Soil Fauna and Litter Decomposition in Primary and Secondary Forests and a Mixed Culture System in Amazonia

Final Report 1996-1999

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Fauna de Solo e Decomposição da Serapilheira em Florestas Primárias e Secundárias e em Sistema de Cultivo Misto na Amazônia

Relatório Final (1996-1999)

Resumo

Estudo sobre a fauna de solo e decomposição da serapilheira foi feito em três diferentes ecossistemas na Amazônia central: uma floresta primária (FLO), uma floresta secundária (SEC), e duas parcelas de cultivo misto (POA, POC). As investigações incluíram a avaliação da produção e estoque de serapilheira, parâmetros do solo, fatores microclimáticos, abundância e biomassa da fauna de solo, a determinação da respiração no solo e biomassa microbiana, medidas das taxas de respiração dos componentes da fauna, e análises de nutrientes.

Fauna de solo e as taxas de decomposição nas áreas cultivadas diferem muito das áreas de floresta primária. Na floresta primária foram encontradas espécies de minhocas de grande porte, e alta freqüência e abundância de formigas e cupins. Por outro lado, nas áreas de cultivo foram raras as espécies de minhocas de grande porte, formigas e cupins tiveram sua diversidade e biomassa reduzida. Nos cultivos, a fauna típica da floresta primária foi substituída por outros grupos (Isopoda, Diplopoda, caracóis). Esta alteração causa provável influência qualitativa no fluxo de nutrientes e no processo de decomposição (produção de húmus).

A área de floresta primária é caracterizada por uma alta produção de serapilheira contendo alta concentração de nitrogênio devido às altas taxas de decomposição e em conseqüência baixo acúmulo na superfície do solo. Comparado às outras áreas de estudo, na floresta primária foram mais altas a concentração de *C* e *N* (matéria orgânica do solo), o conteúdo de água na camada de serapilheira e na superfície do solo. Na área de floresta secundária, de 18 anos, apesar da baixa produção de serapilheira, o acúmulo desta foi mais alto que na floresta primária devido à baixa taxa de decomposição. As duas áreas de cultivo foram muito diferentes: em vários aspectos a área POC foi mais similar à floresta primária, e a área POA mais similar à floresta secundária. Isto mostra a alta influência do microclima, que ao menos nos anos mais extremos como em 1997 (um ano de El Niño), ou nos anos atípicos, tem uma influência restritiva à fauna do solo, e em conseqüência no processo de decomposição. O microclima é, por sua vez, influenciado pelo sistema de cultivo, e.g. através do sombreamento produzido pela planta cultivada, cobertura do solo pela serapilheira, etc. (Na área cultivada (POC) a floresta primária adjacente influenciou no microclima).

Apesar das diferenças observadas entre as áreas de estudo (floresta primária, secundária, e áreas de cultivo – sistema 4 do experimento do projeto ENV23) foi observado que em todas estas o sistema de decomposição da serapilheira foi controlado pela macrofauna. Pode-se concluir que em todos os sistemas de cultivo estudados, estão disponíveis as condições biológicas do solo necessárias para um pretendido manejo do processo de decomposição. A colonização por decompositores primários ocorre em todos as áreas, e a serapilheira é decomposta no devido tempo. Portanto, o sistema funcional do processo de decomposição do material orgânico poder ser melhorado através da manipulação das populações de espécies da macrofauna de modo indireto, i.e. por meio da modificação das condições microclimáticas conforme as espécies cultivadas em sistemas mistos ou pelo aumento da produção de serapilheira pela adição de cobertura morta no solo

Palavras-chave

Fauna de Solo, Microorganismos, Decomposição de Serapilheira, Nutrientes no Solo, Amazônia, Floresta Tropical, Sistemas Agroflorestais, Manejo Sustentável .

Objetivos

Este projeto faz parte da linha de pesquisa "Recuperação de áreas de monocultivos degradadas na Amazônia central", no programa SHIFT. O objetivo básico do projeto foi comparar duas áreas de policultivo de espécies madeireiras e florestas primárias e secundárias adjacentes com relação à quantidade, qualidade e taxas de decomposição da serapilheira, ao papel da microflora, meso e macrofauna no ciclo de nutrientes. Abundância e biomassa foi determinada para todos os grupos de artrópodos de importância funcional no ecossistema tais como Diplopoda, Isopoda, Blattaria, Cupins, Besouros, larvas de outros insetos, formigas, aranhas e Oligochaeta (minhocas e Enchytraeidae) como base para uma avaliação do papel da macrofauna no ciclo de nutrientes.

O objetivo final foi o relacionamento de taxas de decomposição da matéria orgânica, obtidos em experimentos com sacos de serapilheira, com a densidade e abundância dos organismos de solo e a avaliação dos resultados tendo em vista ao uso sustentável da terra sob o contexto agroflorestal nos trópicos.

Condições para a execução do projeto

As condições que levaram ao atendimento das metas do projeto foram - a experiência prévia dos pesquisadores envolvidos em biologia de solos amazônicos, - a participação de vários pesquisadores especialistas na avaliação da importância funcional de grupos de artrópodos e dos microorganismos e, além disto a cooperação de duas instituições brasileiras e duas alemãs.

Os experimentos de campo foram conduzidos em laboratórios e área experimental da Embrapa Amazônia Ocidental, estabelecida em 1992 em cooperação com a Universidade de Hamburgo, no programa SHIFT. Para isto os laboratórios foram reformados com recursos da Embrapa e novamente equipados com fundos do projeto Env52. Embrapa Amazônia Ocidental disponibilizou espaço no laboratório de Entomologia para execução dos experimentos e adicionalmente salas para escritório foram colocadas à disposição. A Embrapa também custeou grande parte das despesas da reforma da instalação elétrica no laboratório, e dos encargos alfandegários. Desta forma os estudos puderam ser concluídos apesar de ocasionais dificuldades técnicas devidos às freqüentes interrupções de energia. A cooperação com a Embrapa Amazônia Ocidental deveu-se acima de tudo ao apoio da administração deste centro de pesquisa; ao esforço pessoal do coordenador Dr. Luadir Gasparotto, e do coordenador técnico M.Sc. Marcos Garcia. Contou-se também com a parceria de outra instituição Brasileira, o INPA. Maior dificuldade foi encontrada no recrutamento de estudantes brasileiros de M.Sc. e PhD. e sua integração no projeto devido

às suas atividades nos cursos de pós-graduação no INPA. Apesar disto, vários estudantes puderam realizar seus estudos no projeto apoiados pelas bolsas de estudos fornecidas pelo CNPq.

Através da cooperação com a empresa privada ECT GmbH, prestadora de serviços na área de ecotoxicologia, foi instalado um aparelho para medição de gás carbônico, (Infrared- Gas-Analyzer - IRGA) e supervisionado o estudo de respiração em animais de solo. Além disto, através de pesquisadores do ECT foram desenvolvidos os estudos com Oligochaeta.

Planejamento e Realização

O projeto iniciou oficialmente em Outubro de 1996; o programa de experimentos foi iniciados em julho de 1997 em Manaus e finalizado em abril de 1999. Nas quatro parcelas de estudo pertencentes a três sistemas distintos (floresta primária - FLO, floresta secundária - SEC, e áreas de policultivo - POA e POC) foram medidos: semanalmente a queda de serapilheira, mensalmente o acúmulo de serapilheira no solo e a cada três meses (total de 8 amostragens) a meso- e macrofauna e microflora de solo. No laboratório as amostras foram pesadas, a fauna extraída e feita sua triagem em grupos taxonômicos e os substratos preparados para posteriores análises químicas (*C/N* e cátions) ou medidas de respiração. Em outubro de 1997, foi instalado no campo, um experimento com 1008 sacos de serapilheira para a medida seletiva da contribuição da fauna de solo na taxa de decomposição. Até outubro de 1998, quatorze sacos de serapilheira, em cada uma das três malhas, foram retiradas em uma serie de 7 datas de coleta e em seguida extraída a fauna, pesadas e avaliadas visualmente. Outro experimento de sacos de serapilheira foi repetido entre abril de 1998 até abril de 1999 perfazendo 6 datas de coletas.

Métodos de avaliação rápida também foram testados tais como "mini-container" (decomposição) e lâminas-isca (atividade trófica da fauna de solo). Estudos sobre a importância de predadores e da influência da qualidade dos substratos no processo de decomposição foi iniciado em 1998.

Como base para a estimativa da biomassa total dos animais de solo foram coletados exemplares dos grupos funcionais mais importantes da fauna e tomados medidas individuais, pesados e feitas análises estatísticas.

Medidas de respiração foram feitas para vários grupos da fauna de solo. Para comparação com as quatro principais áreas de estudo a respiração e decomposição no solo foram medidas em três outros sistemas, dois monocultivos e um policultivo de árvores frutíferas.

Descrição detalhada dos métodos e áreas de estudo estão em Beck et al. (1998a,b) bem como nos relatórios individuais anexados neste documento.

Resumo dos Resultados

Nas amostras destinadas à extração da mesofauna foram encontrados os ácaros Oribatei, decompositores secundários (42 - 55% de todos os artrópodos) e Collembola (4 - 13%) e ácaros predadores (19 - 29%). A abundância e biomassa de Oribatei foi mais baixa na floresta primária e alta no policultivo (POA) contrastando com todos os outros da fauna de solo. Predadores representaram 20-25% (abundância) de toda a mesofauna. A densidade de Enchytraeidae (minúsculas minhocas) apresentou diferença qualitativa entre as quatro áreas de estudo, enquanto que o grupo de Naididae (vermes supostamente aquáticos) os quais foram pela primeira vez estudados quantitativamente no habitat terrestre, foi muito mais abundante na floresta primária que nas outras áreas.

Valores da abundância média de macrofauna em 8 amostragens variaram entre 4442 Ind./m² em SEC e 5876 Ind./m² em FLO. Predadores dominaram em todas áreas com 23 - 37%. Insetos sociais foram mais abundantes em FLO (formigas 28%, térmitas 21%) e SEC (21%, 13%) que em POA e POC (formigas 13% e 16%, térmitas 6%). Ao contrário, os decompositores primários foram mais abundantes nas áreas de policultivos (20%) que nas florestas (9 e 7%). Na área de floresta secundária a macrofauna teve menores abundâncias e grande predominância de predadores e insetos sociais.

A razão formigas/decompositores mostra claramente as diferenças entre as florestas FLO e SEC (4,3 e 3,6) e os policultivos (0,7 e 0,8).

A biomassa da macrofauna (peso seco, desconsiderando minhocas) foi 1,76 g/m² na FLO e 1,57 g/m² na POC e portanto duas vezes mais alta que em SEC (0,89 g/m²) e POA (0,87 g/m²). A proporção total da biomassa de formigas foi reduzida (1,6 - 2,7%) quando comparada com sua dominância em abundância. A proporção de decompositores foi alta com 60, 66 e 70% em FLO, POA e POC, mas baixa em SEC com 33%. Predadores totalizaram 12,5% (POC), 21,5% (FLO e SEC) e 23% (POA) da biomassa de toda a macrofauna. Minhocas, as quais foram amostradas por um método especial, também mostraram maior abundância e biomassa em FLO (2,8 Ind./m², 1,5 g/m²) e POC (2,5 Ind./m², 0,5 g/m²) quando comparado com as duas outras áreas (SEC 1,6 e 1,1 Ind./m², POA 0,2 and 0,04 g/m²).

A composição de espécies da macrofauna de solo e a ordem de espécies por abundância e biomassa nas áreas de policultivos foi diferente das áreas não cultivadas. Poucas espécies de Isopoda (*Circoniscus* sp.) e de Diplopoda (Chelodesmidae, Cyrtodesmidae, Fuhrmannodesmidae, Polyxenida) foram dominantes nos policultivos. Entretanto estes parecem não ser capazes de compensar o efeito no processo de decomposição causado pelo decréscimo em número e biomassa das espécies quando a floresta primária foi convertida em cultivo.

A relação entre a densidade da macrofauna com a quantidade de liteira foi estatisticamente significante ($p<0,001$) em todas áreas de estudo, mas de muito baixo valor de predição, devido aos baixos valores de r^2 e F.

A espécie dominante na vegetação secundária *Vismia guianensis*, usada como material de referência em ambos experimentos de decomposição, teve taxa de decomposição em cerca de 20% do peso original nos sacos de serapilheira de malha grossa na floresta primária (taxa (K) negativa exponencial de decomposição/ano de 2,3 e 3,1).

As taxas de decomposição nas outras áreas foram significantemente mais baixas (Kg/ano 0,6 a 1,4). As taxas de decomposição para as malhas de 20 µm e 250 µm não apresentaram diferenças significantes, mas foram mais baixas (< 50%) que as taxas da malha grossa (10 mm). Do mesmo modo foi também observado um forte decréscimo na decomposição, através da exclusão experimental da macrofauna, em três sistemas de cultivo adicionais (dois monocultivos, um de seringueira e outro de pupunheira e um policultivo de fruteiras).

As taxas de decomposição em sacos de serapilheira nas quatro áreas de estudo foram significantemente correlacionada com a abundância de decompositores (incluindo cupins e formigas) e também com a biomassa de decompositores e de minhocas.

Na floresta primária foi observado o mais baixo acúmulo e por outro lado a mais alta queda de serapilheira em relação às outras áreas. Também na floresta foi observada a maior taxa de decomposição o que pode ser confirmado com os resultados dos experimentos com sacos de serapilheira. Ao contrário a baixa taxa de decomposição na floresta secundária levou a um maior acúmulo de serapilheira. Para as duas áreas de policultivo este dados variaram entre os valores encontrados para as duas áreas de floresta.

Durante o curso da decomposição a relação *C/N* da serapilheira padrão (*Vismia*) diminuiu devido à perda de carbono através da respiração. Este efeito foi mais acentuado em FLO, onde o conteúdo relativo de *N* na serapilheira remanescente um ano após foi significantemente maior que nas outras áreas (no primeiro experimento maior nos recipientes de malha grossa, e no segundo experimento maior naqueles de malha média).

Enquanto que o nível de *N* na serapilheira recém caída e na superfície do solo foi alto em FLO, na camada de serapilheira o nível de *N* não diferiu entre as áreas.

A biomassa microbiana na superfície do solo (0-5 cm) foi relativamente baixa quanto comparada com aquela das florestas de clima temperado (422 µg/g de solo). Ainda na profundidade de (5-15 cm) observou-se a metade deste valor, seguindo o padrão de distribuição da matéria orgânica e nutrientes. A respiração microbiana na camada de serapilheira foi 100 vezes maior que no solo. Entretanto, não foram observadas diferenças entre as áreas de estudo.

Avaliação dos resultados conforme as hipóteses principais.

1. A fauna de solo e as condições dos processos de decomposição nas áreas de policultivo são visivelmente diferentes da floresta primária. Na floresta primária foram encontradas indivíduos de minhocas de maior tamanho, formigas e cupins em alta freqüência e abundância, rápida decomposição e consequentemente fina camada de serapilheira. A importância da maior parte das formigas de hábito predatório ou herbívoro para o processo de decomposição permanece não esclarecido mas pode ser considerada pequena devido aos baixos valores da biomassa que estas representam. Nas áreas cultivadas são raras as minhocas de maior porte, formigas e cupins foram menos abundantes representando baixa biomassa, menor diversidade de espécies de cupins e as taxas de decomposição foram baixas. Componentes da fauna de solo com alta abundância, biomassa e estoque de nutrientes (em seus corpos e ninhos), foram mais comuns na floresta primária que na secundária e nas áreas cultivadas.
2. As áreas de policultivos são pobres em madeira morta e consequentemente são escassos os micro-habitats para espécies da macrofauna se abrigar ou construir seus ninhos (compare. Verhaagh 1991). A abundância de cupins – os quais são os decompositores primários de madeira – foi correlacionada com a quantidade de madeira morta nas áreas.
3. As populações de cupins nas áreas cultivadas foram fortemente reduzidas e sua diversidade funcional foi baixa nestes locais. Entretanto, coletas com armadilhas de luz mostraram que os adultos alados (fundadores de colônias) são capazes de colonizar as áreas plantadas. Quatorze de um total 44 espécies de cupins em revoada foram encontradas exclusivamente nas áreas cultivadas, 12 somente em floresta primária e 18 espécies em ambas áreas. Isto significa que provavelmente as condições específicas da área, como a escassez de locais para abrigo e para os fundadores de ninhos e as condições microclimáticas desfavoráveis são responsáveis pela baixa densidade de cupins nos cultivos.
4. Nas áreas de policultivos foi observado alta abundância de artrópodos comedores de serapilheira (Diplopoda, Isopoda), um certo acúmulo de serapilheira e alta abundância de predadores, bem como grande variabilidade na biomassa de minhocas. Distribuições similares destes grupos funcionais foi observado por Lavelle et al. (1994), em uma ampla comparação entre diferentes ecossistemas tropicais terrestres.
5. Em outros sistemas de cultivo dentro da área experimental do SHIFT foi observado uma composição similar da fauna de decompositores. Além de Diplopoda, Isopoda

e parcialmente minhocas, caracóis foram abundantes especialmente nas áreas muito adubadas (Vohland & Schroth 1999). Aparentemente ocorre uma substituição da fauna "típica da floresta" (dominada por minhocas de grande porte e fauna diversa de cupins) por outros grupos (Isopoda, Diplopoda, Gastropoda).

6. A conversão da floresta primária resulta em forte alteração quantitativa dos grupos funcionais. Vários estudos em outras regiões da Amazônia e em áreas próximas da área de estudo (Reserva Ducke, Embrapa) (Hanagarth 1983; McKay et al. 1991; Römbke & Verhaagh 1992 ; Verhaagh 1991; dados não publicados de Hanne & Martius) sugere que somente poucas espécies de artrópodos tem a capacidade de colonizar sistemas antrópicos. Estas espécies são substituídas por outras de áreas abertas, as quais originalmente vivem em áreas inundadas ou ambientes mais secos como nas Campinaranas e Campinas. No caso dos Diplopoda, algumas espécies que colonizam os cultivos foram originalmente trazidas de outros continentes (Ásia and África), pelo homem, desenvolveram bem e tornaram-se importantes decompositores nos sistemas agrícolas. Em conseqüência pode-se esperar que nestas áreas o fluxo de nutrientes e outros processos da decomposição como humificação e infiltração de material orgânico no solo serão bastante diferentes em termos quantitativos do que ocorre na floresta primária.

7. Em comparação com as outras áreas de estudo, a floresta primária caracteriza-se por alta produção (queda) de serapilheira com alto conteúdo de Nitrogênio (N), alta taxa de decomposição e consequentemente baixo acúmulo desta na superfície do solo. O conteúdo de C, *N* e água na serapilheira e superfície do solo é alto. Na floresta secundária (18 anos) há grande acúmulo de serapilheira, apesar da queda de folhas ser baixa, devido à baixa taxa de decomposição. Os sistemas de policultivos são bastante diferentes em vários aspectos; em muitas das variáveis funcionais uma delas (POC) foi muito similar a floresta primária (FLO) e a outra (POA) similar a floresta secundária (SEC).

8. Estas diferenças mostram a forte influência do microclima que ao menos nos anos atípicos age de modo restritivo no processo de decomposição exercido pela fauna de solo. O microclima também é influenciado pelo tipo de sistema de cultivo, e.g. sombra produzidas por componentes arbóreos e solo coberto por vegetação herbácea ou por serapilheira.

9. Nota-se que apesar das diferenças entre as áreas (floresta primária, secundária e policultivos) o processo de decomposição foram fortemente determinado pela macrofauna. As áreas de policultivos (POA e POC) foram colonizados por um tipo de fauna que mantém a decomposição ("ecosystem-service" - Brussaard 1997) em

um gradiente similar ao das florestas. Isto pode ser verificado pelo estoque de *N* que indica um fluxo sustentável de nutrientes nestes sistemas ainda muito novos. O sistema de decomposição considerado nestas áreas de policultivos é baseado na produção de serapilheira da vegetação secundária deixada entre as linhas de árvores plantadas. Entretanto, em todas outras áreas de estudo, principalmente na floresta primária, ocorreu um enriquecimento (concentração) de *N* na serapilheira durante o curso da decomposição.

Conclusões:

1. Pode-se obter as condições necessárias para a desejada sustentabilidade sob o ponto de vista da biologia do solo. A colonização por decompositores primários ocorreu nos diferentes ambientes estudados, a serapilheira é decomposta em período de tempo normal, a matéria orgânica do solo é formada e a estrutura do solo melhorada.
2. O processo de decomposição pode ser otimizado pelo aumento da densidade e diversidade da fauna do solo os quais podem ser resultado da utilização de diferentes tipos de plantas e materiais usados no manejo da cobertura morta. Tais práticas, resultará a longo prazo em efeitos positivos da fauna na estrutura do solo, tornando sustentáveis os sistemas de uso da terra e permitindo menor entrada de nutrientes via fertilização química. A atividade da fauna do solo será otimizada indiretamente através da melhoria das condições microclimáticas promovidas pela planta de cobertura, pela cultura em faixas ou pela tolerância da vegetação secundária resultando em um aumento da quantidade de serapilheira natural ou ainda pela adição de resíduos através do manejo da cobertura morta ("mulching").

As avaliações finais estão ainda em conclusão e os resultados serão publicados em periódicos especializados. Tais informações estarão também disponíveis nas páginas da Embrapa Amazônia Ocidental (www.cpaa.embrapa.br/env52/) e do Centro de Pesquisas para o Desenvolvimento - ZEF (www.zef.de), na Alemanha.

Utilização prática dos resultados

Os resultados obtidos são a base para posteriores projetos de pesquisa que pretendam levar estes resultados ao uso prático: o manejo e resíduos vegetais através da manipulação da cobertura morta, e.g. pelo uso de leguminosas para produção de "mulch" em sistemas de cultivos em faixas ou usando estes materiais para melhorar a composição química da cobertura misturando-os aos materiais mais pobres existentes no cultivo.

Considerando a importância destes estudos voltados para a aplicação, a equipe de pesquisadores do projeto aqui apresentado, formulou nova proposta de pesquisa em cooperação bilateral entre BMBF (Alemanha) e CNPq (Brasil). Haverá continuidade da cooperação com a empresa privada especializada em avaliação de risco de químicos no ambiente, a ECT Ecotoxicology GmbH situada em Flörsheim - Alemanha e serão ampliados os estudos sobre a toxicologia de pesticidas sobre a fauna de solo e aos processos da decomposição.

Studies of Human Impact on Floodplains and Forests in the Tropics SHIFT Project ENV 52 "Soil Fauna and Litter Decomposition"

Soil Fauna and Litter Decomposition in Primary and Secondary Forests and a Mixed Culture System in Amazonia

Final Report (1996-1999)

Abstract

Soil fauna and litter decomposition were investigated in three different ecosystems of central Amazonia: a primary rain forest (FLO), a secondary forest (SEC), and two agroforestry plantation sites (POA, POC). The investigations included the assessment of litter production and stocks, soil parameters, microclimatic factors, abundance and biomass of the soil fauna, the determination of soil respiration and microbial biomass, the measurement of soil fauna respiration rates, and nutrient analyses.

Soil fauna and the decomposition rates in the culture areas differ considerably from the primary forest. In the primary forest we find large earthworm species, and a high frequency of ants and termites. In the plantations, however, large earthworms are rare, ants and termites also; their biomass (in termites also the species diversity) is reduced. The typical rain forest soil fauna is substituted by other groups (Isopoda, Diplopoda, snails) in the plantations. This is likely to influence the qualitative character of the nutrient fluxes and decomposition processes (humus production).

The primary forest area is characterized by a comparatively high litter production, and a higher *N* concentration in the litterfall, by high litter decomposition rates and therefore low litter stocks. Compared to the other areas, the concentration of *C* and *N* (soil organic matter) and the water content in the litter layer and the topsoil are higher. In spite of the low litter production in the 18 year old secondary forest sites, litter stocks were higher than in FLO, due to the low decomposition rates. The two polyculture systems were much different, in many aspects POC was more similar to the primary forest FLO, and POA more similar to SEC. This shows the large influence of the microclimate, that, at least in extreme climatic years as in 1997 (an El Nino year), or via the extremes in normal years, has a restrictive influence on the soil fauna, and thus, on the decomposition processes. The microclimate is, in turn, influenced by the cropping system, e.g. via shadowing through the plant canopy, soil cover by litter etc. (In POC the adjacent rain forest area is buffering the microclimate).

In spite of all differences it must be stressed that in all investigated areas (primary forest, secondary forest, and polyculture sites – system IV of the SHIFT experiment) we found systems of litter decomposition that were, above all, controlled by the macrofauna. We conclude from this that the soil biological conditions for the intended optimization of the sustainability are available in all studied polyculture systems. A colonization through primary decomposers is given in all cases, and the litter input is decomposed in due time. Thus, the functional system of the litter decomposition processes can be optimized through the manipulation of macrofauna populations, however, above all, indirectly, i.e. via the modification of the microclimatic conditions, through planting or an increase of litter input.

Keywords

Soil fauna, Micro-organisms, Litter decomposition, soil nutrients, Amazonia, rain forest, agroforestry systems, sustainable land use

Objectives

The project is part of the topic "Recultivation of degraded monoculture areas in central Amazonia". Basic task of the project was to compare two wood-polyculture plantations and adjacent primary and secondary forest with respect to litter quantity and quality, litter decomposition and the turnover rates of micro flora and meso- and macro fauna. Abundance and biomass were determined for all functionally important arthropod groups (Diplopods, Isopods, cockroaches, termites, beetles, insect larvae, ants and spiders) and for Oligochaetes (earthworms and enchytraeids) as a basis for a comparative evaluation of the turnover rate of the detritivorous macro fauna.

Final objective was the integration of the data on litter decomposition obtained from litter bag experiments and respiration measurements together with group-specific turnover rates of the soil fauna, and the evaluation of the results with regard to the sustainability of land use forms important under the context of tropical agroforestry.

Conditions for the project development

A principal condition for the success of the project was, besides the previous experience of the involved scientists in soil biological investigations in Amazonia, the participation of several scientists in the differentiated assessment of the functionally important animal groups and of microbiology, and thus, lastly, the cooperation of two Brazilian and three German institutions.

The field studies were carried out in the experimental site established in 1992 by Embrapa in cooperation with the University of Hamburg in the context of the SHIFT program, and in the labs of Embrapa Amazonia Occidental. For that, the labs had to be reformed with funds from Embrapa and newly equipped with project funds. The installation and integration of the lab at "Embrapa Amazônia Ocidental" was in the best way supported by the host institution. Additionally needed rooms were put at the projects disposal at short notice in informal manner. A large share of the costs for the electrical installation needed due to the large number of blackouts was banked by the Brazilian institution. Due to that, the investigations could be carried out in spite of sometimes large technical difficulties. The cooperation with the Embrapa Amazonia Occidental was, above all, due to the support received from Embrapa's administration; the personal efforts of the coordinator, Dr. Gasparotto, and the technical coordinator, M.Sc. Marcos Garcia, has to be seen as extremely successful. We also counted with support from the second Brazilian partner institution, the INPA. More difficult was the recruiting of Brazilian M.Sc. And Ph. D. students and their integration in the project, due to the relatively tight time schedule of the teaching

programs at the INPA. Even so, a number of studies could be realized, because the Brazilian CNPq supplied grants in a very flexible form.

The cooperation with the firm ECT GmbH, that supplied and installed the Infrared-Gas-Analyzer (IRGA) and supervised the respiration measurements and the studies on Oligochaeta, was another central backbone of the success of this project.

