render them susceptible to predation by birds and it can also destroy termite galleries.

Fertilization affects the inputs from biological fixation and cycling of nutrients, both positively (e.g. addition of P stimulates plant growth and can lead to more N fixation) and negatively (e.g. N-application decreases N-fixation).

Irrigation stimulates both the intensity of biological activity and affects the types of biological transformations performed. It may also enhance the biological functions of soil aggregation and bioturbation as well as rates of nutrient turnover and mobilisation.

### **3.4 Values and perceptions of soil biodiversity**

A few studies have recently attempted to assess the loss in biodiversity (aboveground) associated with tropical deforestation, but no evidence is available concerning the value of soil biodiversity and its perception by different groups in society, as research on this topic is currently in an embryonic state.

The principal ecological functions of soil biodiversity have so far been discussed at the plot and farming systems scales. However, soil biodiversity can also have economic functions and further ecological functions at other spatial scales, and these various functions are likely to be valued differently by different groups in society (Box 4).

#### **Example**

Soil biodiversity has three main functions at the plot level:

- It contributes to the productive capacity of the systems (e.g. crop yields, tree biomass, fruit production through plant growth etc.) by ensuring the mineralisation of nutrients from organic materials.
- It may buffer the functions of the soil and the resilience of the (agro)-ecosystem or its capacity to recover from extreme events such as long dry seasons, flooding or fire.
- It contributes to reduction of pest and disease incidence.

Farmers are the group in society most likely to assign a high value to these three functions because of their direct effects on production and indirect effects in reducing risk. Further functions of soil biodiversity at regional and /or national level and at global level were summarised in Table 5, above.

#### Box 4. Valuation of belowground biodiversity based on its functions

A basic notion in economics is that the value of an environmental asset is directly related to the various ecological and economic functions which it fulfils. So, the total value of soil biodiversity from the perspective of stakeholder  $k$  can be defined as the sum of the values of each one of its ecological and economic functions, for the period of time over which they accumulate (Giller *et al.*, 1997).

$$V_{t,k} = \sum_{i=1}^n \frac{V_{i,k}(f_i)}{(1+r)^t}$$

Where,

$V_{t,k}$  = total value of soil biodiversity for stakeholder  $k$

$V_i(f_i)$  = the value of  $i$  th function of soil biodiversity for stakeholder  $k$

$i = (1, n)$

$t$  = time period,  $t = [1, m]$

$r$  = the social rate of time preference (this the rate at which society is willing to trade off present consumption for future consumption, often taken to be equal to the rate of discount).

Although this definition may express the principles to apply, it is by no means clear how to quantify the value for each of the functions of soil biodiversity, especially if options for future land use change are to be included in the valuation.

## 4. Methods for assessing impacts of forest conversion and agricultural intensification on belowground biodiversity

### 4.1 How to measure belowground biodiversity?

Biodiversity is not simply a measurable parameter, because it is essentially a concept rather than an entity in its own right. There are numerous problems in measurement of biodiversity. Problems in the sampling and extraction of organisms from soil are common to many groups. For example, even dispersion of soil by gentle shaking can result in strong shearing forces as particles grind against one another. Furthermore, even at the level of alpha diversity (the diversity within 1 plot or sample, see lecture note 5), the minimum size of the sample must be determined both by knowledge of the ecology of the organism in question and by knowledge of the spatial heterogeneity within the habitat under study, and thus cannot be generalised across groups (Box 5).

Various reasons for the difficulties in assessing the functional implications of animal diversity in soil are listed below.

- a) Technical problems - for example, techniques of sampling and extraction have not yet been fully developed for many groups. A further obstacle is the inability to study the organisms involved *in situ* as they can be hidden behind soil particles

(Wolters, 1998). Diversity measurements are further complicated by the enormous variety of life-cycles and phenology.

- b) Problems associated with the manipulation of biodiversity in soil, e.g. land use change.
- c) The domains of soil organisms are several orders of magnitude below the scales at which ecosystem processes are measured.
- d) There are no clear answers to questions about the functional role of soil invertebrates, for fundamental reasons such as:
  - several mechanisms can compensate for potential effects of species richness at higher temporal and spatial scales,
  - species richness effects depend strongly on local conditions that are insufficiently understood, so that generalisations have little predictive value.

### **Box 5. Problems of belowground biodiversity sampling**

(an excerpt from Giller *et al.*, 1997)

Larger soil animals such as termites can forage over distances of more than 50 m from their nests (Wood, 1988), and can disperse over much larger distances when they fly, whereas smaller animals are relatively sedentary. Even among microorganisms, basidiomycete fungi can forage several metres (Dowson *et al.*, 1988), and a single individual has been shown to cover an area of more than 15 ha (Smith *et al.*, 1992), whereas the habitat for bacterial colonies is better estimated in terms of (micro) aggregates.

Within a predefined and homogeneous sampling area, sample sizes can be optimised by determining the number of species detected in samples of increasing size [sometimes described as species/area curves - see lecture note 5]. The optimum sample size is usually taken at the point above which there is little return (in terms of an increase in the number of species detected) for further increases in sample size. There is an obvious danger that changes in diversity might be overlooked if the resolution of sampling is insufficient, and sampling intensity must be decided based on knowledge or assessment of spatial heterogeneity. Whatever approach to sampling is adopted, it is hard to avoid undersampling rare individuals. Once an acceptably representative sample has been obtained, there are problems in describing the diversity within the sample.

## **4.2. System of classification**

Classification of groups of organisms may be based on genetic and phenotypic characters, or may be purely functional (see section 2), although in practice it is mostly a mixture of the two.

The resolution of a taxonomic classification may allow easy distinction of species or individuals among some groups, but only genera can be distinguished in others. Whichever method of classification is used, there are different scales of biodiversity, and the choice of the scale or resolution for study is often determined largely by the degree of discrimination possible with the available methods.

### **Example**

The taxonomic classification of earthworms and other soil animals is largely based on morphology and is gradually evolving as more types are discovered. An ecological

classification is also used for earthworms and other soil animals, which is based on a variety of criteria (e.g. location in the soil profile, mode of feeding, diet, and morphological characteristics) and thus relates closely to their ecosystem function.

Currently, application of molecular biology methods are revolutionising our understanding of the evolutionary relationship between bacteria. In this lecture note, however, we are going to focus more on biological functions.