Planning and Realization

The project began in October 1996; the central investigation program was initiated in July 1997 in Manaus and lasted until end of April 1999. In the four study sites belonging to three systems (primary forest FLO, secondary forest SEC, polyculture areas POA and POC) we measured litterfall weekly, litter quantity monthly and collected every three months (8 sampling events) the soil meso- and macro fauna and the micro flora. All samples were weighed in the lab, the fauna extracted and sorted and the substrates prepared for chemical analyses (C/N, cations) or respiration measurements. In October 1997a first litterbag experiment with 1008 litterbags for the selective measurement of decomposition rates and the contribution of the soil fauna was set up in the field. Until October 1998 14 litterbags of each of three mesh widths were retrieved in a series of 7 retrieval dates and subsequently extracted, weighed and evaluated. The litterbag experiment was repeated from April 1988 to April 1999 with 6 retrieval dates.

We also tested rapid assess methods like mini-containers (decomposition) and bait lamina (feeding activity of soil fauna). Experimental studies of the importance of predators and the influence of substrate quality for decomposition were started in 1998.

As a basis for the calculation of biomass from the measured abundances of the soil animals via regression we sampled, took metric measurements, weighed and analyzed statistically animals of all functionally important groups

Exemplary respiration measurements were done for several soil fauna groups. In comparison to the main four study sites soil respiration and decomposition were measured in three other systems, two monocultures and a fruit tree polyculture.

A vast description of the methods and the study sites can be found in Beck et al. (1998a, b), as well as in the single reports annexed here.

Summary of Results

The meso fauna samples were dominated by the secondary decomposers Oribatei (42 - 55% of all arthropods) and springtails (Collembola; 4 - 13%) and predatory mites (19 - 29%). Abundance and biomass of Oribatei are in contrast to all other soil fauna groups lowest in the primary forest area and highest in POA. Predators reached 20-25%

(abundance) of the whole meso fauna. Enchytraeid (tiny earthworms) density differs qualitatively between the four sites, whereas Naidids (supposed aquatic worms), which were for the first time quantitatively studied in terrestrial habitat, were much more abundant in the primary forest than in the other areas.

The mean macro fauna abundances over 8 sampling events ranged between 4442 Ind./m² in SEC and 5876 Ind./m² in FLO. Predators dominated in all sites with 23 - 37%. Social insects

were more abundant in FLO (ants 28%, termites 21%) and SEC (21%, 13%) than in POA and POC (ants 13 und 16%, termites 6%). In contrast primary decomposers were more abundant in the polycultures (20%) than in the forests (9 and 7%). In the secondary forest area macro fauna abundances were lowest and strongly dominated by predators and social insects.

The ratio Ants/Decomposers shows the differences between the forests FLO and SEC (4.3 and 3.6) and the polycultures (0.7 and 0.8) clearly.

Macro fauna biomass (dry weight, not considering earthworms) was 1.76 g/m² in FLO and 1.57 g/m² in POC and thus about twice as high as in SEC (0.89 g/m²) and POA (0.87 g/m²). Ants diminished in their portion of total biomass (1.6 - 2.7%) compared with their dominance in abundance. The portion of decomposers was high with 60, 66 and 70% in FLO, POA and POC, but lower in SEC with 33%. Predators made up 12.5 (POC), 21.5 (FLO and SEC) and 23% POA) of biomass of the whole macro fauna. Earthworms, which were sampled with a special method, also showed highest abundance and biomass in FLO (2.8 Ind./m², 1.5 g/m²) and POC (2.5 Ind./m², 0.5 g/m²) when compared with the two other areas (SEC 1.6 and 1.1 Ind./m², POA 0.2 and 0.04 g/m²).

Species composition of the soil macro fauna and species ranking in abundance and biomass in the polyculture sites is different from the not used areas. Few species of Isopoda (*Circoniscus* sp.) and Diplopoda (Chelodesmidae, Cyrtodesmidae, Fuhrmannodesmidae, Polyxenida) dominate on polyculture sites. However they seem not to be able to compensate the effect of the decrease in numbers and biomass of species of the primary forest on decomposition. The dependence of macro fauna density in the litter fraction of the samples from the litter quantity is highly significant ($p<0.001$) in all sites, but of very low predictive value because of low r^2- and F-values.

Our standard litter species *Vismia guianensis,* a dominant species of the secondary vegetation was decomposed in both experiments to about 20% of its original weight in litterbags of coarse mesh width in the primary forest (k-rate of the negative exponential decay/year 2.3 and 3.1).

In all other sites decay rates were significantly lower (k/year 0.6 to 1.4). The decomposition rates of the mesh widths 20 µm and 250 µm did not differ significantly, but are significantly lower (< 50%) than the rates in the coarse mesh width (10 mm). The same strong decrease of decomposition by experimental exclusion of the macro fauna was found in three further studied systems (a rubber tree monoculture, a peach palm monoculture and a fruit tree polyculture).

The decomposition rates from litterbags in the four study sites are significantly correlated with the abundances of decomposers (including ants and termites) and with the biomass of the earthworms and of the decomposers.

In the primary forest area we found the lowest litter quantity together with the highest litter fall of all four areas which shows the higher decomposition rate for the whole area and thus confirms the litterbag results. In contrary the low decomposition rates in the secondary forest led to a litter accumulation. The two polyculture areas range between the forest sites.

During the course of the decomposition C/N-ratios of the standard litter decrease due to the C-loss by respiration. This effect is strongest in FLO, where relative N-contents in the remaining litter after one year were significantly higher than in the other areas (in the first experiment higher in coarse mesh litterbags, in the second experiment higher in the medium mesh bags).

Whereas N-contents in litterfall and in the top soil were higher in FLO, N-contents of the litter layer did not differ between the areas.

Microbial biomass in the top soil (0-5 cm) was relatively low when compared with temperate forests (422 µg/g soil). Deeper in the soil (5-15 cm) it was half this value, following the distribution of organic material and nutrients. Microbial respiration in the litter is more than 100 fold higher than in the soil. Differences between the four areas were not observed.

Evaluation of results with regard to the basic hypotheses

1. Soil fauna and decomposition conditions in the polyculture sites are clearly different from the primary forest. In the primary forest area we find large earthworms, ants and termites in high frequency and abundance, a rapid decomposition and consequently a low litter layer. The importance of the mostly predatory or herbivore ants for the decomposition process remains unclear but is considered low on the base of the low biomass values. In the plantations large earthworms are rare, ants and termites are less abundant and show low biomass and termites also a low species diversity, decomposition rates are lower. Through higher abundances and biomass nutrient pools in the body of the soil animals and their nests are higher in the primary forest than in the secondary forest and the polycultures.

2. The polyculture sites are very poor in dead wood. consequently for many species of the macro fauna hiding places and nesting sites are lacking (compare. Verhaagh 1991). The abundance of termites - which are the main wood primary decomposers - is correlated with the quantity of dead wood in the areas.
3. Termite populations in the plantations are strongly reduced, their functional diversity is lower there. However collections with light- and flight-traps have shown that the winged adult animals (colony founders) are able to colonize the plantations. 14 of a total of 44 swarming termite species were found exclusively in a polyculture, 12 only in primary forest and 18 species in both areas. This probably means that site specific conditions, like the lack of hiding places for nest founders and unfavorable microclimatic conditions are responsible for the low termite densities in the plantations.
4. In the polyculture-wood-plantations we found high abundances of litter feeding arthropods (Diplopoda, Isopoda), a certain litter accumulation and high abundances of predators, as well as an extremely high variability in the biomass of earthworms. Similar distributions of these functional groups were found by Lavelle et al. (1994) in a worldwide comparison of different tropical terrestrial ecosystems.
5. Other agricultural sites within the SHIFT-experimental area show a similar decomposer fauna. Besides Diplopods, Isopods and partially earthworms, snails appear abundantly especially in highly fertilized areas (Vohland & Schroth 1999). There seems to occur a substitution of the typical "forest fauna" (dominated by large earthworms and a highly diverse termite fauna) by other groups (Isopoda, Diplopoda, Gastropoda).
6. The conversion of rainforest results not only in strong quantitative change in functional groups. Diverse studies in other Amazon regions and also in the vicinity of the study area (Reserva Ducke, Embrapa) (Hanagarth 1983 ; McKay et al. 1991; Römbke & Verhaagh 1992 ; Verhaagh 1991; unpublished data of Hanne & Martius) propose that only few rain forest species are able to colonize anthropogenic systems. These species are substituted by species of open land, which originally live in inundation areas or dry habitats like "Campinaranas" and "Campinas". In the case of diplopods also euryzonic species, which were introduced by man from other continents (Asia and Africa), developed well and can achieve importance for the decomposition in agrarian sites. It is expected that consequently in these areas nutrient fluxes and other decay processes like humification and infiltration of organic material into the soil will differ quantitatively from primary forest ecosystems.
7. In comparison with the other sites the primary forest is characterized by higher

litterfall, higher N-contents in litterfall, higher decomposition rates and consequently lower litter quantities. C- and N-content and water content in the litter and in the top soil are higher. In the 18 year old secondary forest site litter quantities on the ground are higher although litterfall is lower, because decomposition rates are low. The polyculture sites are quite different in various aspects, in many functional variables POC is very similar to FLO and POA to SEC.

8. This relative ordering shows in our opinion the strong influence of the microclimate, which at least in extreme years, resp. by its extremes in average years acts restrictive on the decomposition system through the soil fauna. The microclimate itself is certainly influenced by the plantation system, e.g. the shading by tree canopies and the soil cover by cover crops and/or litter.
9. For all that differences it is important to see that in all studies systems (primary forest, secondary forest, polyculture system 4 of the SHIFT-experiment) litter decomposition systems were found which are strongly determined by the macro fauna. The polyculture areas (system 4 - wood plantations in block a - POA and c - POC) are colonized by a fauna, which performs the "ecosystem-service" (Brussaard 1997) decomposition in rather similar rates than the forests. This is shown by the nitrogen pools, which indicate a sustainable flux of nutrients in these very young systems. The decomposition system is herein based nearly exclusively on the litter production of the tolerated secondary vegetation between the rows of planted trees. In all studies sites, however strongest in the primary forest, an enrichment (concentration) of *N* in the litter along the course of decomposition takes place.

The following conclusions are taken from these results:

1. The necessary preconditions for the aspired melioration of the sustainability under soil biological view are given. Colonization by primary decomposers had happened in all areas, the litterfall is decomposed in acceptable space of time, soil organic matter is built and the soil structure improved.
2. The functional circle decomposition could be optimized through promotion of the soil fauna density and diversity, thus leading to improved supply of the useful plants with nutrients from the natural or additionally provided litter. This should, together with the positive effects of the soil fauna on soil structure in the long run, make the land use systems sustainable without high nutrient inputs by mineral fertilization. The performance of the soil fauna is to be optimized indirectly, through melioration of the microclimatic conditions by planting cover or alley crops or toleration of secondary vegetation resulting in an increase of litter quantity and the more even

supply with plant residues (by mulch management).

The final evaluation has not been finished completely. These and further results will be published in specific journals. We refer also to our homepages in the Internet (www.cpaa.embrapa.br/env52/index.html and www.zef.de).

Intended utilization of results and cooperation with the industry

The conclusions form the base of a succeeding project aiming at the utilization of the results in the practice: the management of plant residues through manipulation of litter quantities, e.g. through mulching with alley planted legumes and/or nutrient-poor plant residues.

This project has been proposed to BMBF and CNPq. The successful cooperation with the firm ECT Ecotoxicology GmbH in Flörsheim near Frankfurt will be continued and amplified in the area of ecotoxicology, because the use of insecticides and pesticides certainly could cause a considerable prejudice to the soil fauna and decomposition.

Studies of Human Impact on Floodplains and Forests in the Tropics
SHIFT Projekt ENV 52 "Bodenfauna und Streuabbau"

Bodenfauna und Streuabbau in Primär- und Sekundärwäldern und einem Mischkultursystem in Amazonien

Abschlußbericht 1996-1999

Kurzfassung

Bodenfauna und Streuabbau wurden in drei verschiedenen Ökosystemen in Zentralamazonien untersucht: Einem Primärwald (FLO), einem Sekundärwald (SEC), und zwei agroforstlichen Mischkultursystemen (POA, POC). Untersuchungen schlossen die Erfassung von Streufall und Streumenge, Bodenparametern, Mikroklimafaktoren, Abundanz und Biomasse der Bodenfauna, die Bestimmung der Bodenatmung und der Mikrobenbiomasse, Messungen der Atmungsraten der Bodenfauna, und Nährstoffanalysen ein.

Bodenfauna und die Streuabbauverhältnisse in den Kulturflächen unterscheiden sich deutlich von denen im Primärwald. Im Primärwald finden wir große Regenwurmarten, eine hohe Frequenz und Abundanz von Ameisen und Termiten. In den Pflanzungen dagegen sind Regenwürmer selten, Ameisen und Termiten ebenfalls; ihre Biomasse (Termiten auch Artendiversität) ist reduziert. Es ist allerdings zu erkennen, daß die typische Primärwaldfauna in den Pflanzungen durch andere Gruppen (Isopoden, Diplopoden, Schnecken) ersetzt wird. Deshalb dürften auch die Stoffflüsse und Abbauprozesse (Humifikation) qualitativ anders verlaufen als im Regenwaldökosystem.

Im Vergleich ist die Primärwaldfläche charakterisiert durch hohen Streueintrag und höhere N-Gehalte im Streufall, hohe Streuabbauraten und folglich niedrige Streumengen. Gegenüber den anderen Flächen ist der Gehalt an Kohlenstoff und Stickstoff (organische Bodensubstanz) und auch der Wassergehalt in der Streu und im Oberboden höher. In der etwa 18 Jahre alten Sekundärwaldfläche waren aufgrund der niedrigen Abbauraten die Streumengen trotz geringerem Streueintrag höher. Die beiden Polykulturflächen zeigten sich in vielen Variablen sehr unterschiedlich, in vielen Vergleichen war POC der Primärwaldfläche ähnlicher, POA der Sekundärwaldfläche. Dies läßt den starken Einfluss des Mikroklimas erkennen, das zumindest in extremen Jahren bzw. über die Extreme in normalen Jahren restriktiv über die Bodenfauna auf das Streuabbausystem wirkt. Das Mikroklima seinerseits wird wiederum durch das Pflanzsystem bedingt, d.h. über die Beschattung durch Kronen, die Bedeckung des Bodens durch Streu usw.. (In POC wirkt z.B. die benachbarte Regenwaldfläche mikroklimamäßigend.)

Trotz aller Unterschiede ist festzuhalten, dass sich in allen untersuchten Flächen (Primärwald, Sekundärwald, Polykultursystem 4 des SHIFT-Experiments) Streuabbausysteme fanden, deren Geschwindigkeit im wesentlichen durch die Makrofauna bestimmt wird. Daraus folgern wir, daß in den betrachteten Polykultursystemen die Grundlagen für eine angestrebte Verbesserung der Nachhaltigkeit aus bodenbiologischer Sicht vorhanden sind. Eine Besiedlung durch Primärzersetzer erfolgt in allen Fällen, die zugeführten Streumengen werden in angemessenen Zeitabschnitten abgebaut. Damit ist der Funktionskreis Streuabbau über die Förderung der Makrofaunabesiedlung optimierbar, allerdings vermutlich vor allem indirekt, d.h. über die Veränderung der kleinklimatischen Bedingungen durch geeignete Pflanzmaßnahmen und eine Erhöhung der Streuzufuhr.

Schlagwörter

Bodenfauna, Mikroorganismen, Streuabbau, Bodennährstoffe, Amazonasgebiet, Regenwald, Agroforstsysteme, Nachhaltige Landnutzung

Aufgabenstellung

Das Projekt ist Teil des thematischen Verbunds: Rekultivierung degradierter Monokulturflächen in Zentralamazonien. Aufgabe des Projekts war zunächst die vergleichende Untersuchung zweier Polykultur-Holzplantagen und benachbarter Primärwald- und Sekundärwaldflächen bezüglich Streumenge- und qualität, Streuabbau und Umsatzleistung der Mikroflora und der Meso- und Makrofauna. Für alle funktionell bedeutsamen Arthropoden-Gruppen (Diplopoden, Asseln, Schaben, Termiten, Käfer, Insektenlarven, Ameisen, Spinnen) und Oligochaeten (Regenwürmer und Enchyträen) wurden Abundanz und Biomasse als Grundlage für die vergleichende Beurteilung der Umsatzleistung der detritivoren Makrofauna ermittelt.

Ziel der Auswertung war die Integration der Streuabbaudaten, die durch Streubeutelversuche und Atmungsmessungen an Streuproben ermittelt wurden, mit tiergruppenspezifischen Umsatzleistungen, und die Beurteilung der Ergebnisse unter dem für die tropische Land- und Forstwirtschaft bedeutenden Gesichtspunkt der Nachhaltigkeit von Nutzungsformen.

Voraussetzungen

Wesentliche Voraussetzung für den Erfolg des Projekts war neben der Erfahrung der Koordinatoren und Wissenschaftler mit bodenbiologischen Untersuchungen in Zentralamazonien die Beteiligung mehrerer Spezialisten an der notwendigen differenzierten Erfassung der funktionell wichtigen Tiergruppen und der Mikrobiologie, und damit letztlich die gute Zusammenarbeit zwischen drei deutschen und zwei brasilianischen Institutionen.

Die praktischen Arbeiten wurden auf der 1992 im Rahmen von SHIFT von der Embrapa zusammen mit der Universität Hamburg angelegten Experimentalfläche der Embrapa-CPAA bzw. in deren Labors durchgeführt. Dazu mussten die Labors mit Mitteln der Embrapa ausgebaut und mit Projektmitteln neu ausgestattet werden. Die Installation und Integration des Labors an der Embrapa-CPAA wurde von der gastgebenden Institution optimal vorbereitet und unterstützt. Zusätzlich benötigte Räume wurden kurzfristig unbürokratisch zur Verfügung gestellt und ein großer Teil der unvorhergesehenen Kosten für elektrische Installationsmaßnahmen, die aufgrund der hohen Frequenz der Stromausfälle notwendig wurden, vom brasilianischen Institut übernommen. Dadurch konnten die Untersuchungen trotz z.T. großer technischer Schwierigkeiten erfolgreich durchgeführt werden. Insgesamt ist damit die Zusammenarbeit mit der Embrapa-CPAA, insbesondere aufgrund des Verwaltung-Personals der Embrapa; des persönlichen Einsatzes des Koordinators Dr. Gasparotto und des technischen Koordinators Marcos

Garcia, als äusserst erfolgreich zu beurteilen. Als schwieriger erwies sich die Requirierung und die Integration von Mestrado- und Doutorado-Studenten ins Projekt durch den sehr festgelegten Ausbildungsplan des in Manaus ausbildenden Instituts INPA, dennoch konnte eine Reihe von Arbeiten realisiert werden, da der brasilianische Forschungsrat (CNPq) in besonders bereitwilliger und flexibler Form Stipendien zur Verfügung gestellt hat.
Die Zusammenarbeit mit der Firma ECT GmbH, die den Infrarot-Gasanalysator (IRGA) konstruiert und installiert hat und die Atmungsmessungen betreute, sowie die Oligochaeten bearbeitet hat, war ebenfalls unabdingbare Voraussetzung für das Gelingen des Projekts.

Planung und Ablauf

Das Projekt begann im Oktober 1996; das zentrale Untersuchungsprogramm wurde im Juli 1997 in Manaus begonnen und dauerte bis Ende April 1999. In den vier Untersuchungsflächen der drei Systeme (Primärwald FLO, Sekundärwald SEC und 2 Polykulturflächen POA, POC) wurden wöchentlich die Streufallmengen erfasst, monatlich Streuvorräte gemessen und alle drei Monate die Bodenmeso- und makrofauna sowie die Mikroflora beprobt (8 Termine). Alle Proben wurden im Labor gewogen, die Fauna extrahiert und sortiert und die Substrate für chemische Analysen (C/N, Kationen) oder zur Atmungsmessung weiterverarbeitet. Im Oktober 1997 wurde eine Netzbeutel-Serie mit 1008 Beuteln zur selektiven Erfassung des Streuabbaus und der Abbauleistung der Bodenfauna in den Flächen ausgebracht. Bis Oktober 1998 wurden in 7 Rückholterminen jeweils 14 Beutel pro Maschenweite aus jedem System eingeholt, extrahiert, gewogen und ausgewertet. Eine zweite Serie wurde im April 1998 ausgebracht und in 6 Rückholterminen bis April 1999 auf die gleiche Weise behandelt. Mini-Container und Köderstreifen (bait lamina) wurden als Schnellmethoden an insgesamt 8 Terminen zur Messung von Streuabbau und Bodenfauna-Fraßaktivität getestet. Experimentelle Untersuchungen zur Bedeutung von Räuberpopulationen und der Veränderung der Substratqualität wurden 1998 begonnen. Als Grundlage für die Berechnung von Biomassen aus den festgestellten Abundanzen der Bodentiere mittels Regression wurden alle wichtigen funktionellen Gruppen gesondert gesammelt, vermessen, gewogen und statistisch ausgewertet. Exemplarisch wurden Atmungsmessungen an einigen Tiergruppen durchgeführt. Vergleichend zu den Untersuchungen in den Hauptuntersuchungsflächen wurden Bodenatmung und Streuabbau in drei weiteren Mono- und Polykultursystemen untersucht.
Eine genaue Methodenbeschreibung sowie die Beschreibung der Probeflächen findet sich in Beck et al. (1998a, b), sowie in den einzelnen Teilberichten im Anhang.

Zusammenfassung der wichtigsten Ergebnisse

Die Mesofauna-Proben aus allen Flächen werden dominiert von den Sekundärzersetzergruppen Hornmilben (Oribatei; 42 - 55% aller Arthropoden) sowie Springschwänze (Collembolen; 4 - 13%) und den räuberischen Milben (19 - 29%). Abundanzen und Biomassen der Oribatei sind im Gegensatz zu allen anderen Tiergruppen in der Primärwaldfläche am niedrigsten und in POA am höchsten. Die Prädatoren in den Mesofauna-Proben erreichen Anteile von 20 - 25% (Abundanz) an der Gesamt-Mesofauna. Die Enchytraeenbesiedlung der vier Flächen unterscheidet sich vor allem qualitativ; die zum ersten Mal in terrestrischen Biotopen quantitativ untersuchten Naididen (Oligochaeten) sind dagegen im Primärwald wesentlich zahlreicher als auf den anderen drei Flächen.

Die über 8 Probennahmen gemittelten Makrofauna-Abundanzen liegen zwischen 4442 Ind./m² in SEC und 5876 Ind./m² in FLO. Prädatoren dominieren in allen Flächen mit 23 - 37%. Soziale Insekten sind in FLO (Ameisen 28%, Termiten 21%) und SEC (21%, 13%) häufiger als in POA und POC (Ameisen 13 und 16%, Termiten 6%). Primärzersetzer sind dagegen mit 20% in den Polykulturen häufiger als in den Wäldern (9 und 7%). In der Sekundärwaldfläche sind die Abundanzen insgesamt am niedrigsten und am stärksten von Prädatoren und sozialen Insekten dominiert. Das Verhältnis Ameisen/Zersetzer zeigt die Unterschiede der Waldflächen (4.3 und 3.6) zu den Polykulturen (0.7 und 0.8) besonders deutlich.

Die Makrofauna-Biomasse (Trockengewicht, ohne Regenwürmer) ist in FLO (1.76 g/m²) und POC (1.57 g/m²) etwa doppelt so hoch wie in SEC (0.89 g/m²) und POA (0.87 g/m²). Die Ameisen treten im Gewichtsanteil gegenüber der Abundanz insgesamt stark zurück (1.6 – 2.7%), die Zersetzer erreichen dagegen 60, 66 und 70% in FLO, POA und POC, in SEC aber nur 33%. Prädatoren stellen 12.5 (POC), 21.5 (FLO und SEC) und 23% POA) der Biomasse der Makrofauna. Die Regenwürmer, die mit einer speziellen Methode erfaßt wurden, zeigen ebenfalls deutlich höhere Abundanzen und Biomassen in FLO (2.8 Ind./m², 1.5 g/m²) und POC (2.5 Ind./m², 0.5 g/m²) gegenüber den beiden anderen Flächen (1.6 und 1.1 Ind./m², 0.2 und 0.04 g/m²).

Die Artenzusammensetzung der Makrofauna in den Polykulturflächen unterscheidet sich in Abundanz und Biomasse deutlich von den nicht genutzten Flächen. Wenige Arten der Isopoda (*Circoniscus* sp.) und Diplopoda (Chelodesmidae, Cyrtodesmidae, Fuhrmannodesmidae, Polyxenida) dominieren auf den Kulturflächen, können aber den Rückgang von im Primärwald dominanten Arten zahlen und gewichtsmäßig nur teilweise ausgleichen. Die Abhängigkeit der Makrofaunadichte im Streuanteil der Proben von der Streumenge ist in allen Flächen hochsignifikant ($p<0.001$), aber durch geringe r^2- und F-Werte von geringem Vorhersagewert.

Abundanzen und Biomassen mehrerer Tiergruppen in den Aufsammlungen korrelieren mit den in den Flächen mit Klimaloggern gemessenen Variablen (relative Luftfeuchte und Temperatur am Boden) und zeigen die Bedeutung des bestandestypischen Kleinklimas für die Bodenfauna.

Das als Standard verwendete Laub der dominanten Sekundärvegetationsart *Vismia guianensis* wurde in Netzbeuteln grober Maschenweite (10 mm) in FLO in beiden Serien innerhalb eines Jahres auf ca. 20 % des Ausgangsgewichts abgebaut (k-Wert des negativ exponentiellen Abbaus/Jahr 2.3 und 3.1). In den anderen Flächen lagen die Abbauraten signifikant niedriger (k/Jahr 0.6 bis 1.4). Die Abbauraten in den Netzbeuteln der Maschenweiten 20 µm und 250 µm unterscheiden sich nicht untereinander, liegen aber signifikant unter der Hälfte der Raten der Netzbeutel grober Maschenweite (10 mm). Dieselbe starke Verlangsamung des Abbaus durch experimentellen Ausschluß der Makrofauna wurde auch in drei weiteren Systemen (einer Kautschuk-, einer Pupunha-Monokultur und einer Polykultur mit Fruchtbäurnen) nachgewiesen. Die in FLO, SEC, POA und POC ermittelten Streuabbauraten sind signifikant mit den Abundanzen der Zersetzer (incl. Ameisen und Termiten) und mit der Biomasse der Regenwürmer und der Zersetzer korreliert.

Der in der Primärwaldfläche vergleichsweise niedrige Streuvorrat bei gleichzeitig höherem Streueintrag bestätigt den im Streubeutelexperiment nachgewiesenen effektiveren Streuabbau. Im Sekundärwald dagegen führten niedrigere Abbauraten zu einer Streuakkumulation. Die Polykulturflächen liegen dazwischen.

Das C/N-Verhältnis des Standardmaterials wird im Verlauf des Abbaus durch die Veratmung von C enger. In der Primärwaldfläche ist dieser Effekt am stärksten, wodurch der relative N-Gehalt der Reststreu nach 1 Jahr hier signifikant höher ist als in den anderen Flächen; in der ersten Serie am höchsten in den Beuteln der groben, in der zweiten Serie in den Beuteln der mittleren Maschenweite. Während die N-Gehalte im Streufall und im Boden von FLO höher als in allen anderen Flächen sind, unterscheiden sich die N-Gehalte der Streuvorräte nicht.

Die mikrobielle Biomasse im Oberboden war mit durchschnittlich 422 µg/g Boden niedrig im Vergleich mit Böden gemäßigter Wälder. In der unteren Bodenschicht (5-15 cm Tiefe) betrug sie etwa die Hälfte der oberen Schicht (0-5 cm) und folgt damit der Verteilung des organischen Materials und der Nährstoffe. Die mikrobielle Atmung in der Streu übersteigt die Bodenatmung bis um das Hundertfache. Unterschiede zwischen den untersuchten Flächen liessen sich nicht feststellen.

Beurteilung der Ergebnisse in Bezug auf die Ausgangshypothesen

I. Bodenfauna und die Streuabbauverhältnisse in den Kulturflächen unterscheiden sich deutlich von denen im Primärwald. Im Primärwald finden wir große Regenwürmer, eine hohe Frequenz und Abundanz von Ameisen und Termiten, einen raschen Streuabbau und in Folge eine geringe Streuauflage. Dabei ist allerdings die Funktion der Ameisen -die meist Räuber oder Samenfresser sind - im Abbauprozess als eher niedrig einzuschätzen. In den Pflanzungen dagegen sind gr0ße Regenwürmer selten, Ameisen und Termiten sind seltener und in der Biomasse (Termiten auch in der Artendiversität) reduziert; der Streuabbau ist langsam. Die Menge der Nährstoffe, die im Körper der Arthropoden und in ihren Nestern niedergelegt ist, ist durch die höheren Abundanzen und Biomassen im Primärwald höher als im Sekundärwald und in den Polykulturflächen.

II. Es hat sich gezeigt, daß die Polykulturflächen sehr arm an Totholz sind. Damit fehlen für viele Arten der Makrofauna Versteck- und Nistmöglichkeiten (vgl. Verhaagh 1991). Die Abundanz der Termiten - die hauptsächlichen Holz-Primärzersetzer - ist mit der Totholzmenge auf den Flächen korreliert.

III. Termitenpopulationen in den Pflanzungen der Experimentalfläche sind erheblich reduziert, und ihre funktionelle Diversität ist dort geringer. Aufsammlungen mit Licht- und Flugfallen in den Flächen haben aber gezeigt, daß die geflügelten Geschlechtstiere (Koloniegründer) der Termiten die Pflanzungen durchaus besiedeln könnten. Von 44 insgesamt schwärmenden Termitenarten wurden 14 ausschließlich in einer Polykultur, 12 nur im Primärwald und 18 Arten in beiden Flächen gefangen. Das macht wahrscheinlich, daß flächenspezifische Bedingungen wie das Fehlen von Versteckplätzen für Nestgründer und ungünstige mikroklimatische Bedingungen für die niedrigen Termitendichten in den Pflanzungen verantwortlich sind.

IV. In den Polykultur-Holzplantagen finden wir hohe Abundanzen an streufressenden Arthropoden (Diplopoden, Isopoden), eine gewisse Streuakkumulation und hohe Abundanzen von Räubern sowie eine extrem variable Biomasse an großen Regenwürmern. Ähnliche Verteilungen funktioneller Gruppen wurden von Lavelle et al. (1994) in einem weltweiten Vergleich unterschiedlicher Landökosysteme der Tropen gefunden.

V. Auch die anderen Kulturflächen im SHIFT-Experiment weisen eine vergleichbare Destruentenfauna auf, neben Diplopoden, Isopoden und partiell Regenwürmern treten vor allem in stark gedüngten Flächen auch Gehäuseschnecken auf (Vohland

& Schroth in press). Es scheint also eine Substitution der typischen "Waldfauna" (dominiert von großen Regenwürmern und einer hochdiversen Termitenpopulation) durch andere Gruppen (Isopoden, Diplopoden, Schnecken) stattzufinden.

VI. Die Umwandlung von Regenwald hat nicht nur eine sehr starke quantitative Veränderung der funktionellen Gruppen zur Folge. Aufgrund verschiedener Studien in anderen amazonischen Regionen und im Umkreis des Untersuchungsgebietes (Reserva Ducke, Embrapa) (Hanagarth 1983 ; McKay et al. 1991; Römbke & Verhaagh 1992 ; Verhaagh 1991; unveröff. Daten von Hanne & Martius) ist davon auszugehen, daß nur wenige Regenwaldarten zur Besiedlung anthropogener Systeme fähig sind. Sie werden ersetzt durch einheimische Offenlandarten, die zum Teil aus den Überschwemmungsgebieten oder aus trockeneren Standorten wie "Campinaranas" und "Campinas" stammen. Am Beispiel der Diplopoden kann man auf den SHIFT-Flächen und in vielen Teilen des Siedlungsgebietes von Manaus sehen, daß auch sogenannte „euryzöne", ursprünglich vom Menschen aus anderen Kontinenten (Asien und Afrika) eingeschleppte, Arten sich soweit zahlenmäßig entwickelt haben, daß sie ohne weiteres eine Bedeutung im Streuabbau auf Agrarflächen haben können. Es ist deshalb davon auszugehen, daß damit auch die Stoffflüsse und verschiedene andere Abbauprozesse wie die Humifikation und die Einarbeitung organischen Materials in den Boden qualitativ anders verlaufen als in Regenwaldökosystemen.

VII. Im Vergleich ist die Primärwaldfläche charakterisiert durch hohen Streueintrag und höhere N-Gehalte im Streufall, hohe Streuabbauraten und folglich niedrige Streumengen. Gegenüber den anderen Flächen ist der Gehalt an Kohlenstoff und Stickstoff (organische Bodensubstanz) und auch der Wassergehalt in der Streu und im Oberboden höher. In der etwa 18 Jahre alten Sekundärwaldfläche waren aufgrund der niedrigen Abbauraten die Streumengen trotz geringerem Streueintrag höher. Die beiden Polykulturflächen zeigten sich in vielen Variablen sehr unterschiedlich, in vielen Vergleichen war POC der Primärwaldfläche ähnlicher, POA der Sekundärwaldfläche.

VIII. Diese relative Einordnung der Flächen zeigt unserer Meinung nach den starken Einfluss des Mikroklimas, das zumindest in extremen Jahren bzw. über die Extreme in normalen Jahren restriktiv über die Bodenfauna auf das Streuabbausystem wirkt. Das Mikroklima seinerseits wird sicherlich i. W. durch das Pflanzsystem bedingt, d.h. über die Beschattung durch Kronen, die Bedeckung des Bodens durch Streu usw..

IX. Trotzdem aller Unterschiede ist festzuhalten, dass sich in allen untersuchten Flächen (Primärwald, Sekundärwald, Polykultursystem 4 des SHIFT-Experiments) Streuabbausysteme fanden, deren Geschwindigkeit im wesentlichen durch die Makrofauna bestimmt wird. In den untersuchten Polykulturflächen (System 4 - Holzplantagen in Block a - POA und c -POC) ist eine Fauna angesiedelt, die den "Ökosystem-Service" (Brussaard 1997) Streuabbau in ähnlichem Umfang leistet wie die des Waldes. Das zeigen vor allem die Stickstoff-Pools, die in den sehr jungen Systemen einen nachhaltigen Nährstoffffluss anzeigen. Das Abbausystem basiert dabei im wesentlichen auf der Streuproduktion der zwischen den eigentlichen Anbaupflanzen (geplant) aufgekommenen Sekundärvegetation. In allen untersuchten Flächen, am stärksten allerdings im Primärwald, findet eine Anreicherung (Konzentration) von *N* in der Streu im Verlauf des Abbaus statt.

Aus diesen Ergebnissen können folgende **Schlußfolgerungen** gezogen werden:

1. In den betrachteten Polykultursystemen sind die Grundlagen für eine angestrebte Verbesserung der Nachhaltigkeit aus bodenbiologischer Sicht vorhanden. Eine Besiedlung durch Primärzersetzer erfolgt in allen Fällen, die zugeführten Streumengen werden in angemessenen Zeitabschnitten abgebaut, organische Bodensubstanz wird gebildet und die Bodenstruktur verbessert.
2. Der Funktionskreis Streuabbau ist über die Förderung der Makrofaunabesiedlung optimierbar, wodurch wiederum die Versorgung der Nutzpflanzen mit Nährstoffen aus natürlicher oder zugeführter Streu verbessert werden kann. Dadurch sollten, zusammen mit langfristig positiven Auswirkungen der Fauna auf die Bodenstruktur, Nutzungssysteme ohne starke Nährstoffzufuhr durch Düngung nachhaltiger nutzbar werden. Optimierbar ist die Funktion der Makrofauna nur indirekt, d.h. über die Veränderung der kleinklimatischen Bedingungen durch Pflanzung von Bodendeckern oder das Zulassen von Sekundärvegetation und in Verbindung damit über Erhöhung der Streuauflage und gleichmäßige Zufuhr von Bestandesabfall.

Die Auswertungen sind noch nicht abgeschlossen. Diese und weitere Ergebnisse werden durch Publikationen in einschlägigen Fachorganen veröffentlicht. Wir verweisen insbesondere auf unsere Homepages im Internet (http://www.cpaa.embrapa.br/env52/ und http://www.zef.de).

Beabsichtigte Verwertung der Ergebnisse und Kooperation mit der Industrie

Die Schlussfolgerungen bilden die Grundlage für ein Folgeprojekt zur Umsetzung der Ergebnisse in die praktische Anwendung: im Management pflanzlicher Bestandesabfälle über die Manipulation von Streumengen, z.B. durch Mulchen mit zwischengepflanztem, stickstoff-anreicherndem (Leguminosen-) und/oder nährstoff-ärmerem Pflanzenmaterial. Dieses Folgeprojekt ist bei BMBF und CNPq beantragt. Die erfolgreiche Kooperation mit der Firma ECT Oekotoxikologie GmbH in Flörsheim bei Frankfurt soll im Rahmen des Folgeprojekts fortgeführt und besonders im Bereich Ökotoxikologie ausgeweitet werden, da der Einsatz von Pflanzenschutzmitteln auf Kulturflächen eine erhebliche Beeinträchtigung von Bodenfauna und Streuabbau darstellen kann.

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Annexes:
Sub-Reports

Site and Soil Characterisation

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1. Introduction

As a basis for the biological investigations at the EMBRAPA site it was necessary to determine the soil properties at the four investigation plots. Despite the fact that many studies have been performed in this area, relatively few soil data from precisely identified spots were available. Therefore, as part of the basic sampling program of SHIFT ENV 52, the following soil properties have been determined since December 1996: C/N-ratio (see Chapter C/N-Analyses for details), pH-value, soil moisture, organic content, grain size distribution and water holding capacity. However, these parameters have been measured at different scales: pH and moisture were automatically determined in parallel to the bait-lamina litter removal tests (therefore, a good overview on plot variability is available), whereas the other parameters were only occasionally measured. As far as possible standardised ISO methods have been used in order to produce reproducible and comparable data. Data on microbial respiration and biomass are covered in Chapter Microbiology. In addition to the mentioned parameters, soil samples were shipped to the University of Bayreuth, where the content of lignin decay products, cellulose and hemicellulose in the soil was determined (not covered in this report).

2. Methods

The analysis of the flora was performed according to standardised methods of plant sociology (for details see Preisinger et al. 1994).

In our investigations, the soil properties were mainly determined according to ISO guidelines:

ISO 10390 - 1994	Soil Quality - Determination of pH
ISO 11274 – 1992	Soil Quality - Determination of the water retention characteristic - Laboratory methods
ISO 11465 – 1993	Soil Quality - Determination of dry matter and water content on a mass basis - Gravimetric method

These methods were partly slightly adapted to the conditions of the EMBRAPA laboratory. All routine measurements were performed according to Standard Operation Procedures (e.g. "Measurement of pH in soil") as part of a Manual (available also on the SHIFT 52 homepage). Methods used in other investigations are mentioned in Chapter 3.

3. Results and Discussion

General site description

According to Beck et al. (1998), Höfer et al. (1999) and Vohland & Schroth (1999) the EMBRAPA site can be described as follows: The study area belongs to the agroforestry research station Embrapa Amazônia Ocidental, which is located close to the city of Manaus, Amazonas, Brazil (3°8´S, 59°52´W). The area is flat without elevations (altitude 44 – 50 m a.s.l.; Correia, pers. comm.). The investigations took place on an abandoned plantation of rubber trees (*Hevea brasiliensis;* Seringueira) which has been used as a polyculture forestry research area since 1992 (originally, the area was cleared from primary rain forest in 1979/1980, and the rubber plantation was abandoned in 1984). The plantation is divided into 90 experimental plots of 32x48 m each. Two of these plots (POA and POC; the latter is located close to the edge of the primary forest) were sampled together with two sites in a secondary (SEC) and primary (FLO) forest within a distance of less than 200 m (the latter two with one plot each of 40 x 40 m).

Plant sociology

It is not the intention to give an exhaustive overview on the vegetation of the four study plots. Details can be found in Preisinger et al. (1994) and Preisinger et al. (1998). All vascular plants in various plots of primary and secondary forest as well as in several polyculture plots (100 m^2 each) were recorded, preferably on the species level (in total, approx. 1100 species were found). In addition, the most frequently occurring species were classified with regard to growth form types and regenerative behaviour (Table 1). In the polyculture plots originally 4 different tree species of commercial use were planted in rows (with broad open spaces especially on POA). Whereas Andiroba trees (*C. guianensis*) were still thriving, Parica specimen (*S. amazonicum*) were rare when this study was performed. The tolerated secondary vegetation (mainly *Vismia* spp., Guttiferae) dominated the polyculture plots and especially the litter production. Since this plant is also abundant on the SEC plot, its litter was selected for the decomposition studies (litterbag method; see Chapter Decomposition for details).

Table 1: Characteristics of a sequence of terra firme sites with different use histories in the Central Amazon (EMBRAPA site near manaus) according to Preisinger et al. (1998); n = number of species of vascular plants found in an area of 1600 m^2

Vegetation type	Site History	n	Key families	Dominant species
Primary forest (FLO)	Extensively used for timber extraction	500	Sapotaceae	*Astrocaryum* sp.
			Chrysobalanceae	*Oenocarpus bacaba*
			Burseraceae	*Eschweilera* spp.
			Lecithidaceae	
Secondary forest (8 years old) (SEC)	Primary forest slashed and burned; rubber trees planted and abandoned 2 years later	200	Melastomataceae	*Vismia guianensis* agg.
			Moraceae	*Miconia* spp.
			Rubiaceae	*Bellucia* spp.
			Bignoniaceae	
Polyculture sites (POA, POC)	Slashed and burned twice; timber trees planted in rows	30-60	Guttiferae	*Vismia* spp.
			Meliaceae	*Carapa guianensis*
			Caesalpiniaceae	*Schizolobium amazonicum*

Soil properties

The results provided here were compiled from own measurements as well as literature data. In a first attempt to study the soil properties, samples (three replicates) collected from the three study plots were investigated at ECT in Flörsheim in December 1996 (Table 2). In 1998, mainly the actual moisture and the pH were measured on the four plots (Table 3) at different times in parallel to the bait-lamina litter removal study (see Chapter Bait-lamina). In the following, the main soil properties will be discussed individually.

Grain size distribution

The soil is a Xanthic Ferralsol according to the FAO/Unesco classification (FAO/Unesco 1990), known also as Latossolo Amarelo (Correa 1984). In any case the main mineral is Kaolonite. The grain size distribution at the four investigation plots was not measured individually. Therefore, data measured by Müller (1995) in the polyculture area in the uppermost 10 cm have to be extrapolated to the whole area (60 % clay, 25 % sand, 15 % silt; a sandy clay according to the German classification). The clay content is increasing with soil depth, leading to a percentage of 80 % (13 % sand and 5 % silt) at 60 to

80 cm. The same tendency but on a higher level was found by Correa (1984) for a primary forest site: 81 % clay, 9 % sand, 10 % silt at 0 – 8 cm and 91 % clay, 5 % sand, 4 % silt at 70 – 104 cm depth. Actually the same value (a clay content of 80 %) was measured at a polyculture site in 0 – 10 cm (Vohland & Schroth 1999). Quite different results were obtained by Ulbrich (1999), again at a primary forest on the EMBRAPA site in 0 – 10 cm: the mean values of three samples were 55 % clay, 42 % sand and 3 % silt. Summarising these results and taking the uncertainty about the exact sampling sites into account the data from Müller (1995) seem to be the most reliable.

PH-values

The four plots show no large differences in pH (Table 2 and 3): All measured values were in a range between 3.5 and 4.5. The data gained in parallel to the litter removal study indicate that the plots are quite homogenous conceming this parameter. Data provided by Müller (1995) from different plots at the EMBRAPA site are in range between 4.1 and 5.0, which is practically similar, since he measured the pH in water. The same results are reported by Vohland & Schroth (1999) and Ulbrich (1999): 4.5 (measured in water) for polyculture sites and 3.6 ($CaCl_2$) or 4.4 (water) for a primary forest, respectively. In addition, the data given by Correa (1984) at a primary forest in the EMBRAPA area are only slightly lower (3.8 measured in water in 3.6 in KCl). In the following, the values measured in the litter removal study will be used.

Soil moisture

According to our first measurements, the water capacity values at FLO were higher compared to the other two plots (Table 2), which can be expected from the overall site properties. Since in the litter removal study the moisture values have not been measured at the same time, it is difficult to determine whether there are any clear differences between the plots (Table 3). In any case, no differences between the control and treatment sub-plots could be found. It seems that the removal of the litter layer did not measurably influence the actual moisture level.

Organic content

The organic content in the uppermost soil layer showed a range of 2.5 to 4.5 % without clear differences at the four plots (Table 4; cf. Chapter C/N-analyses). (In the samples of the pre-study, very high values of 12–15% were found, but probably a mixing of soil and litter occurred during transport or sample preparation, leading to these high values). The results differ from those measured by Müller (1995) in the same area (but who used other methods). It is not really clear where the latter author took his samples but, apparently, in various polyculture plots the variability was clearly higher (0.3 – 6.8 %) than in the secondary forest (2.4 – 5.3 %). Correa (1984) and Ulbrich (1999) determined C_{org} values in the uppermost 8 (or 10) cm at the primary forest of 2.04 and 2.51 %, respectively.

Nitrogen content

As for carbon, our measurements of total nitrogen did not indicate a clear difference between the four plots: All values were within a range of 0.20 to 0.31 %. Very similar results were found by Correa (1984) and Ulbrich (1999) for the primary forest (0.18 and 0.22 %N).

Other parameters

Several authors (Correa 1984, Müller 1995, Ulbrich 1999) measured the cation exchange capacity at the EMBRAPA site. However, since they used different methods as well as different measurement parameters, these results are not comparable and will not be reported in detail. In addition, information mainly important for agricultural questions (e.g. concentrations of other nutrients in the soil) are not given here since they are probably not important within the scope of project ENV52.

4. Conclusions and outlook

Summarising the results of our own measurements and comparing them with data provided by other authors it seems that three main conclusions can be drawn mainly focusing on soil properties (it should be kept in mind that most literature data do not refer exactly to the same plots as in our study):

- the available information reveals a very high similarity between own measurements and literature data from the same area
- there are no large differences between the four investigation plots (probably except the water regime: the soil of FLO seems to be more moist)

- in parameters where measurements were undertaken (pH and actual moisture) surprisingly small horizontal differences within one plot were found.

Finally, concerning plant sociology the selected study plots seem to represent quite well a primary forest, a secondary forest and polyculture areas typical for terra firme sites in the region of Manaus.
Conclusively, the plots at the EMBRAPA site can be characterised as in Table 4.

In the future, issues of method standardisation and quality assurance should gain more attention when basic parameters for soil and site characterisation are determined. The use of internationally standardised and accepted methods like those described by ISO is a "must" for ecological investigations. Fortunately, guidance papers covering especially the situation in the tropics have become available (e.g. Van Reeuwijk 1995; 1998).

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Table 2: Different soil properties (mean values of three replicates; data from December 1997) determined at two depths at the three study plots (samples were measured in Flörsheim at ECT). WHCmax = maximum water holding capacity.

Plot	Depth	pH-Value	Moisture (%)	WHCmax (%)
FLO	0 – 10 cm	3.5	43.2	86.4
	10 – 20 cm	3.7	36.5	79.0
SEC	0 – 10 cm	3.8	34.0	79.7
POA	0 – 10 cm	3.9	34.9	76.8
	10 – 20 cm	3.8	33.3	73.2

Table 3: pH values (mean value and standard deviation) and actual moisture (mean value in percent) at the four investigation plots (0 – 5 cm depth) measured in parallel to the "litter removal" bait-lamina tests (10 replicates each)

	FLO	SEC	POA	POC
pH value				
Control	4.0 ± 0.2	4.0 ± 0.1	4.2 ± 0.1	4.0 ± 0.2
Treatment	4.0 ± 0.1	4.0 ± 0.1	4.1 ± 0.1	4.0 ± 0.1
Actual moisture				
Control	22.4 ± 0.8	20.1 ± 0.9	24.6 ± 1.9	18.0 ± 3.2
Treatment	22.2 ± 1.1	20.0 ± 1.3	24.4 ± 1.3	17.9 ± 3.7

Table 4:Short characterisation of the soil properties of the four study plots

Parameter	FLO	SEC	POA	POC
Vegetation	Primary forest	Secondary forest	Polyculture systems	
Soil Type	Xanthic Ferrasol (sandy clay): 60 % clay, 25 % sand, 15 % silt			
pH value ($CaCl_2$)	4.0 ± 0.2	4.0 ± 0.1	4.2 ± 0.1	4.0 ± 0.2
Wk_{Max} (%)	864	797	768	?
C content (%)	3.5 – 4.5	2.5 - 3.3	2.5 – 3.5	3.1 – 4.5
N content (%)	0.26 – 0.31	0.21 – 0.25	0.20 – 0.26	0.23 – 0.30

Microclimate 1997- 1999 in primary forest, secondary forest and agroforestry systems in central Amazonia

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Abstract
Rainfall, average maximum and minimum air temperature, and relative air humidity as measured at the Embrapa wheather station all show that 1997 was a strong El Niño (ENSO) year. The same is true for the microclimate of the study sites (a primary forest (FLO), a 12-year old secondary forest (SEC), polyculture system (sites POA, POC, PolyIIB), and a peach palm monoculture (PupC), where maximum and average air temperature and soil temperature were all highest in September and October 1997. Minimum air temperatures were elevated in the subsequent period, from October 1997 to May 1998. Relative air humidity was extremely low in September 1997; and evapotranspiration and calculated saturation deficit were very high.
Litter temperatures in FLO, SEC, POC, and PupC were very similar; in POA they were consistently higher at about 2 degrees, and in PolyIIB they were about 4 degrees higher. The highest maxima were recorded in POA and PolyIIB, showing that microclimatic conditions are much more variable and unpredictable than in the other sites.
Soil temperatures were lowest in FLO, higher in SEC, and even higher in POA. In FLO, the soil temperature almost equalled the temperature in the litter layer, whereas soil temperatures in POA were considerably lower than the litter temperatures. Air humidity in all sites was lowest in September/October 1997. In the other months, it almost always stayed near 100% in FLO, SEC, POC, but was much lower in POA. In conclusion, the microclimate in the litter and soil layer of polyculture sites can be much harsher than in secondary forest and primary forest in Amazonia, but the mimicking of natural forest structure can be used for the management of microclimatic conditions that affect decomposer fauna.

1. Introduction

The record of microclimatic data is an essential basic task in a study aimed at analyzing differences in soil fauna abundance and performance in differently managed sites. In this project, small data loggers were used to record and store microclimatic data in the litter and soil layer of the studied plots; namely primary forest (FLO), secondary forest (SEC), and two plantations (polyculture system 4; POA and POC; for details cf. Lieberei & Gasparotto 1998, Beck et al. 1998a, b). Additionally, in May to November 1998, the litter layer temperature at two sites was recorded: the Pupunha monoculture in block C (PupC) and the polyculture system "II" in block B (PolyII-B), the sites where the study of Kurzatkowski (see separate subreport) was carried out. Here, we report on the recordings of the Embrapa whether station during the study period which are used as a reference against which to calibrate the data from the study sites; and on the microclimate recordings from the data loggers. An additional analysis of the data is presented in the following report ("Microclimate data that influence the 3-monthly fauna sampling").

2. Material and Methods

The study site located in central Amazonia has been described in detail elsewhere (Lieberei & Gasparotto 1998, Beck et al. 1998a, b). One data set containing daily values for maximum, minimum, and average soil temperature, air humidity, evapotranspiration and rainfall was obtained from the climatic station of the Embrapa Amazônia Ocidental for January 1996 through April 1998. This station is a standard climate station. Monthly averages were computed on the basis of daily values. Saturation deficit was calculated from air temperature and relative air humidity according to the "Magnus formula" (D'Ans-Lax 1967).
The microclimate was measured with data loggers in 6 different sites (Table 1). Due to technical reasons (battery life duration), data were obtained in three subsets: August 1997 to March 1998, May 1998 to November 1998, and November 1998 to April 1999 (details in Table 2).

recorded in POA and PolyIIB, although the minima recorded here (probably at night) do not differ from those at the other sites. The recorded maxima (Table 7) are almost certainly artifacts, because the temperature was measured in loggers enclosed in tranlucent plastic cases, but the information shows that sun light is much more likely to hit the litter and soil surface in these openly-structured sites than under closed canopy, and that, therefore, microclimatic conditions are much more variable and unpredictable in POA and PolyIIB than in the other sites.
Soil temperatures were lowest in FLO (although no difference to SEC was recorded in September 1997), higher in SEC, and even higher in POA (POC not recorded; Figure 6 and Table 7). In FLO, the soil temperature almost equalled the temperature in the litter layer, whereas soil temperatures in POA were considerably lower than the litter temperatures (harsher conditions for the soil fauna in the litter layer; Figure 8).
Air humidity in all sites was lowest in September/October 1997. In the other months, it almost always stayed near 100% in FLO, SEC, POC, but was much lower in POA (Figure 7, Table 7).

We conclude that the microclimate can be much harsher in the litter and soil layer of polyculture sites than in secondary forest and primary forest in Amazonia, but a better developed canopy as in the 12 year old secondary forest (SEC) or the vicinity to closed forest as in POC are factors that offer protection from high variation and high temperature peaks. These results indicate that the mimicking of natural forest structure (closed canopy; mosaic landscape of intermittent ecosystem types instead of large-scale clearcutting) can be succesfully used for the management of microclimatic conditions that affect the important decomposer fauna and microflora of the soil.

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Tables

Table 1: Sites and periods of microclimatic measurements during the project SHIFT 52

Site Code	Description	Measurement Periods
FLO	primary rain forest	Aug 1997 - Mar 1998 May 1998 - Nov 1998 Nov 1998 - Apr 1999
SEC	secondary forest established in 1984	Aug 1997 - Mar 1998 May 1998 - Nov 1998 Nov 1998 - Apr 1999
POA	polyculture system consisting of 4 commercial wood species planted in rows, between which secondary growth was allowed (established in 1992)	Aug 1997 - Mar 1998 May 1998 - Nov 1998 Nov 1998 - Apr 1999
POC	idem	Aug 1997 - Mar 1998 May 1998 - Nov 1998 Nov 1998 - Apr 1999
PolyIIb	another mixed culture system consisting of 4 native Amazonian fruit trees planted in rows, between which only annual plants were admitted (established 1992; the logger was placed between two rows)	May 1998 - Nov 1998
PUP	a monoculture of peach palm (*Bactris gasipaes*; "pupunha" in Brazil). (established in 1992)	May 1998 - Nov 1998

Table 2: Data sets from loggers used for the analyses

	Start	End	Total number of measurements per logger	Days of periods
Aug 1997 - Mar 1998	22.7.1997, 00:00	4.2.1998, 16:00	2372	198
May 1998 - Nov 1998	26.5.1998, 02:00	19.11.1999, 12:00	2130	177
Nov 1998 - Apr 1999	20.11.1999, 20:00	9.4.1999, 10:00	1676	140

Table 3: Logger positioning during the first measurement period (07/97 - 04/98). HUM = humidity loggers; T = temperature loggers; Numbers = logger identification number (serial number). Daily Temp.: values taken all 10 minutes (two loggers set up for comparison).