#### 4.3. What measure of diversity should be related to ecosystem function?

- **Species richness** is species number per area, which is used as an indicator of an ecosystem's diversity. It assumes that all species have potentially equal value with respect to function, but how can we know whether one additional earthworm species is equivalent to 0.5, 1.0, 10 or 100 additional species of mites or fungi? Many biologists lost interest in species richness after community ecologists showed that one predator species could not be treated as equivalent to one plant species.
- **Keystone species** are organisms that are particularly important for the structure and function of the soil system or they are species whose effects on their communities or ecosystems are much larger than expected from their abundance or biomass. This definition does not necessarily include species that are dominant in ecosystems. According to Folke *et al.*, 1996 (in Bengtsson 1998), a limited number of organisms and groups of organisms seem to control the critical processes necessary for ecosystem functioning; an example is the group of 'ecosystem engineers' (section 2). NB please refer to lecture note 5 for a critical examination of the concept of 'keystone' species.
- **Functional groups** are usually defined with respect to some ecosystem function. But what are these ecosystem functions? Ecosystem functions here are loosely defined as ecosystem processes and ecosystem stability. Bengtsson (1998) suggested that the important issues concern:
  - a) whether the diversity of species or functional groups of decomposers and soil animals affects the rates of processes such as decomposition and nutrient cycling,
  - b) if diversity affects process rates or community composition of soil organisms in response to perturbations such as climatic change or introduced species.

Using the diversity of functional groups in an ecosystem would, in theory, be the most efficient and useful way to relate diversity to ecosystem function. However, the tests for the effects of functional group diversity may actually test our ability to properly define functional groups rather than the effects of diversity.

- **Foodweb complexity** is a measure of diversity based on the relationship between complexity (in terms of feeding relations) and stability in ecosystems, using species richness and foodweb connectance as measures of complexity. This measure can also be relevant for the diversity-function issue. For example, ecosystem engineers such as termites and earthworms have effects on carbon and nutrient distributions and soil structure that can not be solely attributed to feeding interactions. These non-trophic effects need to be included in the concept of functional groups to make it more useful, and it would be more desirable to include some measure of the strengths of consumer-resource and non-trophic interactions when defining functional groups. So the construction of interaction webs for soil systems should be based on consistent definitions of functional groups, not only in terms of feeding, but also on the other activities. Therefore, for

measuring biodiversity, collaboration between a large number of soil ecologists will be required.

In soils, this issue has been examined by De Ruiter *et al.* (1998), who argued that real soil food webs are stable because of compartmentation and variation in interaction strength across trophic levels.

#### Questions

Changes of land management may change soil organic matter (SOM) status and belowground diversity.

- Does it matter if one species disappears? Can other species replace its function?

#### Box 6. Case study: Decline in species richness of earthworm as a result of land management (Hairiah, 1999).

Changes of land management may change SOM status and subsequently affect the abundance and diversity of "soil engineers". Most soil biota respond to litter quality, e.g. termites respond more to low quality material, ants respond to high quality, while earthworms appear not respond to litter quality. Brown *et al.* (1998, cited in Hairiah, 1999) showed that when forest was converted to agricultural land in Kenya, Tanzania, Zambia and Zimbabwe, diversity and biomass of fauna was reduced from >16 orders and 9 g m<sup>-2</sup> on average to < 7 orders and 5 g m<sup>-2</sup>. However in some pastures and crop fields, biomass is higher than that found in forests, reaching > 20 g m<sup>-2</sup> primarily due to the stimulation of earthworm, *Coleoptera* (beetle) or termite populations.

Organic matter management practices such as hedgerow intercropping systems can have a big impact on decomposition, nutrient mineralisation and microbial activity. Earlier work in a secondary forest of N. Lampung (Indonesia) showed the highest microbial biomass (106 mg kg<sup>-1</sup>), total microbial populations (224x10<sup>4</sup> CFU\*) and microbial activity (7 mg kg<sup>-1</sup> day<sup>-1</sup> of CO<sub>2</sub> produced) compared to those found on 8 year-old plots of hedgerow intercropping systems with inputs from pruning of *Peltophorum*, *Gliricidia*, *Calliandra*, *Leucaena* or *Flemingia* hedgerows (Priyanto, 1996, cited in Hairiah, 1999). In the same plots, Wibowo (1999, cited in Hairiah, 1999) found 7 species of earthworm under secondary forest, reduced to 6 for hedgerow intercropping systems (*Peltophorum*, *Gliricidia* and mixed *Peltophorum* + *Gliricidia*) and 5 species for control plots (without hedgerows), respectively (Table 7).

**Box 6. (continued). Case study: Hairiah 1999.**

Table 7. Species richness of earthworms under secondary forest and agricultural land in North Lampung in dry (D) and rainy (R) seasons (Wibowo, 1999, cited in Hairiah, 1999).

Species	Forest		Hedgerow intercropping						Control		Ecological group*
	D	R	Pelt.		Gliri.		Pelt+Gliri		D	R	
<i>Megascolex filiciseta</i>	V	V	V	V	V	V	V	V	V	V	Aneic
<i>Glyphidrilus papillatus</i>	V	V	V	V	V	V	V	V	V	V	Endogeic
<i>Drawida burchardi</i>	V	V	V	V	V	V	V	V	V	V	Aneic
<i>Dichogaster affinis</i>	V	V	V	V	V	V	V	V	V	V	Endogeic
<i>Dichogaster crawi</i>	V	V	V	V	V	V	V	V	-	-	Endogeic
<i>Pontoscolex corethrusus</i>	V	V	V	V	V	V	V	V	V	V	Endogeic
<i>Metapheretima carolinensis</i>	V	V	-	-	-	-	-	-	-	-	Epigeic
<b>TOTAL SPECIES</b>	<b>7</b>	<b>7</b>	<b>6</b>	<b>6</b>	<b>6</b>	<b>6</b>	<b>6</b>	<b>6</b>	<b>5</b>	<b>5</b>	

\*Colony Forming Unit

\*\*See section 2

The epigeic species i.e. *Metapheretima carolinensis* disappeared due to forest conversion to agricultural land. A continuous maize monoculture cropping system as the control plot led to the disappearance of 2 earthworm species, i.e. *Metapheretima carolinensis* and *Dichogaster crawi* (endogeic). **Does it matter, if one or two earthworm species disappear?** The missing epigeic species under maize monoculture cropping system may lead to a slower decomposition rate of soil organic matter as this group progressively fragments litter and participates in decomposition *in situ* (Lavelle *et al.*, 1994).

No effect of season and litter quality on the earthworm species richness were found on the sandy loam soil in N. Lampung, as species composition found under *Peltophorum* (low quality i.e. high polyphenolic concentration) equalled that found under *Gliricidia* (high quality).