Stratum	FLO	SEC	POA	POC
Litter layer L	HUM 966	HUM 970	HUM 973	-
	T 109 case	T 110 case	T 111 case	T 118 case
Soil S 0-5 cm	T 112*) & ext. sensor	T 114*) & ext. sensor	T 115*) & ext. sensor	T 116 case**)
Daily Temperature	T 98570 case	-	T 98572 case	-

*) in the lack of original submersible cases, loggers were placed in silicone-sealed plastic flasks, from July 1997 to April 1998

**) no external sensor was available and the logger in the case was buried into the ground to a depth of approx. 5 cm; from July 1997 to April 1998

Table 4: Logger positioning in the second measurement period (05/98 - 11/98). T = Temperature, HUM = humidity logger

	FLO	SEC	POA	POC	Pup-C	PolyII-B
Litter	T 109	T 110	T 111	T 112	T 570	T 572
Soil	T 114	T 115	T 118	T 569	-	-
Rel. Humidity	HUM 966	HUM 970	HUM 973	HUM 767	-	-

Table 5: Logger positioning in the third measurement period (11/98 - 04/99). Notes: In POC, loggers were exposed at 4 points, one in each of the secondary growth strips, approximately at 15 m from "0", to detect small-scale variation. The humidity loggers stopped recording before retrieval, between December and February

	FLO	SEC	POA	POC	POC	POC	POC
Litter	T 109	T 110	T 111	T 112	T 116	T 570	T 572
Soil 5 cm	T 114	T 115	T 118	T 569			
RH	HUM 966	HUM 970	HUM 973	HUM 973			

Table 6: Rainfall data of the station at the Embrapa Amazônia Ocidental (monthly sums) during the study period of the project SHIFT 52. (cf. Figure 1)

	1996	1997	1998	1999
Jan	291,7	251,7	296,5	310,4
Feb	276,0	319.2	226,1	366,1
Mar	385,5	464,1	333,1	290,5
Apr	366,5	271,0	377,3	425,2
May	144,6	177,2	226,2	
Jun	212,8	69,8	187,6	
Jul	133,5	44,9	113,1	
Aug	200,5	137,1	87,9	
Sep	110,4	48,4	125,9	
Oct	116,7	65,6	174,7	
Nov	178,6	261,3	234,4	
Dec	168,2	127,7	162,6	
Total/Year	**2585**	**2238**	**2545.4**	
Average/Month	**215.4**	**186.5**	**212.1**	

Table 7: Litter (L) and soil (S) temperature and relative air humidity (RH) in the study sites (for codes, see Table 1). Averages, Standard Deviations, medians, maxima and minima recorded in each of the three study periods (see Table 2).

1997-98

	109 FLO L	112 FLO S	66 FLO RH	110 SEC L	114 SEC S	70 SEC RH	111 POA L	115 POA S	73 POA RH	118 POC L
Average	26.4	26,1	96,6	26,4	26,1	90,5	28,4	26,6	86,9	26.6
Std.Dev.	1.8	0.7	8,6	1,9	0,8	15,7	5,5	1,0	20,0	2.1
Median	26,2	26,2	100	26,0	25,9	100,0	25.8	26.6	100	26,1
Maxima	34,7	27,7	100	32.6	32.6	32,6	50,9	29,9	100	36.5
Minima	22,6	23,7	43,6	22,8	22.8	22.8	22.2	23.1	20.6	22.8

1998-98

	109 FLO L	114 FLO S	66 FLO RH	110 SEC L	115 SEC S	70 SEC RH	111 POA L	118 POA S	73 POA RH	112 POC L	569 POC S	73 POC RH	570 PupC L	572 PolyII-B L
Average	25,6	25,7	96,9	25,7	25,9	99,3	26,8	26,3	92,5	25,8	25,6	99,3	25,6	29.7
Std.Dev.	1,3	0,5	16,1	1,2	0,4	3,2	3,2	0,9	17,4	2,4	0,6	2,7	2,5	7,3
Median	25,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Maxima	30,1	27,0	100,0	28,9	27,0	100,0	46,0	28,9	100,0	30,1	27,1	100,0	36,2	55,7
Minima	22,9	24,5	0,5	23,2	24,9	72,6	22,9	24,3	0,0	22,0	23,9	76,1	21,9	22,2

1998-99

	FLO L109	FLO S114		SEC L 110	SEC S 115		POA L111	POA S118		POC L112	POC S569		POC L116	POC L570	POC L572

Average	25,2	24,9	25,3	25,4	26	25,9	25.3	25,2	25,0	24,9	25,0	
Std.Dev.	0,6	1,1	1,2	0,6	2,9	0,7	2,0	0,7	1,4	1,3	1,4	
Median	25,1	24,5	25,0	25,2	25,0	25,7	24,5	25,0	24,7	24,7	24,7	
Maxima	27,2	28,5	30,4	27,4	39,0	28,2	35,6	27,8	30,8	30,1	31,2	
Minima	24,0	22,7	23,2	24,1	22,2	24,3	22,3	23,5	22,6	22,2	22,6	

Table 8: Monthly average values of litter (L) and soil (S) temperature and relative air humidity (RH) in the study sites (for codes, see Table 1).

Period		109 FLO L	112 FLO S	66 FLO RH	110 SEC L	114 SEC S	70 SEC RH	111 POA L	115 POA S	73 POA RH	118 POC L
97-98	Aug-97	25,7	25,3	98,8	25,6	25,3	92,3	27,9	25,9	87,6	25,6
	Sep-97	26,8	26,1	92,7	26,9	26,1	83,7	29,5	26,8	79,5	26,8
	Oct-97	27,4	26,7	91,2	27,3	26,7	83,4	30,4	27,4	79,6	27,7
	Nov-97	26,4	26,3	97,7	26,4	26,3	91,3	28,3	26,7	88,5	26,7
	Dec-97	26,5	26,3	99,1	26,4	26,3	93,6	28,1	26,7	90,6	26,7
	Jan-98	25,9	25,9	100,0	25,9	25,9	98,9	26,9	26,1	96,1	26,1
	Feb-98	26,5		99,8	26,3	26,3	98,3	27,6	26,6	95,4	
	Mar-98	26,2		100,0	26,1	26,2	99,9	27,1	26,5	97,6	

		109 FLO L	114 FLO S	66 FLO RH	110 SEC L	115 SEC S	70 SEC RH	111 POA L	118 POA S	73 POA RH	112 POC L	569 POC S	73 POC RH	570 PupC L	572 PolyII-B L		570 PupC L	572 PolyII-B L
98-98	May-98	26,0	26,0	100,0	26,2	26,4	100,0	26,3	26,5	97,6	25,9	26,0	100,0	25,6	28,8		25,6	28,8
	Jun-98	25,3	25,5	100,0	25,6	25,8	100,0	25,7	25,9	97,5	25,3	25,4	99,9	25,1	28,3		25,1	28,3

	Jul-98	25,2	25,3	100,0	25,3	25,7	99,9	25,8	25,7	95,3	25,2	25,2	99,8	25,0	28,9		25,0	28,9
	Aug-98	25,9	25,7	100,0	25,6	25,8	98,4	26,8	26,2	83,8	26,0	25,6	98,8	25,9	30,2		25,9	30,2
	Sep-98	25,7	25,7		25,8	26,0		27,0	26,4		25,8	25,7		25,7	30,3		25,7	30,3
	Oct-98	25,9	25,9		25,9	26,1		28,2	26,7		26,4	25,9		26,3	31,4		26,3	31,4
	Nov-98	25,9	26,0		26,0	26,2		27,7	26,7		26,1	26,0		25,9	29,2		25,9	29,2
		FLO L109	FLO S114		SEC L 110	SEC S 115		POA L111	POA S118		POC L112	POC S569		POC L116	POC L570	POC L572		
98-99	Nov-98	25,5	25,1		25,5	25,7		26,1	26,1		25,5	25,5		25,2	25,1	25,2		
	Dec-98	25,8	25,5		26,1	26,0		27,1	26,5		26,2	25,8		25,8	25,6	25,8		
	Jan-99	25,1	24,6		25,1	25,3		25,6	25,6		25,0	25,0		24,8	24,7	24,8		
	Feb-99	25,1	24,6		25,1	25,2		25,7	25,6		25,1	25,1		24,8	24,7	24,7		
	Mar-99	25,0	24,7		25,1	25,2		25,8	25,6		24,9	24,9		24,8	24,6	24,8		
	Apr-99	25,1	24,6		25,0	25,2		25,5	25,6		24,8	25,0		24,7	24,5	24,7		

Figures

Figure 1: Monthly rainfall (y-axis; monthly sums) of the station at the Embrapa Amazônia Ocidental . (cf. Table 5 for raw data)

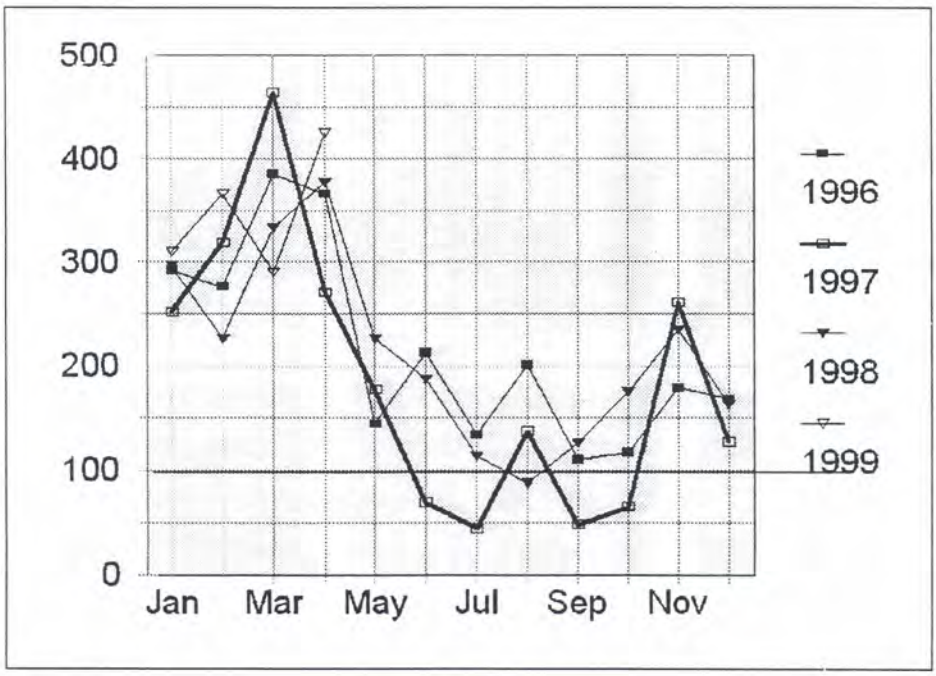


Figure 2: Climatic data as recorded by the Embrapa's wheather station (based on daily readings)

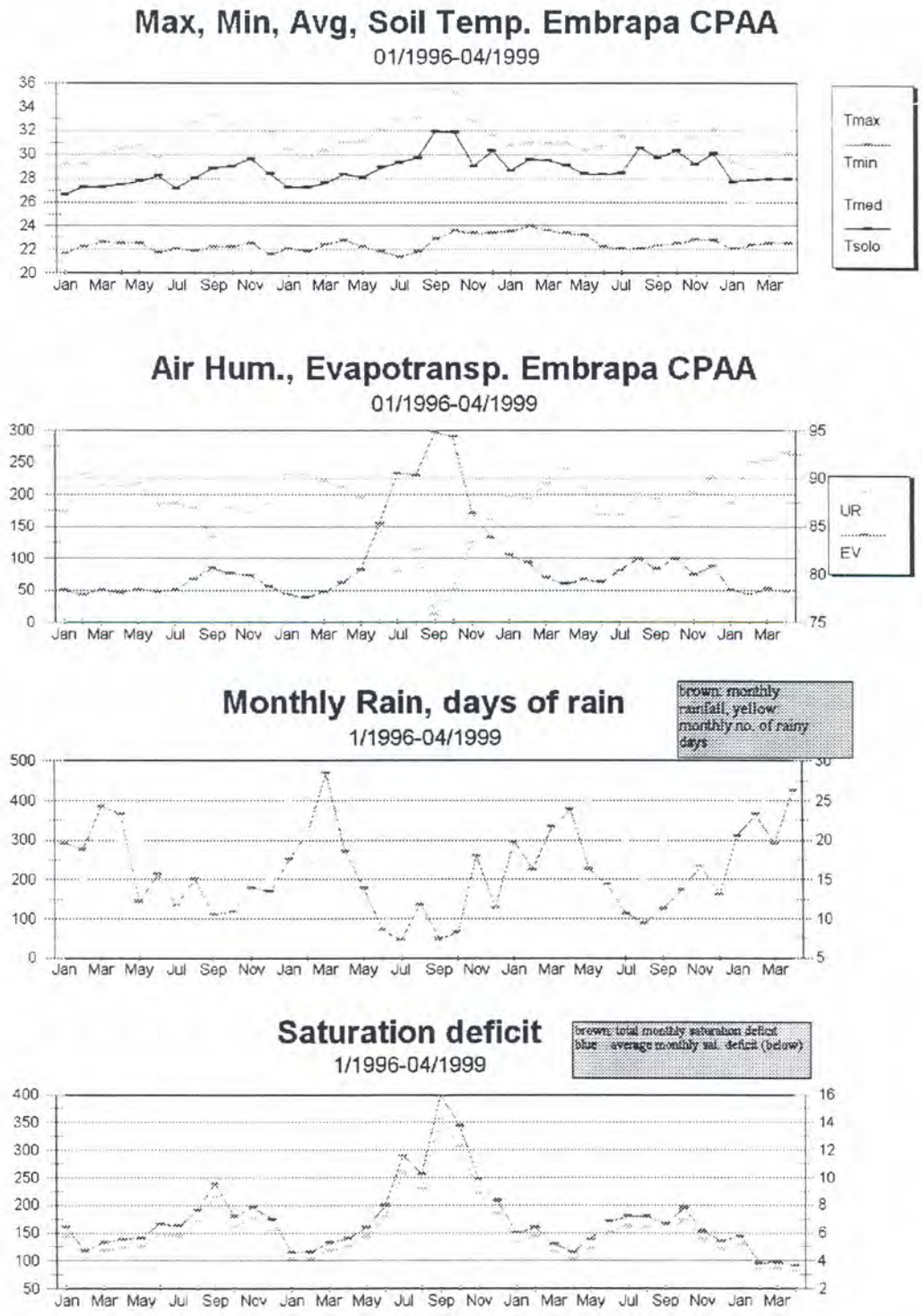


Figure 3: Comparison of air temperatures at the Embrapa's wheather station with the air temperature in the litter layer of the sites FLO, PolyIIb, and POC

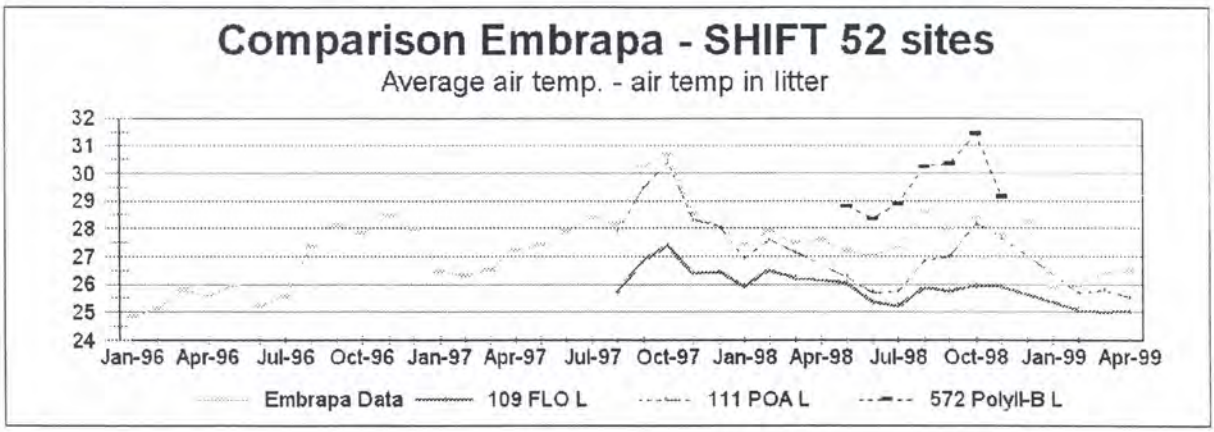


Figure 4: A comparison of loggers at four places within POC

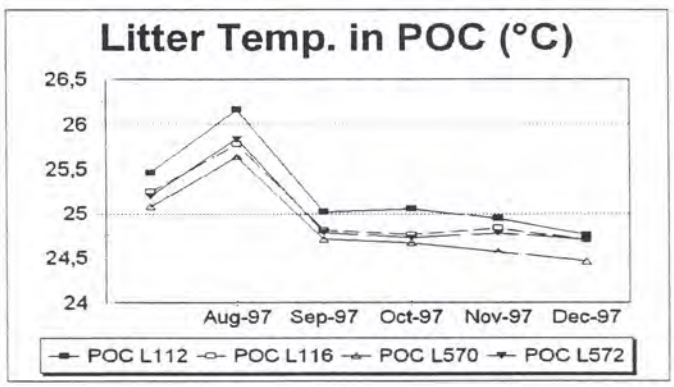


Figure 5: Litter temperatures as measured with data loggers in the study sites (for raw data, cf. Table 8)

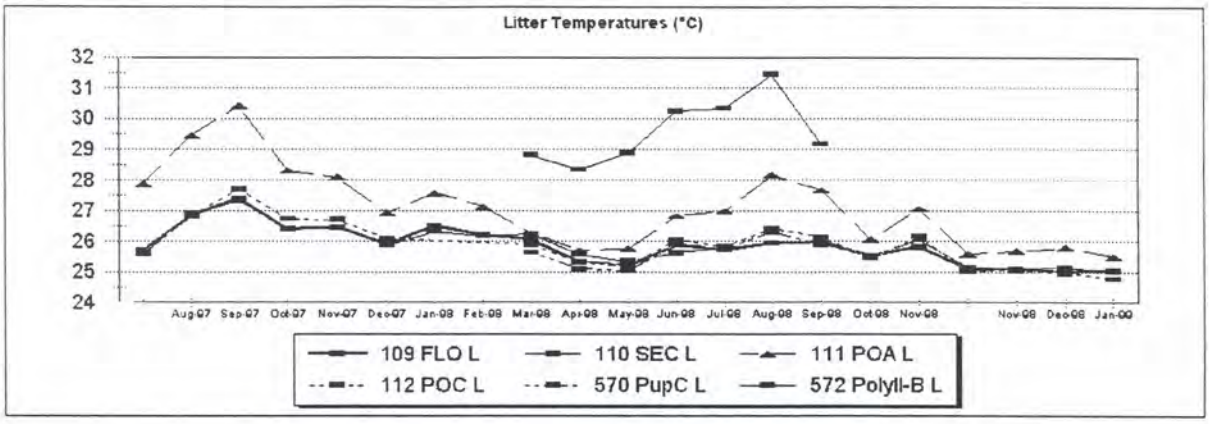


Figure 6: Soil temperatures as measured with data loggers in some study sites (data from table 8)

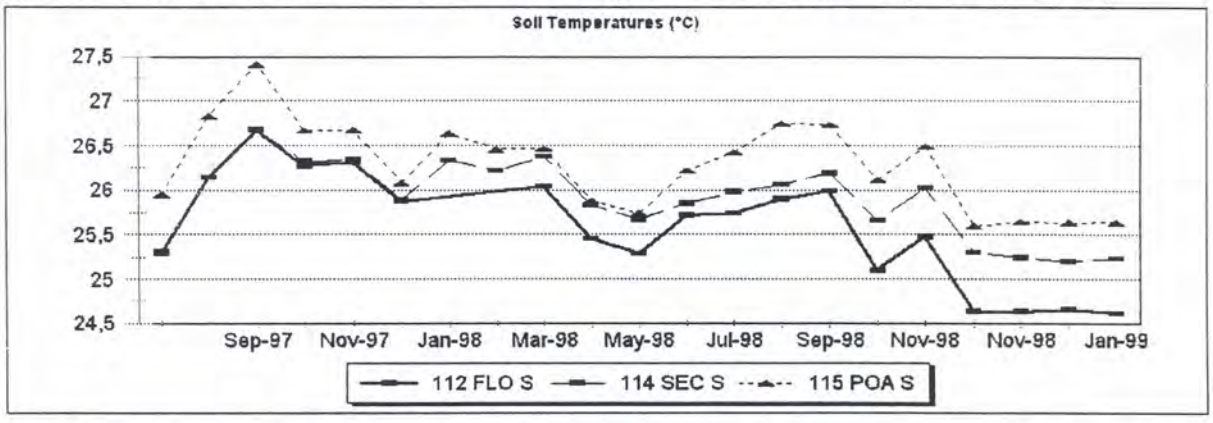


Figure 7: Air humidity in the litter layer (10cm above ground) as measured with data loggers in the study sites (for raw data, cf. Table 8)

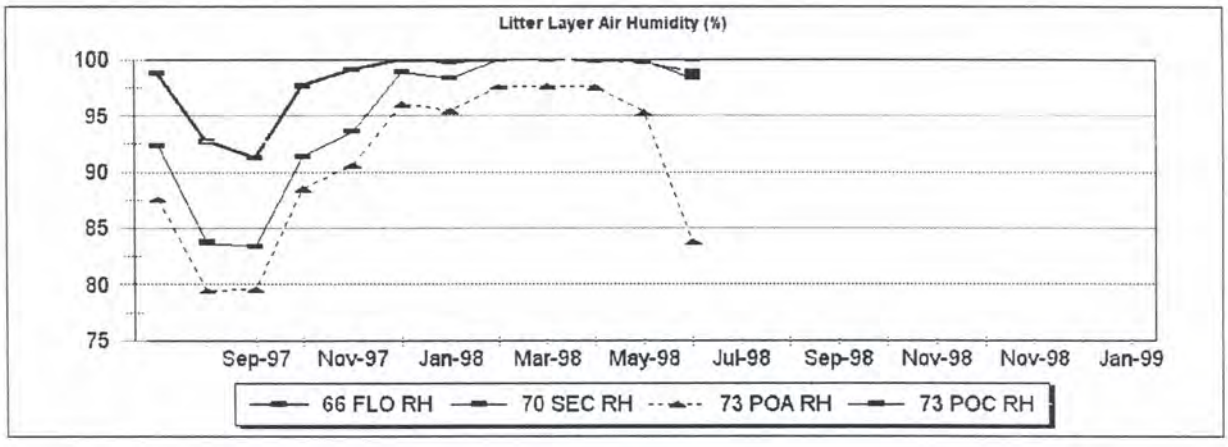
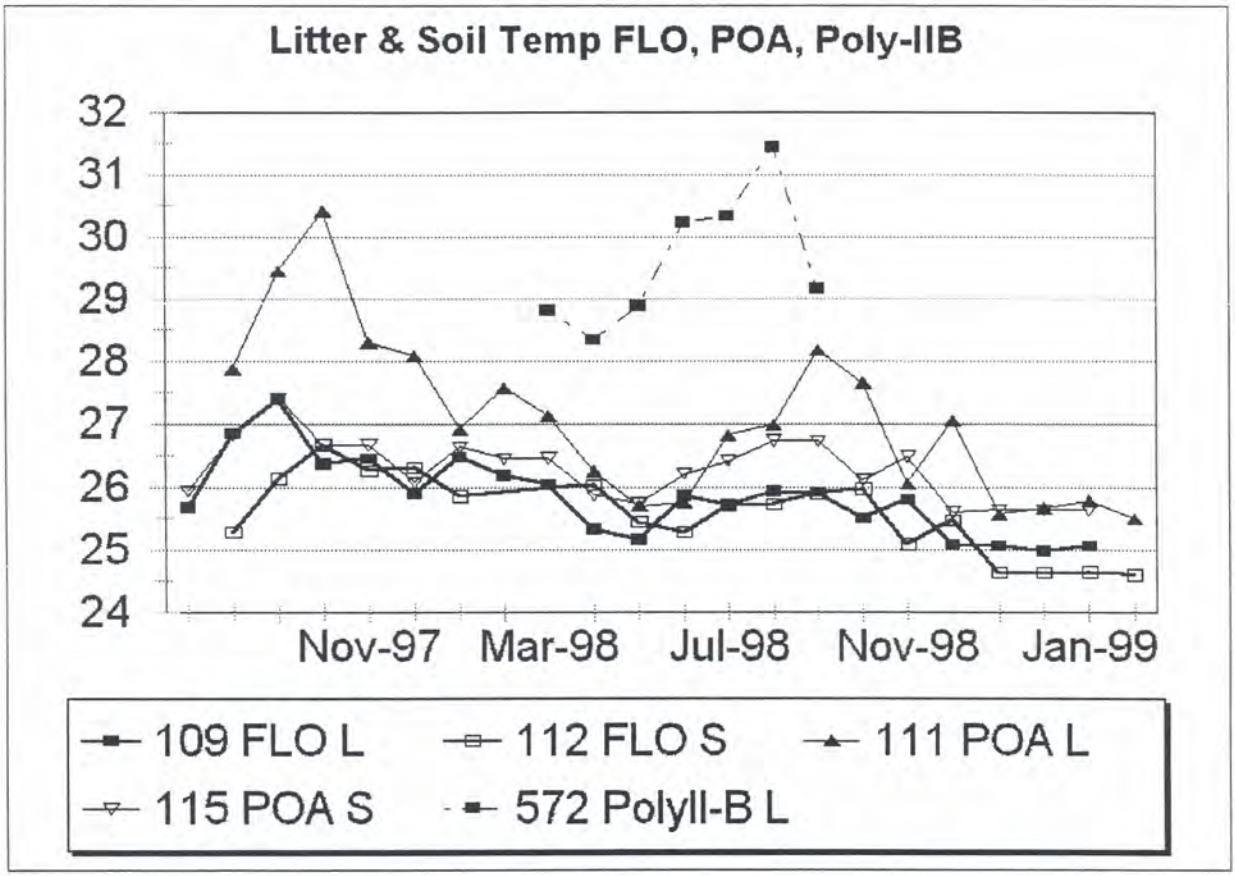


Figure 8: A comparison of litter (L) and soil (S) temperatures in FLO anbd POA. PolyIIB is shown for comparison.



Microclimate data that influence the three-monthly fauna sampling: The example of termites

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Abstract
In this report, we present the climatic data of the short periods that precede the three-monthly soil fauna collections made 1997 to 1999 in the SHIFT Project 52. We present data for the periods of 3, 5, 10, and 30 days before the first day (of every two-day) sampling event. Some data are from the Embrapa climatic station (the average daily rainfall in the period), and other data were measured with data loggers in the different plots (FLO, SEC, POA, POC) of the project (the average litter temperature, the average air humidity in the litter layer, and the average soil temperature of each area). We show how these data were applied to termite biomass.

1. Introduction

In a project meeting in Karlsruhe in Summer 1999 the use of the microclimate data for correlation with soil fauna data was discussed. This report gives the data for use and relates their application to the soil termite data as obtained from the Berlese extraction.

In order to be able to detect factors that determine the abundance and activity of soil fauna in the upper soil strata, we analyzed the climatic data recorded by Embrapa (weather station) and by SHIFT 52 (data loggers) with relation to the collecting dates of the macrofauna/ mesofauna/microflora samples that took place every three months.

2. Material and Methods

"Macrofauna" samples were taken 1996-1999 on four sites belonging to three different ecosystems: one primary forest site (named FLO) and one secondary forest site established 1984 (SEC), and a mixed culture system established 1992 (POA and POC), consisting of 4 tree species planted in rows, among which secondary growth was allowed to develop.
The rainfall data from the Embrapa station and the microclimate data as recorded in these sites with miniature data loggers are presented elsewhere (Martius et al., 1999a). Here, only the data related to the sampling dates of the project (**Table 1**) are presented. For that purpose, I extracted the data of 3, 5, 10, and 30 days, respectively, before each sampling date, from the original data files. The data prepared in that manner are:

1. **Daily rainfall average (mm)** during the recorded period = during 3, 5, 10, or 30 days before the sampling event) - data from the Embrapa meteorological station (Table 3)
2. **Litter temperature** (°C) on each site (the temperature in the litter layer, recorded with data loggers) (Table 5)
3. **Soil temperature** (°C) on the sites (FLO, SEC, POA, POC) in 5 cm depth, recorded with miniature data loggers in the center of each site (Table 6)
4. **Air humidity** (% r.h.) in the litter layer of each site (recorded with miniature data loggers about 10 cm above soil surface, .i.e. in or shortly above the litter layer) (Table 7)
5. The **water saturation deficit** calculated from the Embrapa data for the 3, 5, 10 and 30 days before each sampling event in the project (Table 4)

The saturation deficit was calculated from the maximum daily temperature and the average daily air humidity recorded at the Embrapa wheather station. It is based on the "Magnus formula" (D'Ans-Lax 1967) and is expressed in Hectopascal (hPa). The formula is $E=6.107 \cdot 10^{(7.5t/(237+t))}$; with t= air temperature in °C, and E_o=vapor pressure at saturation above water at 0°C (6.107 hPa, HektoPascal).