Further integrated research is needed, however, to better understand the role of soil engineers in transporting litter from the soil surface to deeper soil layers.

Understanding the important role of soil biota in decomposition of organic material can help us to obtain an improved soil management strategy which may contribute more to sustainable agricultural systems.

**BUT...the other side of the coin: earthworms can also be pests!**

We all believe that under low-input agricultural systems, earthworms play very important functional roles in maintaining soil fertility and crop productivity. An example of earthworms becoming pests in irrigated rice fields in the Philippines, however, is presented in Box 7.

### **Box 7. Case Study: Earthworms in the Ifugao Rice Terraces (IRT), Philippines.**

'Soil engineers' making macropores in the soil are not welcome in all circumstances. In particular, in bunded rice fields, the farmers make an effort to destroy soil structure to reduce the porosity of the soil by puddling, and build dykes to contain the water – only to be counteracted by the 'soil engineers' of the place.

Surveys were conducted across three municipalities of IRT, namely Banaue, Hungduan and Mayoyao. A total of 150 farmers were selected randomly as respondents (Joshi *et al.*, 1999). The purpose of the survey was to learn farmers' knowledge, attitudes and practices on the extent and nature of the problem in the irrigated rice fields that was caused by the earthworm. Of 150 farmer-respondents interviewed, 125 farmers ranked earthworms as the most important pest of terraced rice fields. The farmers described the problem as follows:

***The earthworms seem to cause damage to the rice fields by making tunnels along the terrace walls, causing leaks, resulting in undesired water drainage from the fields.***

*Which species are they?* There are two groups:

a. Terrace-dwelling species

- *Polypheretima elongata* (the dominant one)
- Large worm species belonging to either *Pheretima* or *Metaphire* genera
- *Pontoscolex corethrusus* (Fr Muller)
- *Pithemera bicinta* (Perrier)
- *Amyntas diffringens* (Baird)

b. Non-terrace-dwelling species

- *Polypheretima* sp. -- a hitherto undescribed species.
- *Pheretima* sp.-- a hitherto undescribed species
- *Pleinogaster* sp.

Of all the terrace dwelling species, only *Pontoscolex corethrusus* was present in the neighbouring forest area. The others are probably new to the area, and may be exotic species. These invasions occur most often in locations affected by human activity, and rarely in natural vegetation with a resident earthworm fauna. In general, native earthworms are vulnerable to habitat disturbance and invasion by exotic species.

*How to control them?*

Besides mechanical control (e.g. tillage), farmers used indigenous methods of control e.g. the use of ground wild sunflower (*Tithonia diversifolia*) or seeds of the neem tree (*Azadirachta indica*) mixed with water and poured evenly over the plot, to kill the worms.

#### **4.4. Which groups should we study and why-what do they tell us?**

The diversity below ground is huge, comprising a wide array of fungi, bacteria, protists and representatives of the majority of terrestrial invertebrate phyla. No survey can realistically hope to cover all groups. In the context of the Alternatives to Slash and Burn (ASB) activity, the Tropical Soil Biology and Fertility group (TSBF) suggested the functional groups that should be measured (Table 8). These were: soil engineers; decomposers and foodweb species; C, N and P transformers and symbionts. So the ASB

approach has therefore been to concentrate on a sub-set of taxa. These have been selected largely on two criteria - that they have significant and relatively well-defined functions of significance at the ecosystem scale or beyond; and that they are methodologically accessible for biodiversity studies.

There is, as yet, little evidence to guide us in determining the extent of soil biodiversity that should be maintained in an agroecosystem or other land-use in order to obtain the benefits described in Table 3. The only exception to this generalisation is the case of nitrogen-fixing bacteria which have been studied sufficiently to derive some insights into the value of their benefits, although even here there is still a large area of uncertainty (Giller and Wilson 1991). The challenge remains both to evaluate the benefits of soil biodiversity and to develop the means for its conservation and management.

Soil organisms can be manipulated directly (*e.g.* by inoculation) or indirectly through soil management ('planned diversity', tillage, selective pesticides etc.) or plant and organic matter management (Swift *et al.*, 1998). Thus there is the potential for developing an integrated approach to soil management analogous to the IPM concepts in pest control (Woomer and Swift, 1994; Brussaard, 1998).

#### **4.4. Restoration of biodiversity and functions**

If functions are lost as biodiversity is reduced and organisms become extinct, the restoration of biodiversity should logically lead to the restoration of functions and of resilience. In practice, however, it is likely that restoration of biodiversity and associated biological functions may not follow the same pathway as their loss.

##### **Example**

An introduction experiment by Couteaux *et al.* (1991, cited in Giller *et al.*, 1997) demonstrated a strong effect of resource **quality** on decomposition rates of litter by animal communities of differing complexity. No effects on respiration from litter with a high N content (%) were observed, whilst adding nematodes, collembola and isopods (woodlice) progressively increased respiration rates from a low N content (0.5%) litter. Increased soil respiration indicates a higher activity of soil biota. Such experiments are powerful ways of exploring interactions between different groups of organisms and are very useful in elucidating the importance of biodiversity.

### **5. Results obtained so far on tropical land use change**

#### **5.1 Belowground biodiversity in forest and agricultural land cover types**

A popular assumption is that anthropogenic interference with nature results in a loss of biological diversity. The most frequently cited example of agricultural intensification directly resulting in reduction in biodiversity is that of the tropical rainforest clearance where the diversity of plant and animal species is reduced catastrophically.

Yet examination of the literature suggests that there is little detailed evidence for agricultural intensification resulting in loss of belowground biodiversity. Data collected by the ASB consortium in Indonesia (see Box 8) suggest that the difference between land cover types is smaller than expected -- at least at a 'functional group' level, as applied in the initial surveys.