The exact periods used for the calculations are shown in **Table 1**. In some cases, the climatic data are not available for the full length of the period necessary. For example, as the climatic recordings with loggers only

started on 21.7.1997, the 5, 10, and 30 day period before the sampling event of 23.7.97 is not covered. In other cases, the loggers batteries did not last long enoigh and therefore measurements stopped before time, but as a considerable part of the period is covered, I included the data (e.g., before 2.6.98, data are available only from 26.5. onwards, which corresponds to 7 days instead of 10 or 30 days). The smallest data set is avaliable for POC, where soil temperature and humidity loggers were not available before March 1998 (one was broken and one was lacking). Please refer to the information in **Table 2** for details.
The data files are listed in **Table 3**.

As an example, I applied these data to the termite biomass obtained from the Berlese extraction of large soil cores (macrofauna, 21 cm diameter soil borer used; Martius et al. 1999b). First, I determined the correlation between termite biomass and individuals (separately for litter and soil); in spite of large differences in body weight between the termites, both factors are highly correlated (because small termites dominate). Therefore, I then used only termite biomass for the following calculations. I also determined the correlation between litter and soil biomass; as there is none, I made the following calculations separately for litter and soil termites. In all cases, the Pearson product moment correlation (with P = 0.050) was calculated using Sigmastat 2.03.

3. Results

A comparison of the different data sets

A comparison of the data sets obtained for 3, 5, 10, or 30 days before the sampling shows that

- all temperature data (litter and soil) show a decreasing trend during the course of the study (Figures 1, 2)
- the humidity data (Figure 3) show an increasing trend in SEC and POA. The sudden decrease in the air humidity in Flo at the end of the study is probably due to damaged data loggers and should not be considered. Therefore, these data points have been eliminated from the data set that I provide in annex for your use. (In other words, these data are in the figure but not in the data set).
- the different data sets (3, 5, 10 and 30 days before the sampling event) of the same variables do not differ too much between each other (Figures 1-3). This is principally true for air humidity.
- The areas with a less pronounced canopy (POA and POC) show a visible reduction in litter and soil temperatures in June 1998. This corresponds to the dry season in this year (Martius 1999a; the much more extreme dry season 1997 is not represented in these data).
- The average rainfall in the different periods (3 to 30 days) does not differ too much (Figure 4 above). The variation from date to date is relatively high for the 3-day period, but on average over 10 or 30 days, the curves are smoothened, which means that day-to-day variations are more important than seasonal climatic variation in Amazonia.
- The sum of the rainfall days per period (Figure 4 below), of course, differs, depending on the number of days taken as a base (it is not the average!).
- Figure 5 shows that the saturation deficit is very high in all sampling months in1997 and is reduced in 1998. It has a depression in June 1998 and is lowest in March 1999. Table 4 gives the data.

The correlations between termite data and these data

Litter termites

Litter termite biomass and average daily rainfall (Embrapa data)
A significant positive correlation was only detected for POA with average daily rainfall during 3 days before the sampling event (correlation coefficient = 0.726, P=0.042).

Litter termite biomass and litter temperature in all sites (logger data)
In all cases (all sites -FLO, SEC, POA, POC- vs. all litter temperature data for 3, 5, 10, 30 days before each sampling date), no significant correlation was detected.

Litter termite biomass and air humidity (logger data for each site)
This correlation was not calculated for POC, because of lack of sufficient data points (n=3 only). For all other sites (FLO, SEC, POA), no correlation was detected.

Soil termites

Soil termite biomass and average daily rainfall

Significant positive correlations were only obtained for soil termite biomass in POA against average daily rainfall 5, 10, and 30 days, respectively, before the sampling event.

days before sampling	correlation coefficient	P	n
3	0.539	0.168	8
5	0.729	0.04	8
10	0.968	<0.0001	8
30	0.732	0.039	8

Soil termite biomass and soil temperature in all sites

Significant (negative) correlations are found only for soil termite biomass in POA with soil temperature 5 (coefficient = -0.823; P = 0.023) and 10 days (coefficient = -0.908; P = 0.005) before the sampling day. That means that in this plantation area, termite biomass in the soil was inversely correlated with soil temperature between 5 and 10 days before the sampling day. In all other sites, no such correlations were found.

Soil termite biomass and air humidity

Air humidity was not assessed for soil termites. - Similar calculations could be made for total termite biomass (litter + soil).

4. Discussion

Dibog et al. (1998) found a significant inverse correlation between termite abundance in the soil and rainfall during 2, 7 and 30 days before the sampling event. They found that the correlation for the 2 day-period was stronger, suggesting short-term movements of termites in the soil as important factors. Here, the short periods were not so significantly correlated with termite biomass, and the correlation was only significant for one site, POA. Among our sites, POA is the one with the most extreme microclimate. It is therefore understandable that this site shows the dependence of termite biomass on microclimate most clearly. In the other sites, it seems that the control of termite biomass in litter and soil by microclimate (rainfall, and related to it, soil moisture) is masked more strongly than in POA by other factors. That means that litter and soil termites are controlled by climate if this is extreme, but their distribution depends stronger on other factors in the more forest-like sites.

5. References

Beck, L, Höfer, H, Martius, C, Garcia, MB, Franklin, E, Römbke, R (1998a): Soil fauna and litter decomposition in primary and secondary forests and polyculture system in Amazonia - study design and methodology. Proceedings of the Third SHIFT-Workshop, Manaus, March 15-19, 1998. BMBF, Bonn. 463-469

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Martius et al. (1999a): Microclimate 1997- 1999 of the study sites of SHIFT Project 52 at Embrapa, Manaus, Brazil. Unpublished report

Martius et al. (1999 b): Soil termites in primary forest, secondary forest and an agroforestry plantation system in central Amazonia. Unpublished report.

Table 1: Periods that were used for the calculations of the logger data. dbs = days before sampling. Always: first day 08:00 to last day 06:00 (last day = morning of the first sampling day)

dbs >>	3	5	10	30
sampling				
23.07.97	21-23 (1 d missg.)	n.a.	n.a.	n.a.
09.09.97	6.-9.9.	4.-9.9.	30.8.-9.9	10.8.-9.9.
02.12.97	29.11.-2.12	27.11.-2.12.	22.11.-2.12	2.11.-2.12
02.03.98	27.2.-2.3.	25.2.-2.3.	20.2.-2.3.	31.1.-2.3.
02.06.98	30.5-2.6.	28.5.-2.6.	23.5.-2.6.	3.5.-2.6
01.09.98	29.8.-1.9.	27.8.-1.9.	22.8.-1.9.	2.8.-1.9.
01.12.98	28.11.-1.12.	26.11.-1.12.	21.11.-1.12.	1.11.-1.12.
02.03.99	27.2.-2.3.	25.2.-2.3.	20.2.-2.3.	31.1.-2.3.

Table 2: Technical details of the data analysis and explanation of the files

The accompanying files contain the data necessary to make correlations between fauna data and weather data.
The climatic data of 3, 5, 10 and 30 days before the three-monthly sampling are computed here.

Rainfall:	Average daily rainfall (mm) (Embrapa station)
Temperature, Moisture:	Average of values - Data logger data (FLO, SEC, POA, POC)
Legends:	dbs = days before sampling n.a. = not available

Notes:
The Embrapa temperature data are based on one value (one measurement) per day.

The logger temp. and humidity data are based on the average of a recorded value every 2 hours. The recorded value itself is an average of measurements made by the logger in 10 minute intervals. Thus, the logger data are much more reliable with respect to short-term variation than the rainfall data from Embrapa.

I always used the data of the x days before the first sampling day; x being dbs = 3, 5, 10 or 30. Eg.; if the sampling date was 2. and 3. March, and if dbs = 3 days, I used the data referring to 27.-28.February plus 1. March

For the logger data, the last day before the sampling day terminates on the sampling day at 06:00 h in the morning. This means that for example, the 3 day period for the sampling event on 2. March are those that start 27. February at 08:00 h and end 2. March 06:00 h.

As the logger recording started only 21.7.97, the 5, 10 and 30 day data for 23.7.97 are not good!

Note: In the original file (trigger factors...wb3), I calculated the values on the basis of the original data files.
In the "rainbow52" files, I transformed the data into values, so that you do not need to have the original data files and no links to them (which would make sending the whole data bunch very large).

These files are write-protected, but you can copy all the data!

Table 3: Rainfall and soil temperature befores sampling (from Embrapa wheather station)

	Rainfall average per day (mm) for the period before sampling			
Days before sampling	3	5	10	30
23.07.97	0,0	0,5	2,1	1.7
09.09.97	6.1	6,5	3,2	4,9
02.12.97	0,0	4,2	7,1	8,5
02.03.98	2,0	3,1	4,8	7,6
02.06.98	13,1	10,0	7,2	7,4
01.09.98	10,1	6,9	3,9	2,9
01.12.98	2,2	7,4	13,6	7,9
02.03.99	25,0	16,2	13,2	12,4
	Soil Temperature (°C, average of days before sampling)			
Days before sampling	3	5	10	30
23.07.97	30,3	30,1	29,4	29.1
09.09.97	32,0	32,0	32,5	13.9
02.12.97	21,0	29,4	29,5	29.3
02.03.98	14,7	29,2	29,2	29.6
02.06.98	18,8	28,1	29,3	28.4
01.09.98	29,5	29,6	31,0	30.5
01.12.98	28,6	27,5	28,5	29.1
02.03.99	17,8	26,9	27,6	27.7

Table 4: Water saturation deficit (unit: hPa) before sampling (from Embrapa weather station)

	Saturation deficit average (during the days before sampling)			
Days before sampling	3	5	10	30
23.07.97	13.4	11.7	10.9	91
09.09.97	12.8	10.2	10.0	9.4
02.12.97	12.0	8.8	8.1	9.0
02.03.98	5.3	5.5	45	5.7
02.06.98	5.0	4.7	50	50
01.09.98	3.5	3.6	51	60
01.12.98	4.5	3.9	42	5.4
02.03.99	3.1	4.0	35	3.4

Table 5: **Litter Temperature (Logger data) in the study sites (dbs = days before sampling)**

FLO

dbs	3	5	10	30	
	FloLitTemp035	FloLitTemp010	FLOLitTemp0	FloLitTemp30	
23.07.97	25,9	n.a.	n.a.	n.a.	
09.09.97	26,6	26,4	26,3	26,0	
02.12.97	26,5	26,0	26,2	26,3	
02.03.98	26,2	26,2	26,1	26,5	
02.06.98	25,6	25,8	26,0	26,0	from 26.5.!02.06.98
01.09.98	25,4	25,9	26,2	25,9	
01.12.98	25,5	25,5	25,5	25,8	19.11.lacking01.12.98
02.03.99	25,0	25,0	25,0	25,0	

SEC

dbs	3	5	10	30	
	SECLitTemp0305	SECLitTemp10	SECLitTemp	SECLitTemp30	
23.07.97	25,9	n.a.	n.a.	n.a.	
09.09.97	26,8	26,4	26,4	25.9	
02.12.97	26,5	26,0	26,3	26.4	
02.03.98	26,1	26,1	26,0	26.3	
02.06.98	25,9	26,0	26,2	26.2	from 26.5.!
01.09.98	25,4	25,7	25,8	25.6	
01.12.98	25,7	25,5	25,5	25.8	19.11.lacking
02.03.99	25,0	25,1	25,0	25.1	

POA

dbs	3	5	10	30	
	POALitTemp0305	POALitTemp10	POALitTemp	POALitTemp30	
23.07.97	26,1	n.a.	n.a.	n.a.	
09.09.97	30,0	29,1	29,2	28,5	
02.12.97	28,9	27,7	28,1	28,3	
02.03.98	27,3	27,1	26,9	27,6	
02.06.98	25,8	26,0	26,2	26,2	from 26.5.!02.06.98
01.09.98	25,9	26,6	27,3	26,9	
01.12.98	26,6	26,2	26,1	27,1	19.11.lacking01.12.98
02.03.99	25,3	25,6	25,6	25,7	

POC

dbs	3	5	10	30	
	POCLitTemp0305	POCLitTemp10	POCLitTemp	POCLitTemp30	
23.07.97	26,0	n.a.n.a.		n.a.	
09.09.97	27,0	26,7	26,6	26,0	
02.12.97	26,9	26,3	26,6	26,7	
02.03.98	n.a.n.a.	26,2		26,6	to 25.2.!
02.06.98	25,4	25,6	25,8	25,8	from 26.5.!
01.09.98	25,4	25,8	26,3	26,1	
01.12.98	25,7	25,5	25,5	25.9	19.11.lacking
02.03.99	24,7	25,0	25	25.1	

Table 6: **Soil (5 cm) Temperature (Logger data) in the study sites (dbs = days before sampling)**

FLO

dbs	3	5	10	30	
	FloSoilTemp 0305	FloSoilTemp p10	FLOSoilTem p30	FloSoilTemp	
23.07.97	25,8	n.a.	n.a.	n.a.	
09.09.97	26,1	26,0	25,9	25,5	
02.12.97	26,1	25,9	26,1	26,2	
02.03.98	n.a.	n.a.	n.a.	n.a.	
02.06.98	25,8	25,9	26,0	26,0	from 26.5.!
01.09.98	25,7	25,8	25,9	25,7	
01.12.98	25,2	25,1	25,1	25,7	19.11.lacking
02.03.99	24,5	24,6	24,6	24,6	

SEC

dbs	3	5	10	30	
	SECSoilTem p03p05	SECSoilTem p10	SECSoilTem p30	SECSoilTem	
23.07.97	25,7	n.a.	n.a.	n.a.	
09.09.97	26,2	26,1	26,0	25,6	
02.12.97	26,2	26,0	26,2	26,3	
02.03.98	26,2	26,2	26,1	26,3	
02.06.98	26,1	26,3	26,3	26,3	from 26.5.!
01.09.98	25,8	25,9	26,0	25,9	
01.12.98	25,6	25,6	25.7	26,0	19.11.lacking
02.03.99	25,2	25,3	25.2	25,2	

POA

dbs	3	5	10	30	
	POASoilTem p03p05	POASoilTem p10	POASoilTem p30	POASoilTem	
23.07.97	25,8	n.a.	n.a.	n.a.	
09.09.97	27,1	26,9	26,8	26,3	
02.12.97	26,6	26,2	26,6	26,6	
02.03.98	26,5	26,5	26,4	26,6	
02.06.98	26,1	26,3	26,4	26,4	from 26.5.!
01.09.98	26,1	26,3	26,5	26,2	
01.12.98	26,1	26,1	26,1	26,5	19.11.lacking
02.03.99	25,5	25,6	25,5	25,6	

POC

dbs	3	5	10	30	
	POCSoilTem p03p05	POCSoilTem p10	POCSoilTem p30	POCSoilTem	
23.07.97	n.a.	n.a.	n.a.		
09.09.97	n.a.	n.a.	n.a.		
02.12.97	n.a.	n.a.	n.a.		
02.03.98	n.a.	n.a.	n.a.		
02.06.98	25,6	25,8	26,0	26,0	from 26.5.!
01.09.98	25,5	25,7	25,8	25,6	
01.12.98	25,5	25,5	25,5	25.8	19.11.lacking
02.03.99	24,9	25,0	25,0	25	

Table 7: **Air Humidity in the litter layer (logger data) of the study sites (dbs = days before sampling)**

FLO

dbs	3	5	10	30	
	FLOrH03	FLOrH05	FLOrH10	FLOrH30	
23.07.97	72,8	n.a.	n.a.	n.a.	
09.09.97	98,6	99,2	98,5	98,7	
02.12.97	99,3	99,6	99,2	97,9	
02.03.98	100,0	100,0	100,0	99,8	
02.06.98	100,0	100,0	100,0	100,0	from 26.5.!
01.09.98	100,0	100,0	100,0	100,0	
01.12.98	69,7	67,4	61,4	73,4	19.11.lacking
02.03.99	n.a.	n.a.	n.a.		

SEC

dbs	3	5	10	30	
	SECrH03	SECrH05	SECrH10	SECrH30	
23.07.97	69,6	n.a.	n.a.	n.a.	
09.09.97	89,0	91,7	91,0	91,7	
02.12.97	92,0	94,8	93,2	91,3	
02.03.98	99,7	99,8	99,9	98,3	
02.06.98	100,0	100	100,0	100,0	from 26.5.!
01.09.98	100,0	99,1	97,5	98,3	
01.12.98	99,7	99,8	99.9	99,9	19.11.lacking
02.03.99	n.a.	n.a.	n.a.		

POA

dbs	3	5	10	30	
	POArH03	POArH05	POArH10	POArH30	
23.07.97	68,7	n.a.	n.a.	n.a.	
09.09.97	85,7	88,5	87,3	87,1	
02.12.97	87,4	91,2	90,3	88,5	
02.03.98	96,6	97,6	97,9	95,5	
02.06.98	99,1	98,5	97,8	97,8	from 26.5.!
01.09.98	95,4	93,0	89,0	83,5	
01.12.98	91,8	93,6	87,2	92,4	19.11.lacking
02.03.99	100,0	98,2	98,6	96,6	

POC

dbs	3	5	10	30	
	POCrH03	POCrH05	POCrH10	POCrH30	
23.07.97	n.a.	n.a.	n.a.	n.a.	
09.09.97	n.a.	n.a.	n.a.	n.a.	
02.12.97	n.a.	n.a.	n.a.	n.a.	
02.03.98	n.a.	n.a.	n.a.	n.a.	
02.06.98	100,0	100,0	100,0	100,0	from 26.5.!
01.09.98	99,9	99,3	98,3	98,8	
01.12.98	100,0	100,0	100,0	99,7	19.11.lacking
02.03.99	n.a.	n.a.	n.a.		

Rainbow report

Figure 1:

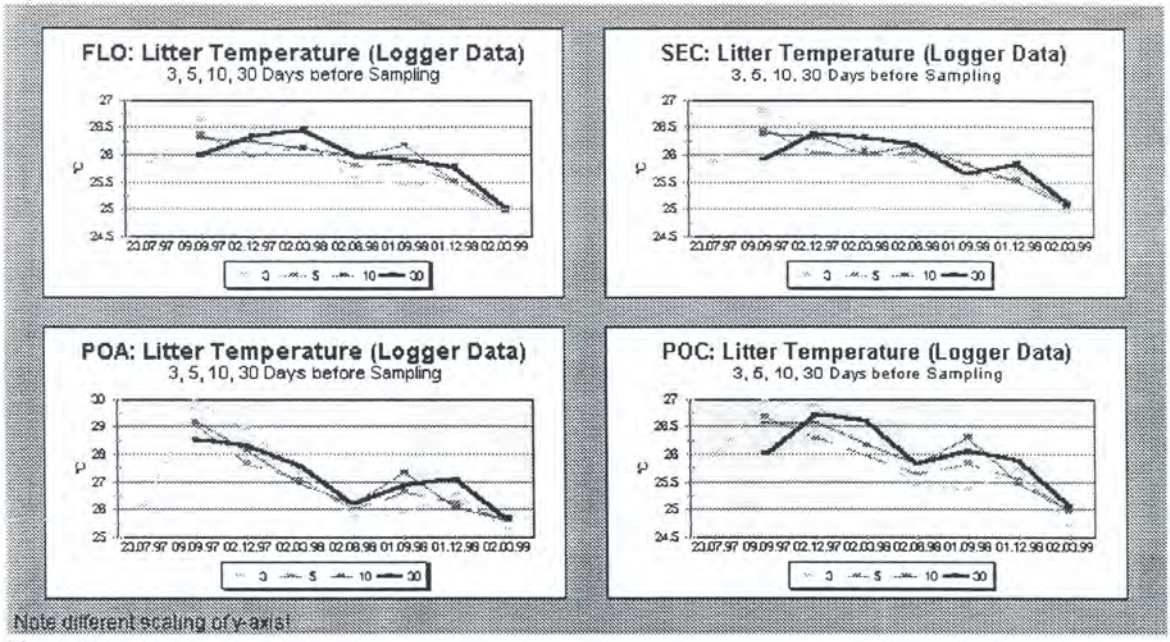


Figure 2:

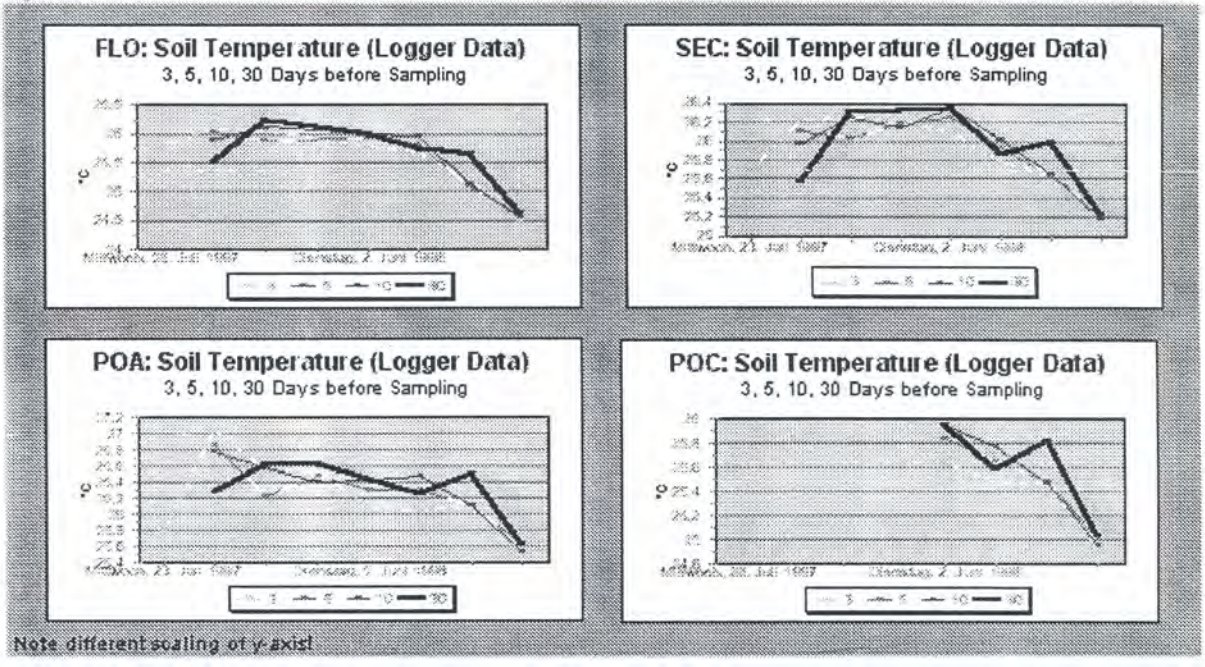
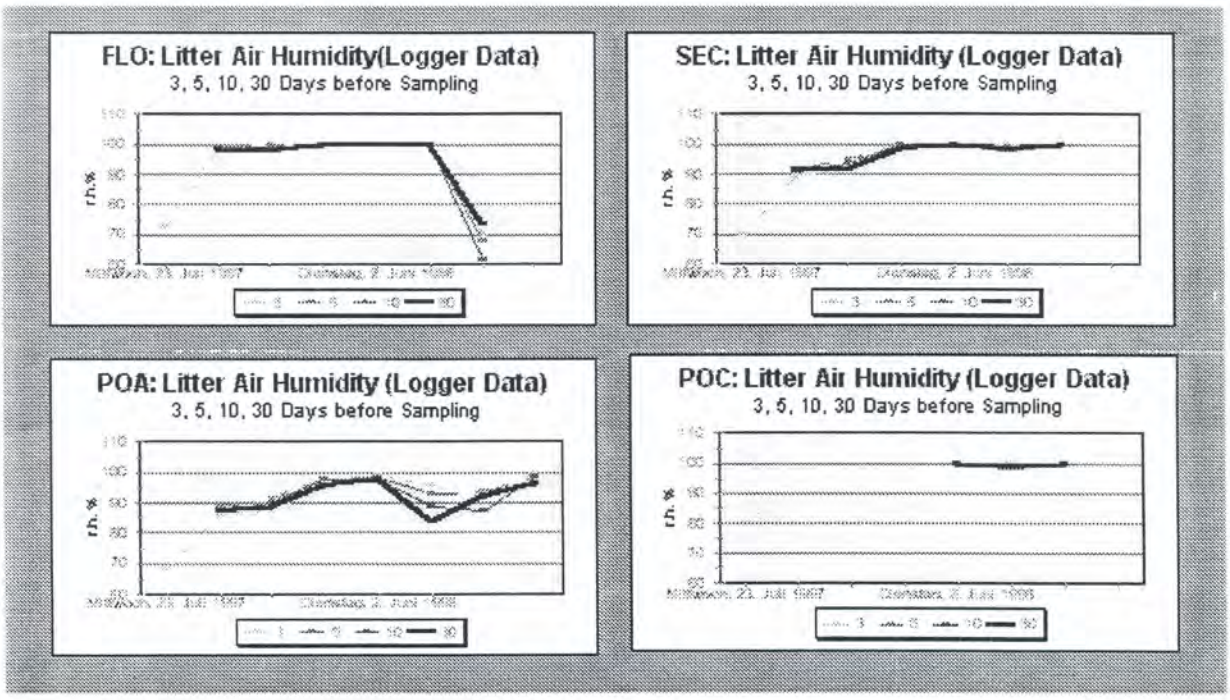


Figure 3:

Figure 4:



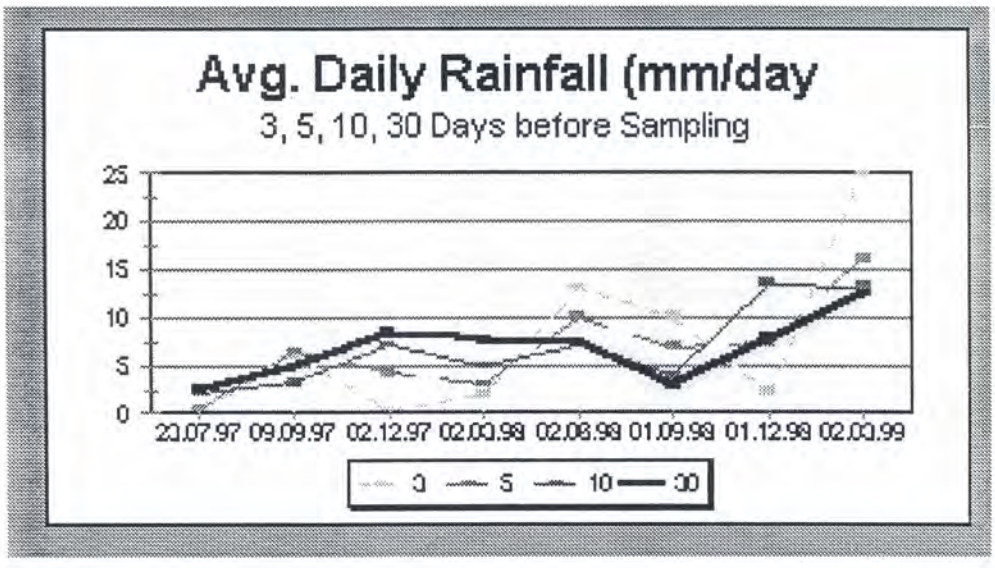
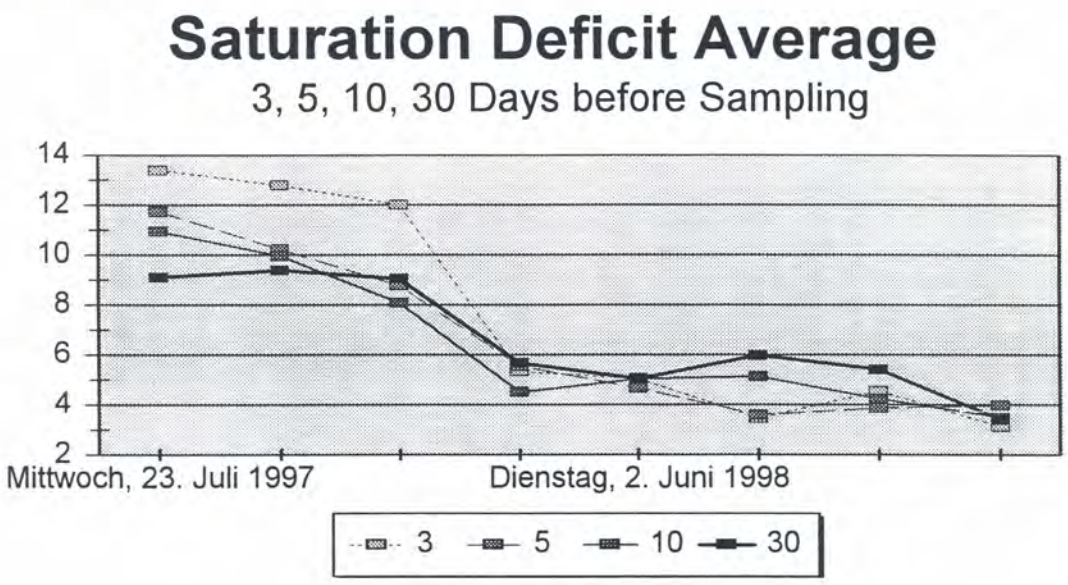


Figure 5: Water saturation deficit for the sampling period



Litter production, litter stocks and decomposition coefficients in a central Amazonian rain forest, a secondary forest and agroforestry systems

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Abstract

Fine litter fall and stocks were determined from July 1997 to March 1999 in an area of primary rain forest (FLO), a 13-year old secondary forest (SEC), and two polyculture culture systems (agroforestry; POA and POC) in Central Amazonia, Brazil. In 1998, the average annual litter production in the forest was 8.37 t ha^{-1} yr^{-1} (in the range of litter production in other rain forests in the region). This was similar to one plantation site (POC; 8.30 t ha^{-1} yr^{-1}), but higher than the secondary forest (SEC; 7.40 t ha^{-1} yr^{-1}) and POA (6.24 t ha^{-1} yr^{-1}). In FLO, leaf material accounted for 67% of the litter; leaf material was relatively more important in the other sites (76-82% of total litter fall), in which much less fine matter and almost no dead wood was recorded than in FLO. The negative linear regression between monthly rainfall and monthly litter fall was significant only for FLO (r^2 = 0.58; P=0.05). Litter production was higher in the one-year period 1997-98 (an El Niño year) than in 1998-99. The production of leaf litter had a much lower variability than that of wood, flowers and fine matter. Leaf litter production variability was also much lower in the plantation sites, indicating a much more homogenous stand structure.

Litter stocks on the forest floor were highest in SEC (24.70 t ha^{-1}), followed by POC and POA; they were lowest in the primary forest (FLO; 11.98 t ha^{-1}). The negative linear regression of litter stocks with rainfall was not significant.

From monthly values of litter stocks (X_{ss}) and total monthly litter production (L), the decomposition coefficient $k_e = L/X_{ss}$ was calculated for each month. It was, on average, highest for FLO (0,059), lower for POC (0,042) and POA (0,040), and lowest for SEC (0,024). Thus, the secondary forest site had the largest litter accumulations and a very low litter production; in short, very slow decomposition processes. In contrast, FLO had a high litter production but low stocks, and therefore, decomposition rates were high. The decay coefficients of the polyculture systems were between the primary forest and SEC.

Keywords: Rain forest, Agroforestry systems, Amazonia, Litter production, Litter stocks, Rainfall, Decomposition

1. Introduction

Litter is an important ecosystem resource. Litter feeds the decomposer food chain and thus initiates the nutrient cycles that are closed with the mineralization of the nutrients enclosed in the litter. Determining the dynamics of litter production and available litter stocks over time therefore is a central task in studies on decomposition on the ecosystem level. Here, we report on the assessment of litter dynamics in one natural and several man-managed ecosystems in central Amazonia, in the context of a study on soil fauna and litter decomposition (Beck et al. 1998a, b) that was initiated in 1996.

2. Material and Methods

Litter production was collected weekly with simple collectors of a basal area of 0.25m^2 (50x50 cm). A collector consisted of a wooden frame 8 cm high and a nylon screen mesh suspended to a height of 50 cm above ground. Twenty of such samplers were used in each of the primary (FLO) and secondary (SEC) forest areas, and 10 samplers in each of the areas of plantation system IV on block A and C (POA and POC). The collectors were distributed at random within the areas and their positions were maintained throughout the study. The collected litter was manually separated into fractions and oven-dried at 65°C for four days, then weighed (dry weight). For the preliminary analysis presented here, average weekly values were calculated and then multiplied with 52 to obtain the annual litter production at each site. The study lasted from 27.7.1997 to 29.3.1999 (608 days, 88 weeks).

Litter stocks were collected monthly with the soil core borers also used for the macrofauna assessment (21 cm diameter), at randomly chosen points in the study sites. Once every month between 26.8.1997 and 2.3.1999, 20 such samples were taken in FLO and SEC, and 10 samples in POA and POC. The collected litter was oven-dried at 65°C for four days, then weighed (dry weight). [Every three months, the material was manually separated into fractions (leaves, coarse wood, fine wood, flowers and seeds, fine matter, and roots). Roots were excluded from the total litter sample, as it was not possible to distinguish between live and dead roots. However, these data are not presented here.]

Data processing. The total study period was 88 months, and therefore the period of whole total data set includes two dry seasons but only one rainy season. As litter fall is related to rainfall, the data had to be adjusted to annual values based on true one-year seasonality (one rainy and one dry season). As inter-annual variation exists, several annual data sets have been produced referring to the periods 1997-98, 1998, and 1998-99.

Due to technical reasons, the sampling of litter fall took place in regular 1-week intervals, whereas stock sampling occurred in irregular intervals (2 to 5 weeks). For the correlation of litter production and stocks and the determination of decomposition coefficients, production data had to relate to the intervals of the stock assessments. Assuming that the litter stocks of a site are predominantly determined by the litter produced during the four weeks before the day of collection, we produced a data set using the production data of the last four-week interval before every stock sampling. In cases where stock sampling occurred in an interval of less than 4 weeks this led to an overlap (re-utilization) of the data of some weeks (Table 1).

3. Results

Litter production

The average weekly litter production (calculated on the basis of all weeks and all collectors, or 88x20 = 1760 data points for FLO and SEC, and 88x10 = 880 data points for POA and POC) was highest in FLO (17.18 ± 15.49 g m^{-2}), and decreased in the order POC > SEC > POA (Table 2). Annual litter fall was calculated for three different one-year periods (Table 3), in all of which the sequence was FLO > POC ≥ SEC > POA. Litter fall in FLO (7.93 - 9.50 t ha^{-1} yr^{-1}) was in the range of litter fall recorded in other sites (e.g. 7.1 ± 8.6 t ha^{-1} yr^{-1} in nearby Reserva Ducke; Martius in prep.).

Variability.

The highest litter fall and the highest variability were seen in the dry season of 1997 in all sites (Figure 1). Variation of litter fall in FLO was higher than in the other sites, due to the higher heterogeneity of stand structure. (One large peak in SEC at the end of 1998 (21.12.98) is due to the collection of 85.1 g/collector in collector AF08, much higher than the average production of 2.5 g/collector in this week).

Fraction distribution.

In all sites, leaves always represented the largest fraction, accounting for 67-82% of the litter. Fine wood (< 1cm diameter) was always the second largest fraction. Whereas large wood accounted for 2.8% of the litter

in FLO, and 1.6% in SEC, almost none of it was found in POA and POC. Flowers and seeds had similar proportions in all sites, but fine matter (5 mm sieve) in FLO (9%) was two times higher than fine matter in the other sites (3-5%) (Table 4). The standard deviation as percent of the average (lower part of the table) indicates how steadily each fraction was produced. The leaf fraction was most predictably produced; this is more pronounced in the simply structured secondary forest and the plantations where cohorts of equally aged trees dominate. The coarse wood fraction was highly unpredictable; much more so in the plantations where dead wood rarely occurred (see above).

Seasonality and inter-annual variability. The highest litter falls were observed in October 1997 in all sites. Litter fall was lowest from February to March 1998, and increased again during the dry season (September) 1998. In FLO, annual litter fall was higher in 1997-98 than in 1998-99, but this trend was not observed in the other sites (Table 3). In FLO, monthly litter fall and monthly rainfall are correlated by a linear regression with an r^2-coefficients of 0.582, but in the other sites, the correlation is much weaker (Table 5).

Litter stocks

The largest stocks were found in SEC, followed by POC > POA > FLO (Table 6). This applies equally to the whole study period (averages from 88 weeks) and to the single annual periods. There are no significant differences of average litter stocks between the single annual periods, but in FLO, average monthly litter stocks are somewhat higher in the first year (97-98), and in SEC, they are lower in the first than in the other two annual periods. All this points to a difference between the El-Niño-year 1997 and the rest of the study period.
Stocks of large (coarse) dead wood in the study sites have been assessed on one occasion (the volume was assessed and converted to biomass; see subreport "Dead wood volume", following chapter). They follow the sequence FLO (24.5 t ha^{-1}) > POC (12.1 t ha^{-1}) > SEC (4.0 t ha^{-1}) > POA (2.4 t ha^{-1}). Thus, whereas leaf litter stocks were highest in SEC, large wood litter stocks were highest in FLO, and almost no large wood litter was found in the plantations. Wood biomass was roughly double that of small leaf litter biomass in FLO, but only about 15-75% of leaf litter in the plantations.
The coefficient of the linear regression of monthly litter stocks in the four sites and monthly rainfall is negative, but the correlations are weak (Table 7; however, the power of the performed tests (with alpha =0.05) generally is too low in order to not exclude a type II error, i.e. assuming no correlation where there actually is one).

4. Discussion

The decay coefficient. From monthly values of litter stocks (X_{ss}) and total monthly litter production (L), the decomposition coefficient $k_e = L/X_{ss}$ (Olson 1963) was calculated for each month (Figure 2). The average of the monthly values was highest for FLO (0,059), lower for POC (0,042) and POA (0,040), and lowest for SEC (0,024). Thus, the secondary forest site had the largest litter accumulations in spite of a relatively low litter production; and here decomposition processes were very slow. In contrast, FLO had a high litter production but low stocks, and therefore, decomposition rates were high. The decay coefficients of the polyculture systems were between the primary forest and SEC.

Acknowledgements

We thank the German Research Ministry (Bundesministerium für Bildung und Forschung - BMBF), Bonn, Germany for funding of the project SHIFT ENV 52 "Soil fauna and litter decomposition", and the Embrapa-Amazônia Ocidental, Manaus, AM, for logistic support during the study. Thanks are due to Francisco Aragão, who collected the litter during the study, and particularly to Gessiene do Nascimento Pereira and Valdinez Montoia who processed the litter material in the laboratory and managed the data spreadsheet.

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Tables

Table 1: Adjustment of sampling dates

How dates are distributed in Stocks assessm.				How dates should be distributed in Production assessment				
Stock dates	corresponds to weeks	n Weeks	n Days	What samples (weeks S...) to take for analysis	Start Date	End Date	n Weeks	n Days
26.08.97	S32-35	4	28	S32-35	29.07.97	25.08.97	4	27
09.09.97	S36-37	2	14	S34-37	11.08.97	08.09.97	4	28
03.10.97	S38-40	3	24	S37-40	01.09.97	29.09.97	4	28
07.11.97	S41-45	5	35	S42-45	06.10.97	03.11.97	4	28
03.12.97	S46-49	3	26	S46-49	31197	01.12.97	4	28
08.01.98	S50-98S01	5	36	S51-98S01	91297	06.01.98	4	28
02.02.98	S02-05	4	25	98S02-S05	60198	02.02.98	4	27
03.03.98	S6-S9	4	29	98S06-09	20298	02.03.98	4	28
07.04.98	S10-S14	5	35	98S11-14	09.03.98	60498	4	28
12.05.98	S15-19	5	35	98S16-19	13.04.98	110598	4	28
03.06.98	S20-22	5	22	98S19-22	04.05.98	10698	4	28
06.07.98	S23-27	3	33	98S23-27	08.06.98	60798	4	28
11.08.98	S28-32	5	36	98S29-32	14.07.98	100898	4	27
01.09.98	S33-35	3	21	98S32-35	03.08.98	310898	4	28
06.10.98	S36-S40	5	35	98S38-41	08.09.98	51098	4	27
05.11.98	S41-S44	4	30	98S41-44	05.10.98	31198	4	29
02.12.98	S45..S48	4	27	98S45-48	03.11.98	301198	4	27
06.01.99	S49..99S01	5	35	98S50-99S01	07.12.98	40199	4	28
05.02.99	S02-S05	4	30	99S02-05	04.01.99	10299	4	28
04.03.99	S06-S09	4	27	99S06-09	01.02.99	01.03.99	4	28

Table 2: Average weekly litter fall (dry weight, g m^{-2}) in the collectors of each site and calculated annual litter fall for 1998

System	Collector		Average	Std. Dev.	Average	Std. Dev.
FLO	Q 31		1779	1338	1718	1549
		Al 16	1751	1391		
		AF 08	1492	1218		
		F 34	1142	1009		
		AM 18	1470	1233		
		AK 20	1680	1215		
		Q 16	2192	1977		
		AJ 29	1536	900		
		AM 33	1346	850		
		P 10	2576	2108		
		H 25	1538	1673		
		H 15	1224	874		
		B 31	1861	2131		
		X 18	1687	1930		
		N 05	1836	1364		
		AD 13	1662	1488		
		AD 01	1152	909		
		AE 22	2099	1841		
		T 09	1730	1282		
		Al 38	2670	2087		
SEC	Q 31		1741	1404	1422	1543
		Al 16	1854	1409		
		AF 08	1536	3935		
		F 34	1489	1113		
		AM 17	1262	900		
		AK 20	1268	1004		
		Q 16	1616	1245		
		AJ 29	1751	1383		
		AM 33	1269	952		
		P 10	2242	2312		
		H 25	1161	1075		
		H 15	962	725		
		B 31	1134	1135		
		X 18	1565	1357		
		Q 06	1389	1195		
		AD 13	1465	1130		
		AD 01	784	712		
		AE 22	1589	1460		
		T 09	1322	1548		
		Al 38	1059	1094		
POA	R 19		1152	810	1265	884

		J 07	1347	998		
		M 25	1837	1198		
		W 26	1455	844		
		F 11	1122	676		
		G 02	847	661		
		S 23	1369	933		
		C 05	1109	762		
		AA 15	1187	649		
		B 07	1213	838		
POC	R 14		1578	932	1510	1165
		AC 21	1611	1454		
		K 05	1555	1417		
		N 15	1297	715		
		U 28	1498	1453		
		V 32	1757	1288		
		F 28	1430	826		
		G 18	608	448		
		S 12	1590	945		
		C 30	2171	1120		

Table 3: Average annual litter fall (dry weight, t ha^{-1} yr^{-1}) in each site, calculated for different periods out of the study period 1997-1999 (see text)

Area	1997-98		1998		1998-99	
	22.7.97-21.7.98		31.12.97-28.12.98		30.3.98-29.3.99	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
FLO	950	881	837	682	793	659
SEC	719	776	740	763	757	764
POA	642	489	624	419	647	411
POC	719	619	830	616	872	603

Table 4: Percentage of fractions in litter production. Average of 10 (FLO, SEC) and 5 (POA, POC) collectors and 88 weeks.

	Area	Leaves	Wood >1cm	Wood <1cm	Flowers and Seeds	Fine Matter (5mm sieve)	Sum
Percentage of each Fraction	FLO	67.4	2,8	15.1	5,6	9,2	100
	SEC	80,2	1.6	9.4	5,6	3,2	100
	POA	75,7	0,1	10,8	8,5	4,9	100
	POC	81,9	0,1	9.4	5,0	3,7	100,0
Standard Deviation	FLO	15,1	6,6	11,4	6,2	6.6	0
	SEC	12,7	7,7	8,3	6.3	2,4	0

	POA	11,5	0,6	7.7	9.8	3	0
	POC	9,5	0,7	7,0	4,8	2.5	0
Standard Deviation as % of Average	FLO	22.4	239,7	75,5	109.7	72.2	0
	SEC	15,8	475,5	88,8	113.6	75.4	0
	POA	15,3	938,1	71,3	114,4	59.9	0
	POC	116	685,4	74,3	96,7	69.4	0

Table 5: Linear regressions (y =ax +b) of monthly litter fall (t ha^{-1} $month^{-1}$)and monthly rainfall (mm) for the study sites primary forest (FLO), secondary forest (SEC), and the plantation sites (POA and POC) (data set Aug 1997 - Feb 1999)

site	a	b	r^2
FLO	-17	1006	582
SEC	-14	844	299
POA	-6	640	224
POC	-9	775	176

Table 6: Average monthly litter stocks in the study sites during the study period (n= 20 months; August 1997-March 1999), and average stocks based on one-year periods

Area	Average stocks (t ha^{-1}) ± Std. Dev.	Std. Dev. as % of Average
FLO	11.98 ± 4.27	357
SEC	24.70 ± 3.43	139
POA	15.06 ± 3.03	201
POC	16.19 ± 4.12	255

Area	1997-98		1998		1998-99	
	22.7.97-21.7.98		31.12.97-28.12.98		30.3.98-29.3.99	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
FLO	1268	446	1128	139	1090	142
SEC	2282	871	2522	886	2664	598
POA	1475	712	1355	560	1423	510
POC	1602	821	1511	544	1526	479

Table 7: Linear regressions (y =ax +b) of monthly litter stocks (t ha^{-1})and monthly rainfall (mm) for the study sites primary forest (FLO), secondary forest (SEC), and the plantation sites (POA and POC) (full data set; Aug 1997 - Feb 1999)

site	a	b	r^2
FLO	-193	1598	278
SEC	-250	2990	95
POA	-296	2121	238
POC	-265	2168	161

Legends to Figures

Figure 1: Average weekly litter fall (t ha^{-1} $week^{-1}$) and standard deviation for 20 (FLO, SEC) or 10 (POA, POC) litter samplers in the study area. Week 0 ends 27.7.1997 , week 88 ends 29.3.1999. Lit prod annual.JNB: graph page 3 ALL

Figure 2: Monthly litter stocks (X_{ss}; t ha^{-1}), litter production (L; t ha^{-1} $month^{-1}$), decay coefficient ($k_e = L/X_{ss}$; no units), and rainfall (mm) for the study sites FLO, SEC, POA and POC. Lit Stock prod L Xss.JNB graph page 1

Fig.1

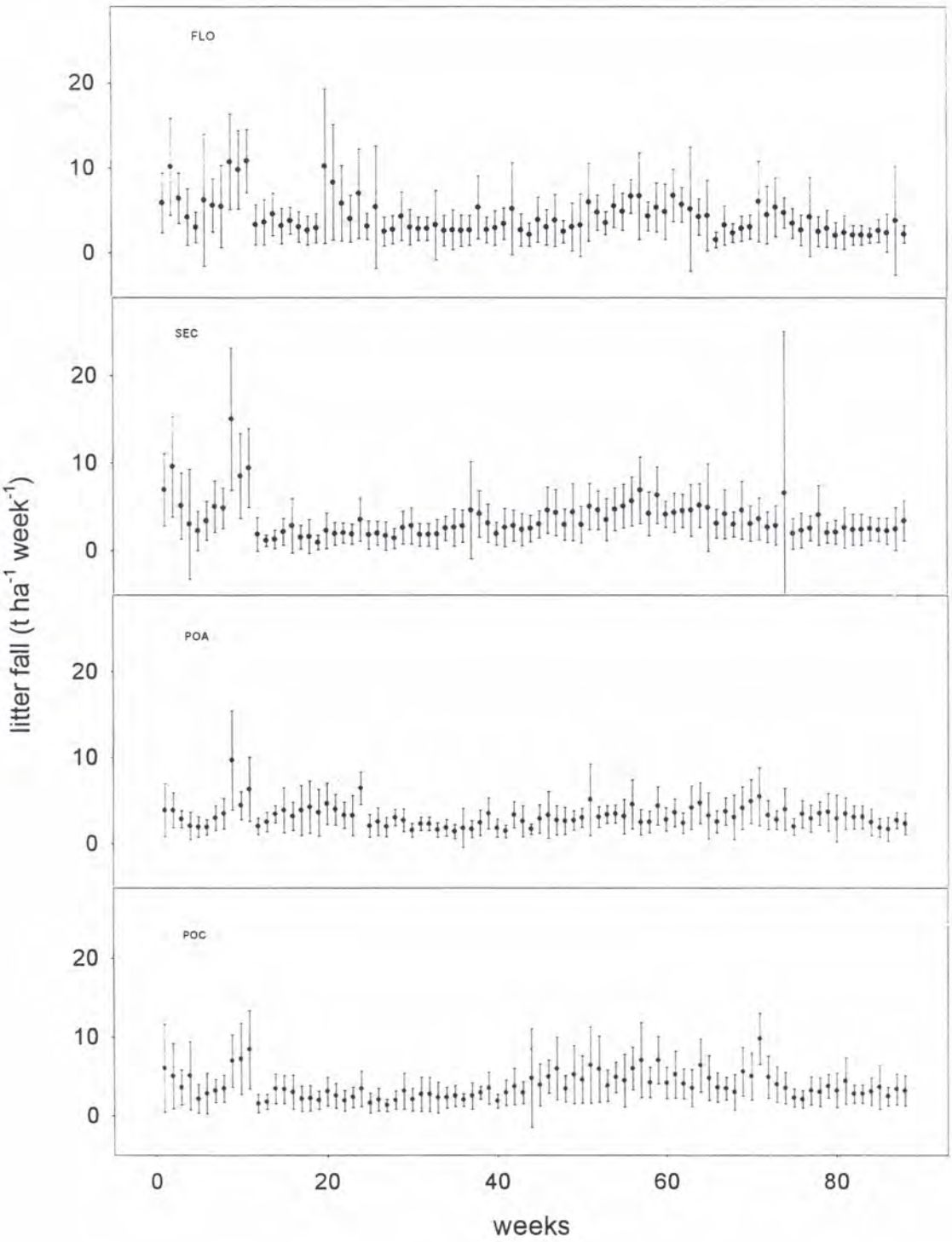
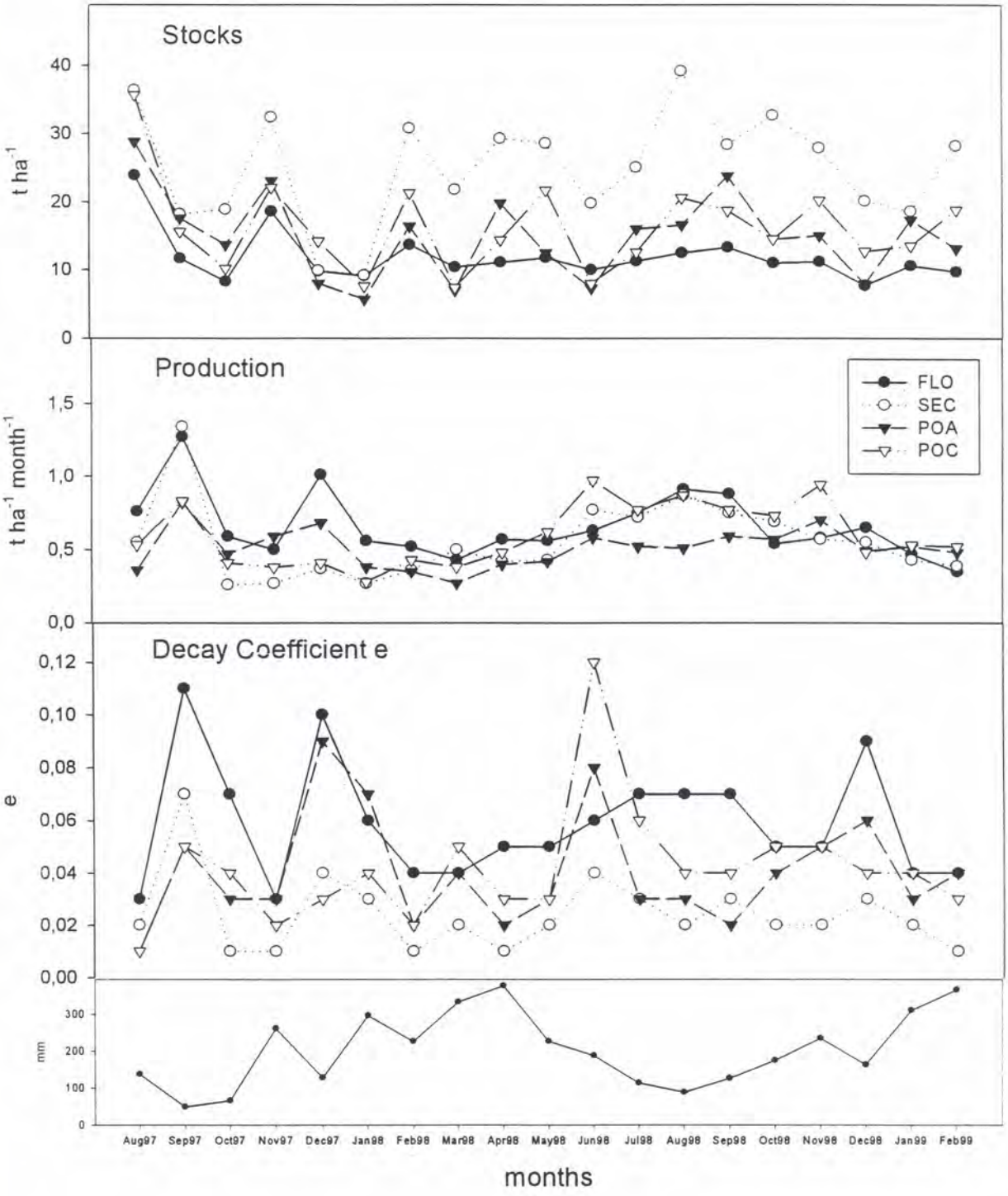

FLO
SEC
POA
POC
20
10
0
0
20
40
60
80
weeks
litter fall (t ha-1 week-1)

Fig. 2


Stocks
t ha-1
Production
t ha-1 month-1
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POC
Decay Coefficient e
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Aug97 Sep97 Oct97 Nov97 Dec97 Jan98 Feb98 Mar98 Apr98 May98 Jun98 Jul98 Aug98 Sep98 Oct98 Nov98 Dec98 Jan99 Feb99
months

Dead wood volume in primary forest, secondary forest and an agroforestry plantation system in central Amazonia

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Abstract
Dead wood volume on the forest floor. assessed in 1997, was large (35.5 m^3/ha) in the primary forest, but much lower in POC (17.5 m^3/ha), and virtually no dead wood is found in the other sites (3.5-5.8 m^3/ha in SEC and POA). Termite biomass is positively correlated to dead wood volume.