Table 8. Main functional groups of soil organisms; the groups in *italics* are included in the TSBF Soil Biodiversity Network in the ASB project

	engineers & comminutors	decomposers & foodweb	C, N and P transformers	acquisition & manufacture symbionts	rhizovores, plant parasites & diseases	antagonists & suppressants
macrofauna	<i>earthworms</i> <i>termites</i>	<i>ants</i> , <i>cockroaches</i> , <i>millipedes</i> , <i>centipedes</i>				
mesofauna	enchytraeids	<i>nematodes (omnivores, bacterivores, fungivores, predators)</i> , Collembola, mites			termites (plant parasitic)	
microfauna		protozoa				
fungi		" <i>microbial biomass</i> ", <i>platable fungi, substrate-specific groups</i>		<i>mycorrhiza (endo- and ecto-)</i>		parasitic fungi, nematophagous fungi
protista						
bacteria			methanogens & <i>methanotrophs</i> <i>nitrifiers</i> & denitrifiers, P-solubilizers	<i>Rhizobium</i> , Frankia, Azotobacter Azospirillum		

**Box 8. ASB-Indonesia results** (see Tomich *et al.*, 1998)

As part of the ASB research in Indonesia, a comparison was made of soil biodiversity in representative land use systems in Jambi and Lampung. The data are here grouped into five classes:

- F = forest (in Jambi: approximately natural or logged-over, in Lampung: logged-over, degraded)
- A = agroforest (rubber agroforest or mixed fruit trees)
- R = regrowing trees, young plantations and agroforests
- C = cassava, potentially in rotation with Imperata grassland
- I = Imperata grassland, potentially in rotation with cassava

Data collection included soil fauna of the litter layer and the upper layers of the soil. As a first approximation presence/absence was evaluated of a number of 'functional groups', roughly representing Orders as taxonomic units (e.g. millipedes, centipedes, cockroaches, beetles, spiders...). Data are here represented as the maximum number of groups observed for a given location or land cover.

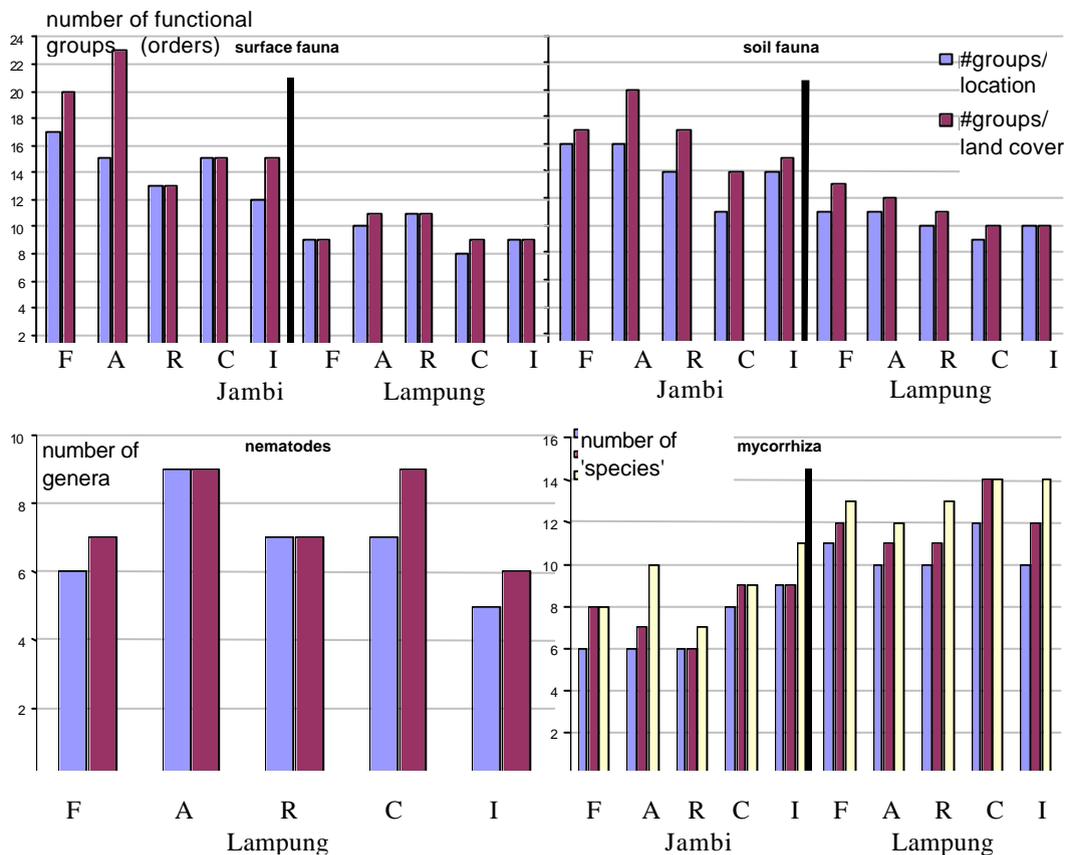


Figure 5. Results of belowground biodiversity surveys by ASB in Indonesia

The results of ASB surveys in Indonesia (Box 8, Figure 5) showed that at this level of analysis the effect of even very drastic land cover change, is not nearly as dramatic as expected: most functional groups at order level remain present when forest cover disappears and is replaced by a cassava field or Imperata grassland. For groups where more detailed data were collected, i.e. nematodes at genus level and mycorrhiza spores

at 'species' level (Figure 5), land cover did not influence richness (nematodes) or there was a tendency for enrichment in the C and I land cover types (mycorrhiza).

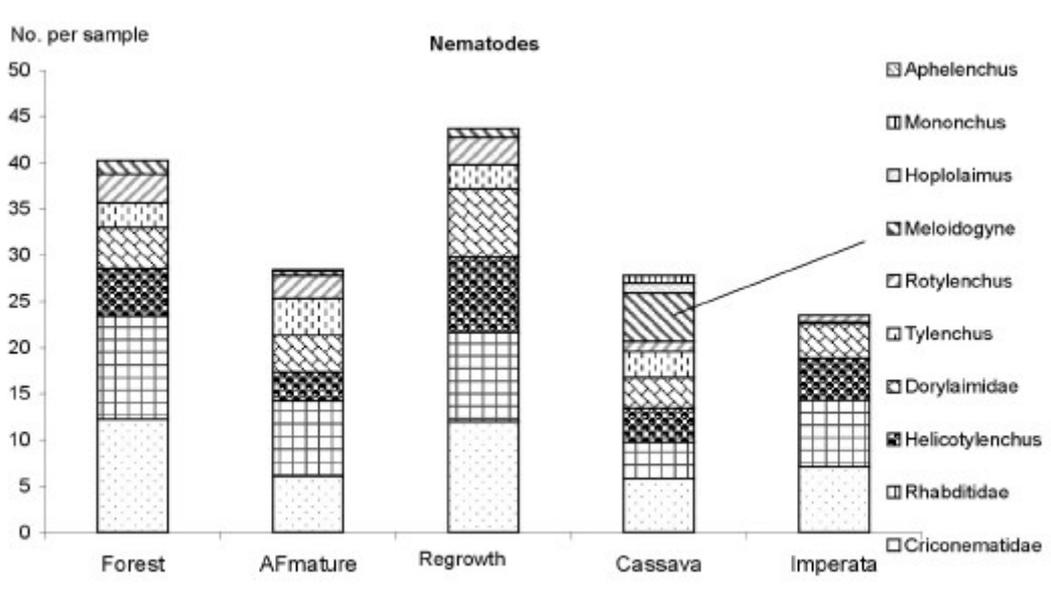


Figure 6. Nematode abundance in five land cover types sampled by ASB Indonesia (unpublished data of Gede Swibawa, Lampung University).