1. Introduction

Dead wood is an important food resource for wood-feeding organisms, among which termites and wood-feeding beetles prevail. It is also an spatial resource for many arthropods that do not feed on wood but predate on wood-feeders or simply look for shelter. Due to its lignin content and the presence of repellent substances in many species, wood is a rather recalcitrant source of carbon. Assessing the amount of wood in a given ecosystem is therefore not only important for estimating the size of the food niche for wood-feeders, especially termites, but gives also an estimate of a large part of the carbon stocks in the system. Assessments of dead wood mass are time-consuming and labourious, due to the often considerably effort involved (Martius & Bandeira 1998). In the present study, we tested a rapid appraisal method based on estimating wood volume only. Although no correlation exists between dead wood volume and biomass (Martius 1989), the method has its merits as it allows the relatively fast comparison of different areas.

2. Material and Methods

The assessment of wood volume was made during several days in November and December 1997 in the four study areas of the project SHIFT 52: one primary forest site (named FLO) and one secondary forest site established 1984 (SEC), and a mixed culture system established 1992 (POA and POC) and consisting of 4 tree species planted in rows, among which secondary growth was allowed to develop (for details cf. Beck et al. 1998 a, b, and Lieberei & Gasparotto 1998). The size of the areas is 40x40m (1600 m^2 FLO and SEC), and 32x48 m (1536 m^2 POA and POC). The whole area was assessed by 3-4 persons. Diameter at both ends and length was measured with a flexible tape in all dead wood samples above 3 cm diameter and 40 cm length on the ground. If diameter at both ends differed, the average value of both was used for the calculation of the volume, based on the formula of a cylinder ($V = \pi r^2 \cdot h$). In spite of the non-existing correlation between dead wood volume and mass, we used an average value of wood density (0.69 g m^{-2}) to calculate wood biomass of the sites for comparison.

3. Results and Discussion

The volume was highest in FLO (35.5 m^3/ha), and was half of that value in POC (17.5 m^3/ha); much lower values were recorded in SEC and POC (Table 1). The average size of wood sample (single wood item) and number of single wood samples (irrespective of size) followed the same ranking order FLO > POC > POA/SEC. The calculated biomass of 24.5 t/ha in FLO is double that of a nearby site, Reserva Ducke, where only 9.5 t/ha were recorded (Martius & Bandeira 1998), it corresponds well to the 18.2 t/ha recorded by Klinge et al. (1975) in the Reserva Egler (about 40 km away), and is lower than the 33.0 t/ha given by Higuchi and Biot (1995) for the reserva EEST of the INPA; these data indicate that there are large inter-site differences in wood biomass in undisturbed plots in central Amazonia. Only the biomass in POC, which is an area near to a primary forest patch, is in the range of these values, which reflects the fact that several large dead trees are found in this area. The other plantations are almost devoid of large dead wood. the biomass of termites which is significantly and linearly correlated to wood volume (Figure 1). It remains pen to further studies whether this reflects the higher availability of the food resource to termites or whether the correlation is a coincidence, both factors being linked to some other characteristic of the sites.

Acknowledgements
We are grateful to the technicians Frank Antonio de Oliveira Campos, and Jânio da Costa Santos, of the entomological lab of INPA-CPPF, for their help in the field.

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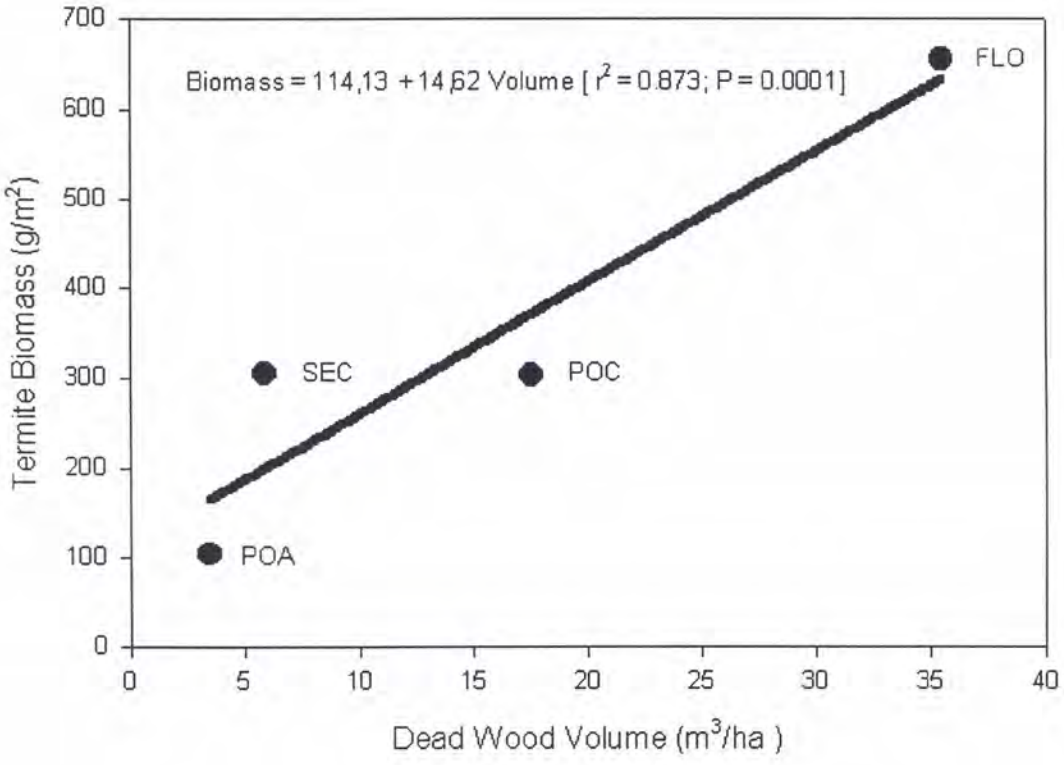
Tables

Table 1: Dead wood volume and biomass (calculated per ha); average size of wood samples and number of samples (per area)

	FLO	SEC	POA	POC
Volume (m^3/ha)	35.5	5.8	3.5	17.5
Calculated Biomass (t/ha)	24.5	4.0	2.4	12.1
Average (l per wood item) ± Std. Dev.	71.0 ± 86.3	49.2 ± 92.5	19.1 ± 16.8	49.9 ± 98.9
No. of samples in area	80	19	28	54
Size of area (m^2)	1600	1600	1536	1536

Figures

Figure 1: Linear regression showing the correlation between wood volume and termite biomass in the study plots



Microbial Respiration and Biomass

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1. Introduction

Microorganisms are the most abundant organisms in soil and litter layers. Their biomass is an important structural element of the soil compartment. In the northern hemisphere more than 80 % of the non-plant biomass of soil is provided by microorganisms. Moreover microorganisms play an important role in the decomposition of organic matter and in the cycling of nutrients, thus fulfil essential ecosystem functions. There are only few data available on the microbial biomass and activity in tropical forest soil and litter (Yang & Insam 1991, Feigl et al. 1995, Wood 1995).
The aim of the study was to determine the microbial biomass and their metabolic activity of soil and plant litter of different tropical forest types: a primary and a secondary forest and an abandoned plantation of rubber trees (Seringueira) which was used as a polyculture forestry research area since 1992.

2. Study sites and methods

Study sites

Study sites were four plots of three different forest systems - one plot of 40 x 40 m in a primary forest (FLO), one plot of 40 x 40 m in a nearby secondary forest (growing since 1984, SEC) and two plots, each 32 x 48 m of polycultures (POA, POC), where 4 different tree species of commercial use have been planted in rows. In the polyculture plots the tolerated secondary vegetation (mainly *Vismia* spp., Guttiferae) still dominated the stand and especially the litter production (Beck et al. 1998; Höfer et al. 1999).

Soil sampling

Every three months twenty soil cores (dia 6.5 cm, length 15 cm) were taken randomly from each experimental site and separated into the layers 0-5 cm and 5-15 cm. In the laboratory soil was sieved (<4 mm) and stored at 6-8° C for max. 2 weeks. Soil respiration was measured before (basal respiration) and after adding glucose (substrate-induced respiration, SIR). From the SIR values microbial biomass was calculated according to the formula described by Anderson and Domsch (1978).

Litter sampling

Leaf litter material was sampled randomly from the surface of the field plots and also from litter bags containing leaf litter of *Vismia spec.* that were exposed on the soil surface of the experimental plots. In the laboratory the litter was cut with scissors into small pieces (approx. 2 cm) and pre-incubated at a water content of 300 % (based on litter dry weight) and 28° C for one week before measurement of respiration.

Respiration Measuring Device:

The respiration of soil and litter samples was determined by measuring the carbon dioxide production over time via infra-red gas analysis in a continuos flow through system at a constant flow rate of 300 mL fresh air per minute.
A portable computerised photosynthesis measuring system HCM-1000 (Heinz Walz GmbH, Effeltrich, Germany) was used. The central unit of the system consists of an infra-red gas analyser (IRGA), a peristaltic air pump, a mass flow meter and is connected to a measuring chamber (cuvette). It works in an open flow mode (differential mode) measuring the difference between the CO_2 concentration of the ambient air before and after passing the cuvette. The system is controlled via a computer. To measure soil respiration the central unit was connected to a specially designed rag containing 17 cuvettes. Each cuvette was connected via tubing and solenoid valves to the central unit. A special software allowed to switch the soil or litter containing cuvettes alternately to the IRGA. Each soil or litter sample was measured once within one hour over a period of up to 24 hours.

Microbial respiration was calculated according to (1):

(1) Respiration [nL CO_2 min^{-1} g^{-1} soil] = $(C * F) / S$

where C = IRGA measured CO_2 –value [ppm]
F = Flow rate through cuvette [mL/min]
S = Soil dry weight [g]

Microbial biomass was calculated according to (2):

(2) Microbial biomass (Cmic) [µg Cmic g^{-1} soil] = $(R * 40.04) + 0.37$

where R = Respiration [µL CO_2 g^{-1} h^{-1}]

3. Results

Soil

The highest "maximum initial response" of substrate-induced respiration (SIR) appeared at a glucose concentration of 8 mg/g soil dry weight (Fig. 1). SIR exceeded the basal respiration (0 mg Glucose) by a factor of approximately 7 (Fig. 1).
Biomass results are summarized in Table 1 for the top soil 0 - 5 cm and in Table 2 for the 5-15 cm soil layer. The overall microbial biomass in the upper soil layer (0-5 cm) appears to be low as compared to forest soils of the temperate zone (e.g. Joergensen et al. 1995). There was no statistically significant difference between the four experimental sites. Also there was no seasonal change in the biomass detectable. The amount of microbial biomass in the lower soil layer (5-15 cm) was about half of the biomass found in the top soil.

Litter

The highest "maximum initial response" of substrate-induced respiration (SIR) of the litter material appeared at a glucose concentration of 50 mg/g soil dry weight (Fig. 2). SIR of the litter exceeded the basal respiration by a factor of approximately 3. Compared to the soil basal respiration of the litter was up to 70 times higher (Fig. 2). There was no statistically significant difference in the basal respiration activity of the litter exposed on the different fields. Microbial biomass of *Vismia* litter was highest in the medium and fine mesh size litterbags exposed in the primary forest (Fig. 3 – Fig.5). In SEC and POA, there was no difference between the coarse, medium, and fine litterbags.

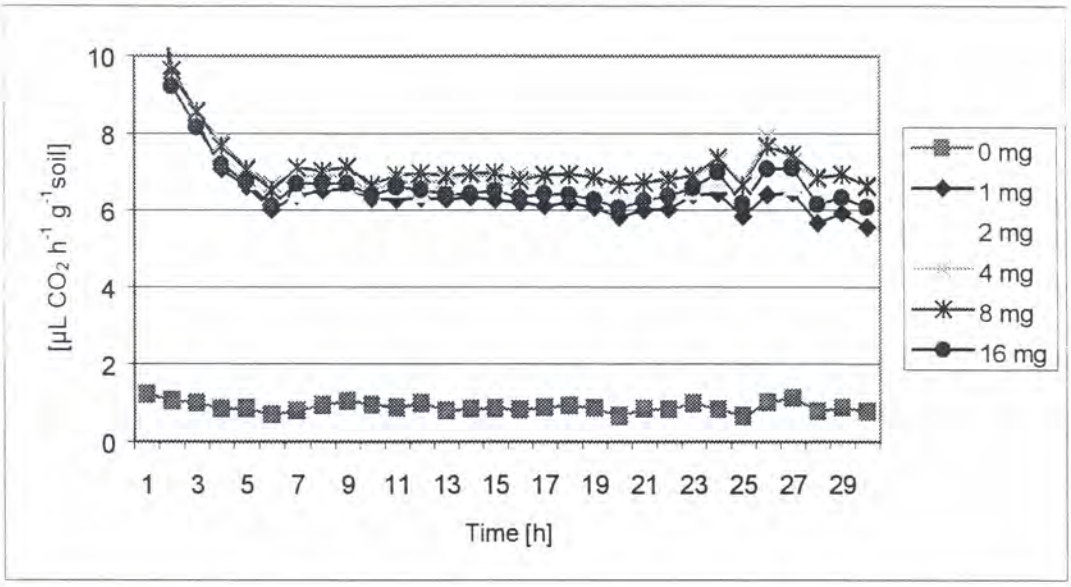

Fig.1: Substrate-induced respiration of soil (0-5 cm) from the primary forest (FLO) after adding different amounts of glucose [mg/g soil dry weight].

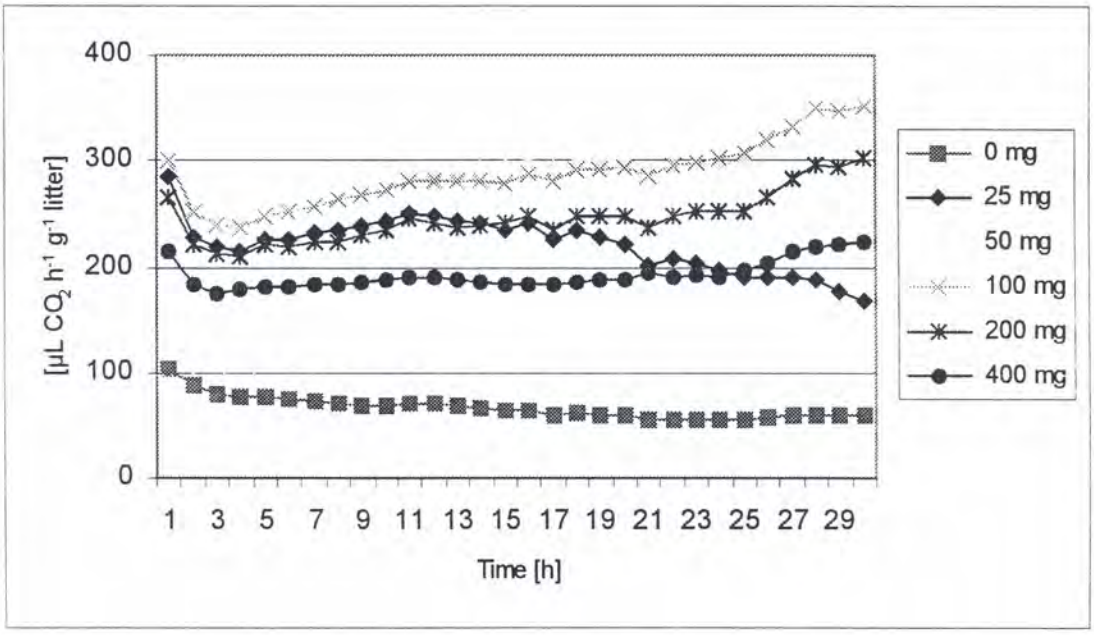

Fig.2: Substrate-induced respiration of litter from the primary forest (FLO) after adding different amounts of glucose [mg/g litter dry weight].

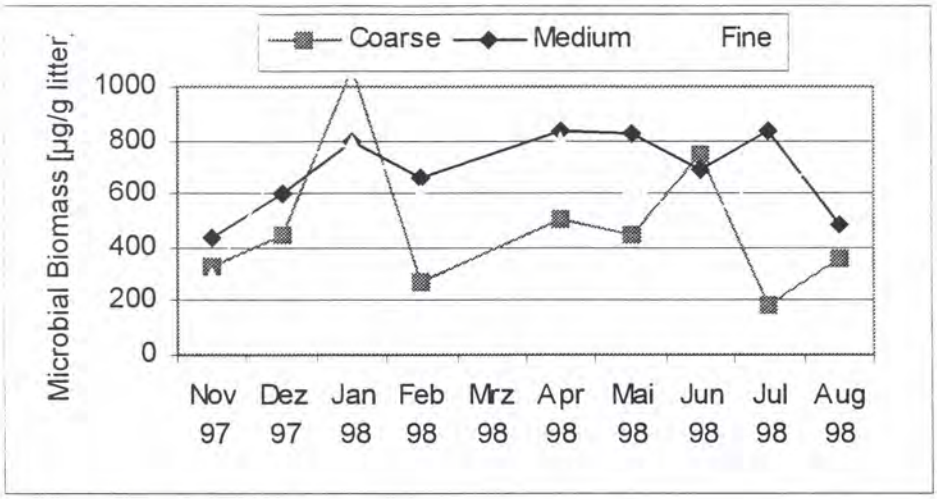

Fig. 3: Microbial biomass of leaf litter (*Vismia spec.*) exposed in litter bags on the soil surface of the primary forest (**FLO**) from November 97 to August 98. Mesh widths of the litter bags were 10 mm (coarse), 0.250 mm (medium) and 0.02 mm (fine).

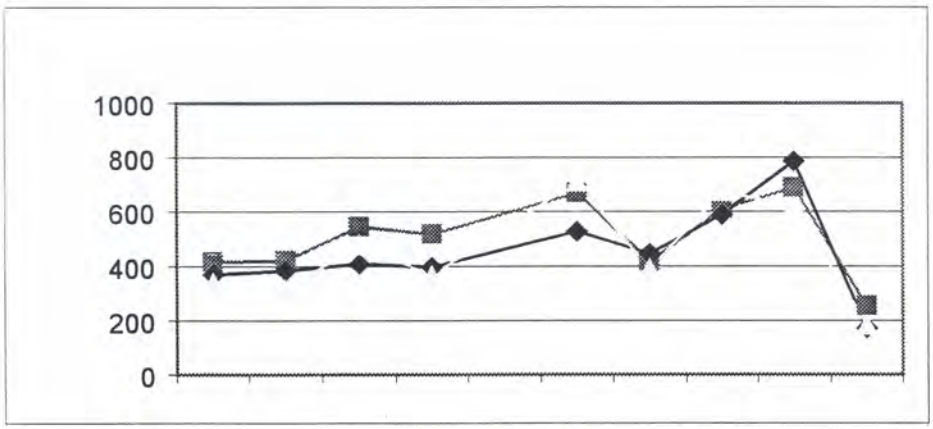

Fig. 4: Microbial biomass of leaf litter (*Vismia spec.*) exposed in litter bags on the soil surface of the secondary forest (**SEC**) from November 97 to August 98.

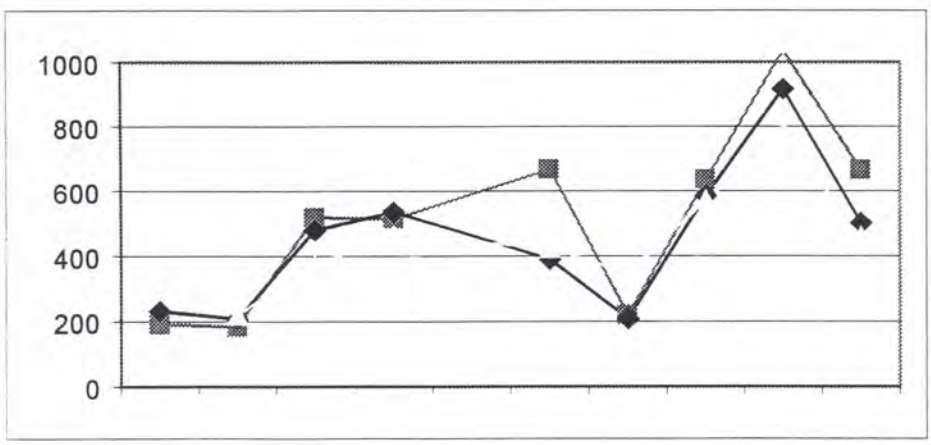

Fig. 5: Microbial biomass of leaf litter (*Vismia spec.*) exposed in litter bags on the soil surface of the polyculture (**POA**) from November 97 to August 98.

Table 1: Mean values (n = 20) of microbial basal respiration [µL CO_2 h^{-1} g^{-1}soil] and microbial biomass carbon [µg C_{mic} g^{-1}soil] of the top soil layer (0-5 cm) from the experimental sites Primary Forest (FLO). Secondary Forest (SEC), Polyculture C (POC) and Polyculture A (POA).

	FLO		SEC		POC		POA	
	Basal	Biomass	Basal	Biomass	Basal	Biomass	Basal	Biomass
July 97	1.91	426.13	2.07	398.29	1.99	429.46	1.40	454.82
Sept. 97	1.52	385.63	1.13	464.88	1.09	390.07	1.70	503.71
Dec. 97	2.07	396.23	1.79	418.97	1.62	421.08	1.90	510.26
Mar. 98	1.75	378.80	1.48	411.47	1.40	393.37	1.48	370.30

Table 2: Mean values (n = 20) of microbial basal respiration [µL CO_2 h^{-1} g^{-1}soil] and microbial biomass carbon [µg C_{mic} g^{-1}soil] of the soil layer (5-15 cm) from the experimental sites (see legend of Table 1).

	FLO		SEC		POC		POA	
	Basal	Biomass	Basal	Biomass	Basal	Biomass	Basal	Biomass
07/97	0,95	231,32	0,98	217,90	0,91	247,98	0,80	275,05
09/ 97	0,62	200,06	0,23	182,93	0,43	227,97	0,96	289,08
12/97	0,71	195,38	0,67	203,37	0,48	233,97	0,64	261,52
03/98	2,40	225,78	1,80	214,91	0,71	235,69	3,42	211,17

Table 3: Mean values of microbial basal respiration [µL CO_2 h^{-1} g^{-1}litter] of *Vismia spec.* litter exposed in litter bags on the experimental sites (see legend of Table 1).

Mesh widths of the litter bags were: 10 mm (C), 0.250 mm (M) and 0.020 mm (F).

	FLO			SEC			POC			POA		
	C	M	F	C	M	F	C	M	F	C	M	F
11/ 97	36.4	38.5	34.3	67.4	60.4	55.4	68.0	64.1	42.7	24.0	23.1	27.8
12/97	74.5	86.7	86.3	106.3	74.1	94.3	74.9	81.7	53.4	66.2	119.8	120.1
01/98	132.9	84.1	86.9	48.7	35.6	42.2	39.8	38.6	42.3	46.5	43.5	44.4
02/98	27.0	50.7	58.2	38.4	25.7	35.9	21.8	38.1	18.8	27.8	38.0	37.5
04/98	61.1	61.4	67.9	53.0	44.6	61.4	71.4	79.0	80.0	64.4	63.0	64.8
05/98	63.5	89.7	126.0	147.9	129.1	156.1	138.0	122.3	181.4	119.2	85.6	81.7
06/98	62.6	46.0	67.9	54.3	61.4	60.1	41.3	71.2	84.3	62.4	86.6	81.3
07/98	24.8	95.6	71.7	55.3	56.2	52.5	51.3	56.4	81.8	61.6	88.1	91.3
08/98	1.16	22.3	28.9	15.0	45.6	22.9	42.6	31.0	35.6	32.5	2.0	43.9

4. Discussion

It is assumed that the low amounts of soil microbial biomass found in the investigated plots are assumed are due to the low pH of the soil. Microbial biomass of the top soil (0-5 cm) was higher compared to the lower soil layer (5-15 cm). This could be expected since the amount of organic material and nutrients in soil also decreases with the depth. Microbial biomass did not differ significantly between the 4 investigated forest types. Therefore all calculations given below are based on the average microbial biomass of 422 µg g^{-1} soil of the 0-5 cm soil profile. Assuming an average soil density of 1g cm^{-3} and an average carbon content of 3.5% the microbial biomass carbon (Cmic) in the 0-5 cm soil layer comprises 21.1 g C m^{-2}. This would represent 1.2% of the C-stock in soil. Compared to the results of Feigl et al. (1995) who found the ratio to be 3-4% for soils of the same region the values reported here seem to be small. The reason for this is not clear.

For temperate soils the ratio between organic carbon (Corg) and Cmic usually is in the range of 1-4 % (Domsch 1992). Grisi et al (1998) found that the organic matter was mineralised more rapidly in temperate than in the tropical soils and concluded from this, that the organic matter in tropical soils was more degraded or humified than in temperate soils.

Respiration of the litter was measured under standardized moisture conditions. Under field conditions, differences in respiration activity may occur due to spatial and temporal differences in the actual moisture of the litter.

The average microbial respiration activity (basal respiration) was 7 g CO_2 –C a^{-1} kg^{-1} dry mass for the top soil (0-5 cm) and 319 g CO_2 –C a^{-1} kg^{-1} dry mass for the leaf litter Thus, the yearly loss of C via soil respiration can roughly be calculated to be 359 g m^{-2} yr^{-1}. This value is in accordance with Medina et al. (1980) who measured soil respiration in the field and calculated the C-loss of an Amazonian laterite forest soil to be 273 g m^{-2} yr^{-1}. For a tropical forest soil in India the C-loss via soil respiration was calculated to be 683 g m^{-2} yr^{-1} (Rajvanshi & Gupta, 1986).

5. Conclusions and outlook

The most important results gained so far when investigating the microbial biomass and respiration of the four EMBRAPA plots can be summarized as follows:

The differences between the four investigated plots (FLO, SEC, POA, POC) with regards to the microbial biomass were found to be negligible. Biomass of the soil and of the litter as determined via the SIR method was relatively low. Due to the low pH of the investigated soil, the fungal part of the microbial biomass may be more important than bacteria.

Acknowledgements

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Soil fauna

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1. Introduction

The central aim of the project was to study the regeneration and better use of already degraded areas, to diminish the human impact on primary rain forest in Amazonia. The basic hypothesis of all investigations within this project was that soil fauna and micro-organisms are extremely important for the maintenance of „healthy" (functional) nutrient cycles. The study of the soil ecosystem included structural and functional endpoints. One of the objectives was to evaluate the specific contribution of the different functional soil fauna groups to the decomposition of organic matter and the resulting nutrient supply to the plants.

Central questions of the project were:

- Which taxonomic and functional groups of the soil fauna represent the cenosis of the decomposers and predators in a primary and secondary forest and in polyculture forestry plantations?
- Which differences exist between the biocenosis of the studied areas?
- Are there correlations between certain functional groups of organisms and the decomposition rate of organic matter residues?
- Do have the mesofauna and the macrofauna the same or a similar role in decomposition processes?

This report on soil fauna summarises the most important of the project. Detailed data are discussed in the species reports (see Annex: Soil fauna). In several papers project data were published and presented on workshops, taking reference on the methodology and special aspects on soil fauna (e.g. Beck et al. 1998, Höfer et al. 1999, Römbke et al. 1999).

2. Study sites and methods

Study sites

Study sites were four plots of three different forest systems - one plot of 40 x 40 m in a primary forest (FLO), one plot of 40 x 40 m in a nearby secondary forest (growing since 1984, SEC) and two plots of 32 x 48 m large polycultures (POA, POC), where 4 different tree species of commercial use have been planted in rows. In the polyculture plots the tolerated secondary vegetation (mainly Vismia spp., Guttiferae) still dominated the stand and especially the litter production (Beck et al. 1998; Höfer et al. 1999).

Methods

The basic sampling program for soil fauna comprising sampling of abundance and biomass of mesofauna, macrofauna and earthworms was done on 23-24 July 1997, 1-2 September 1997, 1-2 December 1997, 2-3 March 1998, 1-2 June 1998, 1-2 September 1998, 1-2 December 1998, 2 and 4 March 1999 (each collection took two days to be accomplished). Four sampling methods have been applied in several replicates at each date: Small core samples (6,5 cm diameter) were taken for (1.) mesofauna (arthropods) extraction with the Kempson extraction apparatus, and (2.) microdrilids were collected from litter and soil by a wet-extraction-method and large core samples (21 cm diameter) were taken for (3.) the extraction of macrofauna (arthropods) with the Berlese apparatus and 4.) large macrofauna were captured in areas of 4 m² (macroarea) by hand-sorting and earthworm were collected by formal extraction in the same plots.