A closer look at the survey data for nematodes in the land cover types in Lampung, Indonesia (Figure 6) gives the impression of several shifts in abundance of groups. For example the plant parasitic root-knot nematodes (*Meloidogyne* spp.) are most abundant in the cassava plots, but virtually absent in *Imperata* grassland. Such shifts are not noticed if we only look at presence/absence of major groups.

A possible explanation for this lack of major impacts, however, can be that in the soil the loss of forest cover takes time to be noticed – root residues of forest trees remain present for several years after forest conversion (e.g. Box 9), and continue to provide a micro-environment for soil biota that may not be able to survive in the new land cover/land use system as such. So, it is possible that the survey data do not yet show the full impacts of land use change, but represent a transitional or lag phase.

Therefore, it seems likely that we have to look at biodiversity in more detail than just at the level of 'overall functional groups', and look at the actual species they contain. Fragoso *et al.*, 1997, reported that agricultural intensification resulted in a loss of biodiversity in soil e.g. the changes in earthworm populations on conversion from tropical rainforest to pasture where a single (introduced?) species survived: this led to soil compaction due to the massive surface casting activity of this species. This is an important example where the reduction in diversity (within a 'group') is coupled to, and presumably responsible for, a loss in function that has resulted in substantial loss in agricultural productivity. In other cases, the extent to which soils can be mistreated and yet crops still continue to support abundant plant growth seems remarkable. Thus, not only is there no clear link between agricultural intensification and biodiversity, but the consequences of loss of biodiversity for functioning of ecosystems also await detailed investigation.

### Box 9. Old tree root channels

Partly decomposed remains of root systems can facilitate subsequent plant roots and their symbionts. In acid soils in the humid tropics old tree root channels can be important for crop root penetration, water infiltration and nitrogen management (Van Noordwijk *et al.*, 1991). Decaying roots of a previous forest vegetation provide a micro-environment facilitating nodule development of subsequent tree plantations (Figure 7).

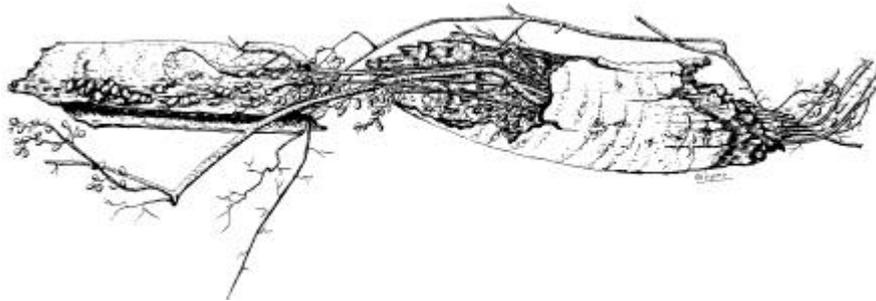


Figure 7. *Acacia mangium* growing in decaying tree root from the previous forest vegetation in southern Sumatra (Indonesia). Inside this old tree root, the *A. mangium* roots had many root hairs and were profusely nodulated, while nodulation in mineral soil was far less (drawing by Wiyono).

## 5.2 Effects of burning on belowground biodiversity

The long term impacts of land use change on soil biota were smaller than expected (Box 8). What about the direct impacts of Slash-and-Burn? Results from a field study (Djunaedy, 1999) on the effect of burning on the biological activity of soil biota and on the populations of microbes and earthworms are presented in Box 10.

### Box 10. Direct effects of slash-and-burn land clearing fires on soil biota (Djunaedy, 1999)

The objectives of this field study were:

- to study the effects of burning on populations and activities of soil organisms
- to study the recovery after burning.

#### *Methods*

Controlled 'secondary burns' were carried out, using piles of wood left over from a primary (whole-field) burn. Repeated sampling was conducted, to measure CO<sub>2</sub> release (an indicator of the activity of soil organisms), microbial activity ('Most Probable Numbers' obtained by the method of 'plating out' in a dilution series) and earthworm presence. The samples were classified by the maximum surface temperature achieved during the burn event.

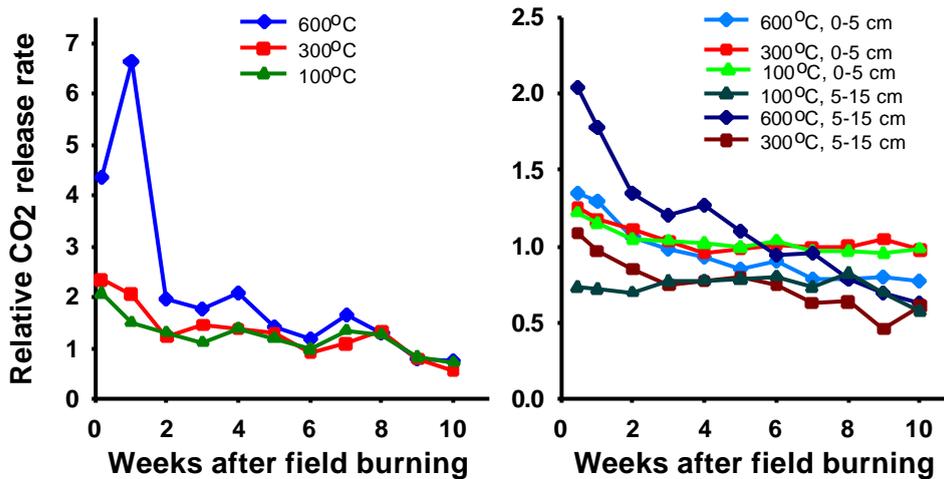


Figure 8. Rate of CO<sub>2</sub> release from soils (relative to that of a forest soil used as control) as a function of time after a pile-up burn, at sites where the soil surface temperature reached 100, 300 or 600°C during the fire: *in situ* measurements made in the field (graph on left); *ex situ* measurements made in the laboratory (graph on right).

The rate of CO<sub>2</sub> release from the burnt plots remained high for 2 weeks (Figure 8), but eventually declined to below that of a forest control (relative figures are given, as small peaks in respiration after rainfall complicate the picture otherwise).

Fire virtually sterilised the top 5 cm of soil (Figure 9), but within 1 week the patch was recolonized, probably contributing to the high CO<sub>2</sub> release by respiration of remaining organic substrate in the soil.

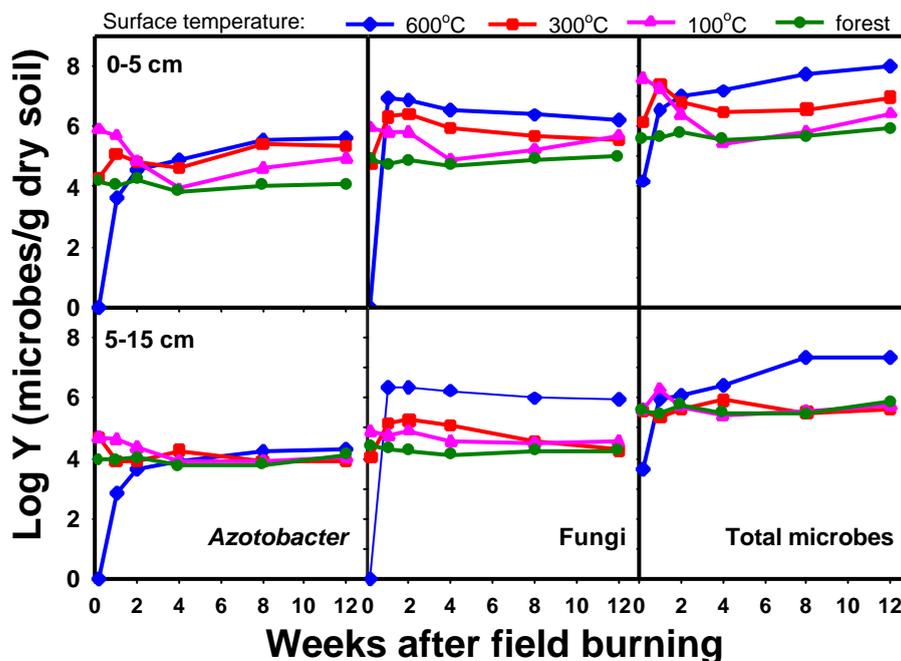


Figure 9. Development of microbial populations after fires of different intensities.

Earthworms don't like it hot, but also don't like the dry 'control' forest; overall the impacts of these secondary burns can not be distinguished from the effects of a long dry season in the 'control' forest (Figure 10).

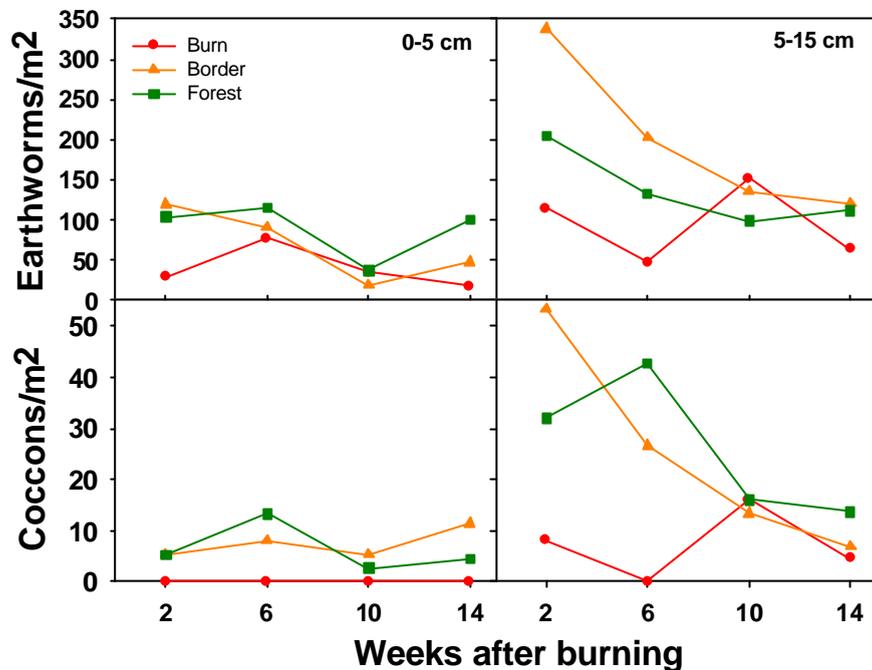


Figure 10. Earthworm counts as a function of time, under secondary burn plots (classified by their peak surface temperature during the burn) and in a neighbouring, non-burned 'control' forest where the soil dried out progressively.

### Conclusions

- Burning immediately reduced microbial populations (*Azotobacter*, fungi and total microbes) on the hottest sites, but one week later the population started to recover,
- Although short-term CO<sub>2</sub> release increased, long-term soil respiration declined after intense and moderate burning,
- Slash-and-burn practices (with low-medium burn intensities) do not significantly affect earthworm populations.

## 5.3 Effect of fallow-type on belowground crop parasites

The conversion of forest to agriculture is just one aspect of tropical land use change that affects belowground biodiversity. Changing an agricultural system, by 'improving' the fallow vegetation that occurred between cropping cycles, also had an effect on belowground biodiversity, in a way that was very important to farmers (Box 11).

**Box 11. Case study from Kenya (Desaeger and Rao, 2000):**

**Parasitic nematodes under sesbania cover crops reduced the yield of subsequent crops**

Fallows (either short or long duration) are generally expected to increase soil fertility as evident from the yield of subsequent crops. Sesbania (*Sesbania sesban*) is one of the best cover crops because of its high N-fixation, rapid growth and high biomass production and good quality of leaf residue (Kwesiga and Coe, 1994; Mafongoya *et al.*, 1998, cited in Desaeger and Rao, 2000). BUT...the downside is that it is a host plant for root-knot nematodes (*Meloidogyne* spp.) which attack many field crops such as bean (*Phaseolus vulgaris*), tobacco (*Nicotiana tabacum*), cotton (*Gossypium* spp.), potato (*Solanum tuberosum*), tomato and many other vegetables. Replacing a multi-species natural fallow by a monoculture of sesbania as a fallow may thus entail a risk for subsequent crops, despite the increased N supply in the soil.

A field study was conducted at two sites in western Kenya during 1995-1997, to evaluate the effects of a 6-12 month Sesbania cover crop in comparison with 6 and 12 month natural 'weed fallows', a 6 month crotalaria (*Crotalaria agatiflora*) cover crop and continuous maize cropping on the dynamics of parasitic nematode populations and their effects on subsequent maize and bean crops (Desaeger and Rao, 2000). The four types of nematodes monitored were: root-knot (*Meloidogyne* spp), root-lesion (*Pratylenchus zae*), reniform (*Rotylenchulus variabilis*) and spiral (*Helicotylenchus* spp, and *Scutellonema*). The results showed that:

- Although a number of plant species in **natural fallows** were hosts to two species of root-knot nematodes (*Meloidogyne incognita* and *Meloidogyne javanica*), even natural fallows 12 months long **DID NOT increase** populations of these nematodes to a level which caused any significant yield reduction in the subsequent nematode-susceptible bean.

BUT.....

- A 12-month **sesbania fallow** increased *Meloidogyne* spp. populations greatly in soil and roots, and sesbania itself appeared to be fairly tolerant to nematodes over a 12-month growing period. Maize was not damaged by the root-knot nematodes after sesbania, but bean yields were reduced by 52 – 87 %.

## 6. Hypotheses and conclusions

There appears to be less variation among land uses in belowground biodiversity compared to aboveground biodiversity. This may be due to:

- c) a 'lag' effect as the full impacts of land use change on belowground organisms take a longer time to come into effect than for aboveground organisms,
- d) too crude a level for evaluating the impacts – the main 'functional groups' remain present, but it is the within-group diversity that is affected

Explanations a) and b) can be the basis for **hypotheses** that warrant further testing.

The direct impact of slash-and-burn land clearing events on soil microbial properties and earthworm activity is limited and of the same magnitude as the effect of a long dry season. The resilience of soil organisms in re-colonising soil layers or patches that have become temporarily unsuitable is remarkable.

Despite little aboveground biodiversity, *Imperata* grasslands appear to provide a healthy belowground ecosystem. There is no evidence of serious soil biological constraints to conversion of *Imperata* grasslands to other agricultural land uses.

For specific groups such as nematodes or earthworms, changes in species composition (not necessarily in diversity as such) can have important consequences, and may require detailed study; we understand too little about the belowground foodwebs to attribute such effects to ‘biodiversity’ at large.

A coherent set of methods is available for sampling soil biota to further test the tentative results and hypotheses presented here.

### III. Reading Materials

#### Textbooks

- Alexander M. 1977. *Introduction to Soil Microbiology*. Wiley, London. 467 pp.
- Brown S, Anderson JM, Woome PL, Swift MJ and Barrios E. 1994. Soil biological processes in tropical ecosystems. In: Woome PL and Swift MJ. (eds.) *The Biological Management of Soil Fertility*. John Wiley & Sons, UK. pp. 15-46.
- Giller KE and Wilson KJ. 1991. *Nitrogen Fixation in Tropical Cropping Systems*. CAB International, Wallingford, UK. 200 pp.
- Lavelle P, Dangerfield M, Fragoso C, Eschenbrenner V, Lopez-Hernandez D, Pashanasi, B and Brussaard L. 1994. The relationship between soil macro-fauna and tropical soil fertility. In: Woome PL and Swift MJ. (eds.) *The Biological Management of Soil Fertility*. John Wiley & Sons, UK. pp. 137-170.
- Marschner H. 1995. *Mineral Nutrition of Higher Plants*. Academic Press Ltd, London. pp. 447-458.
- Rao NSS. 1977. *Soil Microorganisms and Plant Growth*. Science Publishers, Inc. pp. 7-74.
- Woome PL and Swift MJ. 1994. *The Biological Management of Soil Fertility*. John Wiley & Sons, UK. 243 pp.

#### Proceedings

- Hairiah K. 1999. Changes of decomposition rate of different litter quality under different soil biological condition. In: A Gafur, FX Susilo, M Utomo and M van Noordwijk (eds.). *Proceedings of a Workshop on Management of Agrobiodiversity in Indonesia for Sustainable Land Use and Global Environmental Benefits*. UNILA/PUSLIBANGTAN, Bogor, 19-20 August 1999. ISBN 979-8287-25-8. p53-61.
- Hairiah K, Cadisch G, van Noordwijk M, Latief AR, Mahabharata G and Syekhfani. 1995. Size-density and isotopic fractionation of soil organic matter after forest conversion. In: A Schulte and D Ruhiyat (eds.) *Proc. Balikpapan Conf. on Forest Soils Vol. 2*: 70-87. Proceedings also published as: A Schulte and D Ruhiyat (eds.) 1998. *Soils of Tropical Forest Ecosystems: Characteristics, Ecology, and Management*, Springer Verlag, Berlin. 206 pp.
- Van Noordwijk M and Swift MJ. 1999. Belowground biodiversity and sustainability of complex agroecosystems. In: A Gafur, FX Susilo, M Utomo and M van Noordwijk (eds.). *Proceedings of a Workshop on Management of Agrobiodiversity in Indonesia for Sustainable Land Use and Global Environmental Benefits*. UNILA/PUSLIBANGTAN, Bogor, 19-20 August 1999. ISBN 979-8287-25-8. p 8- 28.

#### Scientific journal articles

- Beare MH, Reddy MV, Tian G and Srivastava SC. 1997. Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of decomposer biota. *Applied Soil Ecology* 6(1): 87-108.
- Bengtsson J. 1998. Which species? What kind of diversity? Which ecosystem function? Some problems in studies of relations between biodiversity and ecosystem function. In: Wolters (ed.) *Functional aspects of animal diversity in soil*. *Applied Soil Ecology* 10: 191-199.
- Black HIJ and Okwakol MJN. 1997. Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of termites. *Applied Soil Ecology* 6(1): 37-54.
- Brussaard L. 1998. Soil fauna, guilds, functional groups and ecosystem processes. *Applied Soil Ecology* 9: 123-135.

- De Ruiter PC, Neutel AM and Moore JC. 1995. Energetics, patterns of interaction strengths and stability in real ecosystems. *Science* 269: 1257-1260.
- De Ruiter PC, Neutel AM and Moore JC. 1998. Biodiversity in soil ecosystems: The role of energy flow and community stability. In: Wolters (ed.) *Functional aspects of animal diversity in soil. Applied Soil Ecology* 10: 217-228.
- Desaeger J and Rao MR. 2000. Parasitic nematode populations in natural fallows and improved cover crops and their effects on subsequent crops in Kenya. *Field Crops Research* 65: 41-56.
- Eggleton P, Bignell DE, Sands WA, Mawdsley NA, Lawton JH, Wood TG and Bignell NC. 1996. The diversity, abundance and biomass of termites under differing levels of disturbance in the Mbalmayo Forest Reserve, southern Cameroon. *Phil. Trans. R. Sco.* 351: 51-68.
- Fragoso C, Brown GG, Patron JC, Blanchart E, Lavelle P, Pashanasi B, Senapati B and Kumar T. 1997. Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of earthworms. *Applied Soil Ecology* 6: 17-35.
- Giller KE, Beare MH, Lavelle P, Izac AMN and Swift M J. 1997. Agricultural intensification, soil biodiversity and agroecosystem function. In: Swift M J (ed.), *Soil biodiversity, agricultural intensification and agroecosystem function. Applied Soil Ecology* 6 (1): 3-16.
- Joshi RC, Matchoc ORO, Cabigat JC and James SW. 1999. *Journal of Environmental Science and Management* 2(2):1-12.
- Sanchez PA, Villachica JH, Bandy DE. 1983. Soil fertility dynamics after clearing a tropical rainforest in Peru. *Soil Science Society of America Journal* 47 (6): 1171-1178.
- Swift MJ, Andren O, Brussaard L, Briones M, CouteauxMM, Ekschmitt K, Kjoller A, Loiseau P and Smith P. 1998. Global change, soil biodiversity and nitrogen cycling in terrestrial ecosystems: three case studies. *Global Change Biology* 4 (7): 729-743.
- Van der Putten WW, Van Dijk C and Peters BAM. 1993. Plant-specific soil-borne diseases contribute to succession in foredune vegetation. *Nature* 362: 53-56.
- Van Noordwijk, M., Widiyanto, Heinen, M. and Hairiah, K. 1991. Old tree root channels in acid soils in the humid tropics: important for crop root penetration, water infiltration and nitrogen management. *Plant Soil* 134: 37-44.
- Van Noordwijk M, Brouwer G and Harmanny K. 1993. Concepts and methods for studying interactions of roots and soil structure. *Geoderma* 56: 351-375.
- Wolters V. 1998. Functional aspects of animal diversity in soil introduction and overview. In: Wolters (ed.) *Functional aspects of animal diversity in soil. Applied Soil Ecology* 10:185-190.

## Reports / Manuals

- Swift MJ and Bignell D (eds.), 2000. Standard methods for assessment of soil biodiversity and land use practice. *Alternatives to Slash and Burn Project. ICRAF, Nairobi.* 41 pp.
- Tomich TP, van Noordwijk M, Budidarsono S, Gillison A, Kusumanto T, Murdiyarso D, Stolle F and Fagi AM, eds. 1998. *Alternatives to Slash-and-Burn in Indonesia: Summary Report & Synthesis of Phase II. ASB-Indonesia Report Number 8. Bogor, Indonesia: ASB-Indonesia and ICRAF Southeast Asia.*

## Theses

- Djunaedy. 1999. Pengaruh tebas bakar terhadap populasi dan aktivitas organisma tanah. [Effect of slash-and-burn on populations and activity of soil organisms.] MSc Thesis. Program Pasca Sarjana, Institut Pertanian Bogor [Bogor Agricultural University, Indonesia]. 58 pp.

## Contents of this series of lecture notes

1. Problem definition for integrated natural resource management in forest margins of the humid tropics: characterisation and diagnosis of land use practices  
*by: Meine van Noordwijk, Pendo Maro Susswein, Cheryl Palm, Anne-Marie Izac and Thomas P Tomich*
2. Land use practices in the humid tropics and introduction to ASB benchmark areas  
*by: Meine van Noordwijk, Pendo Maro Susswein, Thomas P Tomich, Chimere Diaw and Steve Vosti*
3. Sustainability of tropical land use systems following forest conversion  
*by: Meine van Noordwijk, Kurniatun Hairiah and Stephan Weise*
- 4A. Carbon stocks of tropical land use systems as part of the global C balance: effects of forest conversion and options for 'clean development' activities.  
*by: Kurniatun Hairiah, SM Sitompul, Meine van Noordwijk and Cheryl Palm*
- 4B. Methods for sampling carbon stocks above and below ground.  
*by: Kurniatun Hairiah, SM Sitompul, Meine van Noordwijk and Cheryl Palm*
5. Biodiversity: issues relevant to integrated natural resource management in the humid tropics  
*by: Sandy E Williams, Andy Gillison and Meine van Noordwijk*
- 6A. Effects of land use change on belowground biodiversity  
*by: Kurniatun Hairiah, Sandy E Williams, David Bignell, Mike Swift and Meine van Noordwijk*
- 6B. Standard methods for assessment of soil biodiversity and land use practice  
*by: Mike Swift and David Bignell (Editors)*
7. Forest watershed functions and tropical land use change  
*by: Pendo Maro Susswein, Meine van Noordwijk and Bruno Verbist*
8. Evaluating land use systems from a socio-economic perspective  
*by: Marieke Kragten, Thomas P Tomich, Steve Vosti and Jim Gockowski*
9. Recognising local knowledge and giving farmers a voice in the policy development debate  
*by: Laxman Joshi, S Suyanto, Delia C Catacutan and Meine van Noordwijk*
10. Analysis of trade-offs between local, regional and global benefits of land use  
*by: Meine van Noordwijk, Thomas P Tomich, Jim Gockowski and Steve Vosti*
- 11A. Simulation models that help us to understand local action and its consequences for global concerns in a forest margin landscape  
*by: Meine van Noordwijk, Bruno Verbist, Grégoire Vincent and Thomas P. Tomich*
- 11B. Understanding local action and its consequences for global concerns in a forest margin landscape: the FALLOW model as a conceptual model of transitions from shifting cultivation  
*by: Meine van Noordwijk*
12. Policy research for sustainable upland management  
*by: Martua Sirait, Sandy Williams, Meine van Noordwijk, Achmad Kusworo, Suseno Budidarsono, Thomas P. Tomich, Suyanto, Chip Fay and David Thomas*

35 M

30

20

10



**DSO**



 **Queen Mary**  
University of London



INTERNATIONAL CENTRE FOR RESEARCH IN AGROFORESTRY

Southeast Asian Regional Research Programme

Jl. CIFOR, Situ Gede, Sindang Barang

PO Box 161, Bogor 16001, Indonesia

Tel: +62 251 625415, fax: +62 251 625416, email: [icraf-indonesia@cgiar.org](mailto:icraf-indonesia@cgiar.org)

Web site: <http://www.icraf.cgiar.org/sea>

10 bc1b c  
9 28