In each of the studied plots (primary forest FLO, secondary forest SEC, polyculture system 4 (POA and POC) 10 samples for each method were taken at the first day, starting with the polyculture POA and continuing in SEC and FLO. In the field the samples were differentiated in 2 depth (litter-layer including the root-mat and soil 0 - 5 cm). In total, 120 samples were taken per date: POA and POC 10 samples each; SEC and FLO 20 samples each.

In addition to the soil and litter samples the fauna (arthropods) was extracted from litterbags using a Berlese extraction apparatus for macrofauna. In general, the litterbag samples were handled in the same way as samples coming from a soil corer. (developed by Graefe; Römbke 1995). Nearly no microdrilids were found in other samples (e.g. in large soil corer - diameter of 21 cm - or Berlese samples) due to the small size of these worms. For detailed information on sampling methods see Annex.

Classification of functional groups

Meso- and macrofauna can be classified in several ways:
Two systems base on body length (Dunger 1964, 1983, Brauns 1968). Independent from taxonomic groups, soil fauna is classified into four body size categories. Van der Drift (1951, from Dunger 1964 and Brauns 1968) and Bachelier (1971) applied different ranges of body length (Table 1).

Table 1: Classification systems of soil fauna categories based on body length

	Van der Drift (1951)	Bachelier (1971)
	Body length (mm)	Body length (mm)
Microfauna	< 0,2	<0,2
Mesofauna	0,2-2,0	0,2-4,0
Macrofauna	2,0-20,0	4,0-80,0
Megafauna	>20,0	>80,0

Another system bases on the separation of larger taxonomic and ecological groups (Luxton & Petersen 1982). The latter system was used and adapted to our requirements.
We separated at first hand by the sampling method (small and large cores, macroarea) and the extraction method (wet extraction of enchytraeids, Kempson- and Berlese-extraction of all arthropods and other invertebrates, formalin extraction of earthworms).
In the litterbag experiment separation of meso- and macrofauna was done, based on a pre-experiment (Beck et al. 1998) using mesh widths of 20 µm, 250 µm and 10.000 µm (1cm). This experiment showed, that mesofauna as well as macrofauna was widely excluded from litterbags having mesh widths of 20 µm. These litterbags are colonised only by microorganisms (microfauna, bacteria and fungi) and a very small portion of mesofauna. The largest portion of mesofauna could pass mesh widths of 250 µm, but the macrofauna remained excluded. Indeed, litterbags having the largest mesh width were colonized by all categories of soil fauna.

In the following, the terms used were:
Kempson-fauna comprises all meso- and macrofauna of small core samples, and extracted by the Kempson-method and the Berlese-fauna included all macrofauna of large core samples, extracted with the Berlese-method. The differentiation of the meso- and macrofauna and their mayor trophic groups is given in Table 2, which follows principally the classification of Luxton & Petersen (1982). Earthworms, which could be considered as megafauna, are included into the macrofauna category. The meso- and macrofauna has been separated into four mayor trophic groups: predators, decomposers, herbivores and others (unclassified taxonomic groups).

Table 2: Classification of the soil fauna and their main food items

Guilds	Taxa	Main food items (feeding types)	Sampling Method
Mesofauna			
Meso-predators			
	Acari: Non- Oribatida (*)	Micro- + mesofauna, (dead plant material)	Kempson (**)
Meso-decomposers			
	Acari: Oribatida (*)	Plant litter, mixed dead organic material microflora	Kempson (**)
	Collembola (*)	Dead plant material, bacteria, fungi	Kempson (**)
	Pauropoda (*)	Detritus, microflora	Berlese (***)
	Protura (*)	Detritus, microflora, mycorrhiza	Berlese (***)
	Symphyla (*)	Detritus, microflora, plant roots	Berlese (***)
	Microdrilids (*)	Detritus, microflora	Wet extraction(*)
Macrofauna			
Macro-predators			
	Araneae (*)	Macro- and mesofauna	Berlese (***)
	Opilionida (*)	Macro- and mesofauna	Berlese (***)
	Palpigradi (*)	Macro- and mesofauna	Berlese (***)
	Pseudoscorpionida (*)	Macro- and mesofauna	Berlese (***)
	Ricinulei (*)	Macro- and mesofauna	Berlese (***)
	Scorpionida (*)	Macro- and mesofauna	Berlese (***)
	Uropygi (*)	Macro- and mesofauna	Berlese (***)
	Chilopoda (*)	Macro- and mesofauna	Berlese (***)
	Coleoptera (part.) (*)	Macro- and mesofauna	Berlese (***)
	Dermaptera (*)	Macro- and mesofauna	Berlese (***)
	Diplura (*)	Mesofauna	Berlese (***)
	Formicidae (part.) (*)	Macro- and mesofauna	Berlese (***)
Macro-decomposers			
	Blattodea (*)	Dead plant material, omnivore	Berlese (***)
	Coleoptera (part.) (*)	Dead plant material, fungi, bacteria, (mesofauna)	Berlese (***)
	Diplopoda (*)	Dead plant material, microflora	Berlese (***)
	Diptera, larvae (*)	Dead plant material, detritus, fungi, bacteria	Berlese (***)
	Formicidae (part.) (*)	Dead plant material, fungi	Berlese (***)
	Gryllidae (*)	Dead plant material, living plants	Berlese (***)
	Isopoda (*)	Dead plant material, living plant tissue, dead wood, fungi	Berlese (***)
	Isoptera (*)	Dead plant material, dead wood	Berlese (***)
	Trichoptera (*)	Dead plant material, plant roots	Berlese (***)
	Mollusca (*)	Dead plant material, living plants, fungi	Berlese (***)
	Lumbricida (*)	Dead plant material, detritus	Macroarea (****)
Macro-herbivores			
	Coleoptera (part.) (*)	Living plant material	Berlese (***)
	Formicidae (part.) (*)	Living plant material	Berlese (***)
	Hemiptera (*)	Living plant material	Berlese (***)
	Homoptera (*)	Living plant material	Berlese (***)
	Lepidoptera, larvae (*)	Living plant material	Berlese (***)
	Thysanoptera (*)	Living plant material	Berlese (***)
	other Orthoptera (*)	Living plant material	Berlese (***)
Macrofauna (others)			
	Coleoptera (part.) (*)		Berlese (***)
	Formicidae (part.) (*)		Berlese (***)
	Embioptera		Berlese (***)
	Thysanura		Berlese (***)

(*) Groups for biomass estimations (**) Small core; (***) Large core; (****) Formalin extraction

Biomass calculation

Fresh weight and dry weight biomass was calculated for most of the taxonomic groups, using data of body length or other metric variables. The following function was used for calculating group specific regression curves: $y = ax^b$ y = biomass (mg), x = body length or other metric variable (mm), a and b = coefficients. For other taxonomic groups body weights were determined using body size-body weight categories (Tables 3 and 4).

Fresh weight was determined by weighing living or recently killed animals. Posteriorly the same individuals were oven-dried during 72 hours (65°) for the determination of their dry weight. Statistical calculations were done with Sigmastat 2.03 and graphics made with Sigmaplot 4.0 (Jandel Scientific Software).

Due to the long time span between the single sampling events and the randomization of the sampling points over all samples we treated the single sample dates as independent and compared abundances in the three different systems by One-Way ANOVAs, followed by a Repeated Measure ANOVA of the means (or medians) of the sample dates.

To see if eventually all areas were influenced by the same factor (e.g. climate) we checked the course of the abundance over the 11 months by Pearson correlations.

Table 3: Basic data for biomass estimation with regression curves

		Regression: Fresh weight (mg)			
Taxon	Criterion	Coeff. A	Coeff. b	R^2	adj. R^2
Araneae	body length (mm)	0,1821	2,8774	0,9780	0,9780
Chilopoda	body length (mm)	0,0017	3,1557	0,9970	0,9940
Diplopoda, Polydesmoida	body length (mm)	0,0260	2,7344	0,9836	0,9834
Diplopoda, Polyzoniida	body length (mm)	0,0484	1,7262	0,9693	0,9659
Blattodea	body length (mm)	0,0511	2,9142	0,9626	0,9621
Pseudoscorpionida	body length (mm)	0,1503	2,4861	0,9400	0,9390
Opilionida	body length (mm)	0,2265	3,3720	0,9630	0,9628
Ricinulei	body length (mm)	0,5484	2,2856	0,9278	0,9188
Isopoda (Circoniscus sp.)	Width of 1. segment (mm)	0,6837	2,9116	0,9763	0,9740
Isopoda (others)	body length (mm)	0,0196	3,4182		
Staphylinidae (Coleoptera)	body length (mm)	0,0699	2,2000		
Carabidae (Coleoptera)	body length (mm)	0,0666	2,7054		
Coleoptera, larvae	body length (mm)	0,0192	1,7737	0,9601	0,9674
		Regression: Dry weight (mg)			
Taxon	Criterion	Coeff. A	Coeff. b	R2	adj. R2
Araneae	body length (mm)	0,0172	3,2298	0,9890	0,9880
Chilopoda	body length (mm)	0,0006	3,1469	0,9950	0,9940
Diplopoda, Polydesmoida	body length (mm)	0,0093	2,7344		
Diplopoda, Polyzoniida	body length (mm)	0,0174	1,7262		
Blattodea	body length (mm)	0,0070	3,2065	0,9700	0,9695
Pseudoscorpionida	body length (mm)	0,0560	2,5690	0,8880	0,8870
Opilionida	body length (mm)	0,0410	3,8798	0,9584	0,9581
Ricinulei	body length (mm)	1,0955	1,4916	0,9800	0,9760
Isopoda (Circoniscus sp.)	Width of 1. segment (mm)	0,2050	2,9560		
Isopoda (others)	body length (mm)	0,0065	3,4282		
Staphylinidae (Coleoptera)	body length (mm)	0,0230	2,2060		
Carabidae (Coleoptera)	body length (mm)	0,0233	2,7054		
Coleoptera, larvae	body length (mm)	0,0407	1,8678	0,9746	0,9733

Table 4: Basic data for biomass estimation with body size-body weight categories

Taxon	Average length (mm) *)	Fresh weight (mg)	Dry weight (mg)
Dermaptera	10,5	18,00	5,50
Diplura	2,10	0,12	0,02
Diptera, larvae	3,5	3,19	0,80
Embioptera	5,5	2,12	0,56
Hemiptera larvae	1,9	0,655	0,164
Hemiptera, adults	2,4	1,121	0,336
Homoptera, adults	2,3	0,901	2,7
Homoptera, larvae	2	0,75	0,187
Lepidoptera, larvae	8	7,68	1,98
Mollusca (slugs)	25,0	1498,00	240,00
Mollusca (snails)	7,0	45,00	19,60
Palpigradi	1,0	0,19	0,07
Pauropoda **)		0,036	0,006
Protura **)		0,0024	0,0004
Scorpionida	16,3	725,20	247,40
Symphyla	8,25 pairs of legs	0,23	0,08
Thysanoptera	2,10	0,10	0,02
Trichoptera, larvae	2,5	1,00	0,22

*) Estimated average length (mm) in samples
**) dry weight following Luxton & Petersen (1982)

3. Results

Mesofauna

Mean mesofauna density in the primary forest area ranged between 15.000 ind./m² (September 1998) and 30.000 ind./m² (December 1998). Biomass (dry weight, calculated by group specific factors from own measurements, see Mesofauna report) ranged between 373 (September 98) and 736 mg/m² (June 98). Dominating by abundance and biomass are oribatid mites (43 % of ind. and 58 % of biomass) and predatory mites (18 % and 17 %), followed by enchytraeids (23 % and 12,5 %) and collembolans with 13% of individuals and 11 % of biomass.

Mean mesofauna density in the secondary forest area ranged between 13.300 ind./m² (July 1997) and 36.600 ind./m² (December 1998). Biomass ranged between 320 (July 97) and 975 mg/m² (March 98). Dominances in abundance and biomass are similar to the primary forest.

Mean mesofauna density in the polycultures ranged between 13.800 and 35.500 in POC and 14.100 and one extreme of 77.366 individuals/m² in POA, biomass between 400 and 916 resp. 480 and 2.400 mg/m² (table 1). The mesofauna abundance in the polycultures is also dominated by oribatid mites, which count on average for 59 and 51 % of all individuals and 71 and 65 % of the mesofauna biomass (POA, POC). Predatory mites were equally abundant as in the forests (18 and 22 % ind./m²; 11 and 16 % of biomass). Collembola did account for 5 % of abundance and 5.2 and 7.3 % of biomass. Enchytraeida were abundant with about 16 and 17 % of individuals and 6.5 resp. 8.3 % of biomass.

Oribatid mites which are important primary decomposers were more abundant in POA and SEC, while the other important decomposers - collembolans were more abundant in FLO and POC.

Multiple regression analyses showed significant dependencies of oribatid and collembolan abundance, principally in the litter of the forests (FLO and SEC), from accumulated rainfall during 1-10 days before the sampling events, number of rainy days before sampling and dry weight of litter.

Mesofauna biomass dry weight (mg/m²) (litter & soil)

Primary forest

taxon	Jul'97	Sep'97	Dec'97	Mar'98	Jun'98	Sep'98	Dec'98	Mar'99	sum	mean	stds in %	median
Acari	110,97	125,74	110,08	123,77	91,27	53,51	111,95	117,20	844,50	105,56	22,30%	111,46
Acari: Oribatida	264,38	339,92	559,75	395,53	388,18	185,17	332,58	340,45	2805,97	350,75	30,95%	340,19
Acari: total	**375,35**	**465,66**	**669,83**	**519,30**	**479,45**	**238,69**	**444,53**	**457,65**	**3650,46**	**456,31**	**26,74%**	**461,66**
Collembola: Arthropleona	40,67	47,71	0,00	20,17	46,75	10,89	36,83	66,29	269,30	33,66	64,75%	38,75
Collembola: Poduromorpha	7,69	6,40	15,82	13,13	42,59	5,76	46,43	19,85	157,68	19,71	81,63%	14,48
Collembola: Symphypleona	3,52	7,37	20,72	5,44	29,78	3,84	5,44	21,51	97,62	12,20	83,57%	6,40
Collembola total	**51,88**	**61,48**	**36,54**	**38,75**	**119,12**	**20,49**	**88,70**	**107,64**	**524,60**	**65,58**	**54,59%**	**56,68**
Pauropoda	0,28	0,23	0,57	0,51	0,16	0,49	0,48	0,19	2,91	0,36	44,85%	0,38
Protura	0,05	0,04	0,02	0,03	0,03	0,04	0,05	0,02	0,29	0,04	35,54%	0,04
Symphyla	11,20	17,55	7,97	8,66	2,77	13,86	17,32	5,08	84,42	10,55	51,52%	9,93
others	**11,53**	**17,83**	**8,56**	**9,20**	**2,96**	**14,39**	**17,85**	**5,29**	**87,61**	**10,95**	**50,21%**	**10,36**
Enchytraeida	61,39	22,80	17,73	46,04	134,55	99,68	99,53	130,38	612,09	76,51	60,17%	80,46
Total Mesofauna	**500,14**	**567,77**	**732,67**	**613,29**	**736,08**	**373,25**	**650,62**	**700,96**	**4874,77**	**609,35**	**20,64%**	**631,95**

Secondary forest

taxon	Jul'97	Sep'97	Dec'97	Mar'98	Jun'98	Sep'98	Dec'98	Mar'99	sum	mean	stds in %	median
Acari	69,93	97,18	114,25	121,14	117,20	39,07	149,71	136,25	844,73	105,59	34,16%	115,73
Acari: Oribatida	140,06	253,89	369,82	682,47	558,14	299,53	603,26	482,61	3389,79	423,72	44,45%	426,22
Acari: total	**209,99**	**351,07**	**484,07**	**803,61**	**675,35**	**338,60**	**752,97**	**618,85**	**4234,51**	**529,31**	**40,82%**	**551,46**
Collembola: Arthropleona	12,81	24,02	8,33	74,93	38,11	7,04	42,27	75,57	283,07	35,38	78,55%	31,06
Collembola: Poduromorpha	3,20	4,80	7,37	34,90	25,94	7,04	13,45	8,01	104,71	13,09	86,76%	7,69
Collembola: Symphypleona	0,32	0,64	0,64	2,24	8,01	0,32	3,84	9,29	25,30	3,16	114,11%	1,44
Collembola total	**16,33**	**29,46**	**16,33**	**112,08**	**72,05**	**14,41**	**59,56**	**92,86**	**413,08**	**51,64**	**73,94%**	**44,51**
Pauropoda	0,10	0,03	0,10	0,24	0,18	0,20	0,13	0,24	1,22	0,15	50,38%	0,16
Protura	0,01	0,01	0,03	0,06	0,02	0,05	0,07	0,02	0,27	0,03	66,16%	0,02
Symphyla	11,78	9,24	22,52	15,71	5,89	11,78	18,36	5,77	101,05	12,63	46,89%	11,78
others	**11,90**	**9,28**	**22,64**	**16,01**	**6,09**	**12,03**	**18,56**	**6,03**	**102,53**	**12,82**	**46,15%**	**11,96**
Enchytraeida	82,55	34,87	24,88	43,21	129,78	44,85	118,60	201,15	679,89	84,99	71,87%	63,70
Total Mesofauna	**320,76**	**424,68**	**547,93**	**974,91**	**883,27**	**409,89**	**949,69**	**918,90**	**5430,01**	**678,75**	**41,02%**	**715,60**

Polyculture A

taxon	Jul'97	Sep'97	Dec'97	Mar'98	Jun'98	Sep'98	Dec'98	Mar'99	sum	mean	stds in %	median
Acari	70,26	143,80	225,87	140,51	95,87	22,98	121,47	147,74	968,50	121,06	49,79%	130,99
Acari: Oribatida	321,04	287,47	692,44	200,00	700,83	431,20	2133,96	572,83	5339,76	667,47	93,05%	502,02
Acari: total	**391,30**	**431,26**	**918,31**	**340,51**	**796,69**	**454,18**	**2255,43**	**720,57**	**6308,26**	**788,53**	**79,79%**	**587,37**
Collembola: Arthropleona	10,89	21,77	0,00	10,25	37,15	8,97	29,46	87,10	205,58	25,70	107,37%	16,33
Collembola: Poduromorpha	16,01	4,48	35,22	35,22	1,28	6,40	7,69	10,25	116,56	14,57	92,32%	8,97
Collembola: Symphypleona	0,00	0,00	0,00	0,64	67,89	0,00	0,64	0,00	69,17	8,65	276,88%	0,00
Collembola total	**26,90**	**26,26**	**35,22**	**46,11**	**106,31**	**15,37**	**37,79**	**97,35**	**391,31**	**48,91**	**69,47%**	**36,50**
Pauropoda	0,23	0,02	0,02	0,02	0,00	0,00	0,02	0,35	0,64	0,08	163,83%	0,02
Protura	0,00	0,00	0,00	0,00	0,00	0,02	0,03	0,01	0,07	0,01	100,93%	0,00
Symphyla	33,26	53,12	108,09	45,73	7,62	11,32	31,41	20,56	311,10	38,89	82,47%	32,33
others	**33,49**	**53,14**	**108,11**	**45,75**	**7,63**	**11,34**	**31,45**	**20,91**	**311,81**	**38,98**	**82,20%**	**32,47**
Enchytraeida	28,91	37,25	19,82	84,33	118,01	21,75	77,03	97,30	484,40	60,55	63,04%	57,14
Total Mesofauna	**480,59**	**547,91**	**1081,46**	**516,71**	**1028,64**	**502,64**	**2401,70**	**936,12**	**7495,78**	**936,97**	**68,69%**	**742,02**

Polyculture C

taxon	Jul'97	Sep'97	Dec'97	Mar'98	Jun'98	Sep'98	Dec'98	Mar'99	sum	mean	stds in %	median
Acari	97,83	78,14	79,45	145,11	42,68	160,21	78,14	165,47	847,03	105,88	42,75%	88,64
Acari: Oribatida	305,30	225,57	383,99	652,57	666,21	359,86	401,82	437,49	3432,80	429,10	36,38%	392,90
Acari: total	**403,14**	**303,70**	**463,44**	**797,68**	**708,89**	**520,07**	**479,96**	**602,96**	**4279,83**	**534,98**	**30,23%**	**500,01**
Collembola: Arthropleona	25,62	39,71	47,39	33,30	1,92	23,06	51,23	49,95	272,19	34,02	49,47%	36,50
Collembola: Poduromorpha	1,28	9,61	5,76	8,33	3,84	3,20	2,56	30,74	65,32	8,17	117,07%	4,80
Collembola: Symphypleona	1,28	1,28	0,64	14,09	1,28	1,28	1,92	23,06	44,83	5,60	149,23%	1,28
Collembola total	**28,18**	**50,59**	**53,80**	**55,72**	**7,04**	**27,54**	**55,72**	**103,75**	**382,34**	**47,79**	**60,00%**	**52,20**
Pauropoda	0,02	0,09	0,16	0,40	0,19	0,81	0,09	0,38	2,13	0,27	97,84%	0,17
Protura	0,04	0,01	0,07	0,07	0,02	0,06	0,01	0,05	0,31	0,04	66,82%	0,04
Symphyla	19,63	21,71	21,02	15,47	5,08	20,09	24,94	12,01	139,96	17,50	36,49%	19,86
others	**19,68**	**21,80**	**21,24**	**15,94**	**5,29**	**20,97**	**25,04**	**12,44**	**142,40**	**17,80**	**35,69%**	**20,33**
Enchytraeida	46,79	23,54	25,33	46,79	67,50	45,15	77,93	100,13	433,14	54,14	48,44%	46,79
Total Mesofauna	**497,79**	**399,64**	**563,80**	**916,12**	**788,72**	**613,72**	**638,64**	**819,27**	**5237,71**	**654,71**	**28,64%**	**626,18**

Macrofauna

General description, abundances and biomass

Abundance. Macroarthropods were abundantly collected in all our for study areas. Mean abundances over all 8 sampling events were highest in the primary forest (FLO) with nearly 5.000 ind./m^2 and lowest in the secondary forest area (SEC) with nearly 4.000 ind./m^2. Highest abundances during the whole sampling period of 21 months were observed in July 1997 in FLO and December 1997 in both polyculture areas (POA and POC). With the exception of the primary forest area arthropods were always more abundant in samples taken in December, at the beginning of the rainy season and less abundant in June, at the beginning of the dry season.
Predatory arthropods made up between 46 and 53 % of the individuals, decomposers between 34 and 43 %. Most abundant predators were pseudoscorpions, diplura and spiders. Predatory ants were more abundant in the forest areas, especially in the primary forest, than in both polycultures.
Termites (Isoptera) were the most abundant decomposers in FLO and SEC (24 and 14 % of all arthropods) and clearly less abundant in the polycultures, whereas in the polycultures diplopods dominated the decomposer group (7 and 9 % of all arthopods). Ants classified as decomposers made up 7 to 11 % of all arthropods.

Biomass. Mean biomass of the macrofauna over all sampling events, expressed as dry weight (mg/m^2), was 2678 mg/m^2 in FLO, 2288 mg/m^2 in POC, 1378 mg/m^2 in SEC, 1360 mg/m^2 in POA. Highest biomass values were recorded in December 1997. Predators were less dominant in biomass (17 - 55%) than in abundances, especially when regarding medians. Chilopoda dominated by biomass within the predators, followed by predatory ants and beetles, pseudoscorpions and spiders. The decomposer fauna biomass is strongly dominated by termites in FLO (24 % of all arthopods) and SEC (22 %), which made 8 % in POA and 13 % in POC. Diplopods (in FLO and SEC 8 %; in Poa 18 % and in POC 12 %) and isopods (in FLO 11 and in SEC 2 %; in Poa 17 % and in POC 43 %) made also a considerable portion of the biomass. These two groups dominated strongly in the polyculture areas.
Herbivores had a higher portion of the biomass than of abundances and reached 30 % in SEC and POC. Compared to the arthropods, abundances and biomass of molluscs (snails and slugs) was low.
Earthworms, which were collected with an other method were very important decomposers. Although their abundances were rather low and highly variable, they reached a comparatively high dry weight biomass in FLO (1541 mg/m²) , whereas their biomass attained only about one third of that of macroarthropods and molluscs in SEC (1053 mg/m²), POA (397 mg/m²) and POC (963 mg/m). In FLO mean dry weight biomass of macroarthropods and molluscs was 51 % and that of earthworms 49 %, whereas the portion of macroarthropods and molluscs was considerably higher in SEC (68 %), POA (72 %) and POC (65 %) in these study plots. Correspondingly the percentage of earthworm biomass varied between 28 % and 35 %. The total mean biomass of macrodecomposers was highest in FLO (mean biomass of 8 sampling events: 3126 mg/m^2) and lowest in SEC (804 mg/m^2). The biomass of macroarthropods and molluscs was highest in POC (mean 1776 mg/m^2) and FLO (1585 mg/m^2), lower in POA (997 mg/m^2) and very low in SEC (544 mg/m^2). These differences of biomass of total macroarthropods (and mollucs) and earthworms fitted well with our findings on the quantity of litter stock and was correlated highly to decomposition processes, indicating the importance of earthworms. In FLO biomass of macrodecomposers (earthworms included) was high and litter stock quantity was low, whereas in SEC biomass of macrodecomposer and that of earthworms was low and litter stock quantity was very high.

Mean macrofauna abundance (ind./m²) over all 8 sampling events

Functional groups of macrofauna

	FLO			SEC			POA			POC		
predators	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**
Araneae	221,05	63,75	4,54%	178,64	84,93	4,72%	184,42	73,39	4,91%	158,79	93,49	3,72%
Chilopoda	64,96	24,46	1,33%	28,33	15,64	0,75%	45,47	48,13	1,21%	36,81	19,26	0,86%
Coleoptera (part.)	157,15	47,25	3,23%	179,34	55,52	4,74%	189,89	93,04	5,06%	148,66	78,37	3,48%
Dermaptera	1,26	2,61	0,03%	1,44	1,89	0,04%	0,00	0,00	0,00%	0,72	1,34	0,02%
Diplura	187,12	81,24	3,85%	431,45	202,89	11,41%	580,32	406,92	15,45%	434,16	220,63	10,16%
Formicidae (part.)	803,71	399,23	16,52%	296,84	192,11	7,85%	119,31	43,68	3,18%	274,64	184,79	6,43%
Opilionida	46,56	12,84	0,96%	4,51	5,80	0,12%	4,33	5,56	0,12%	19,85	16,14	0,46%
Palpigradi	31,40	27,96	0,65%	11,73	8,33	0,31%	10,47	8,30	0,28%	5,78	8,02	0,14%
Pseudoscorpionida	775,38	511,56	15,93%	865,97	498,05	22,90%	603,06	386,92	16,06%	948,43	623,04	22,20%
Ricinulei	2,71	2,37	0,06%	1,26	1,20	0,03%	1,44	1,54	0,04%	7,58	7,23	0,18%
Scorpionida	0,90	1,71	0,02%	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%
Uropygi	26,53	33,41	0,55%	5,96	5,09	0,16%	2,17	5,06	0,06%	0,72	1,34	0,02%
total	**2.292,21**	**1.004,66**	**47,11%**	**1.999,52**	**886,43**	**52,88%**	**1.738,71**	**898,46**	**46,30%**	**2.035,42**	**1.057,63**	**47,65%**

decomposers	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**
Blattodea	15,16	7,98	0,31%	11,19	6,63	0,30%	11,19	12,29	0,30%	8,30	7,31	0,19%
Coleoptera (part.)	121,22	58,76	2,49%	147,49	59,75	3,90%	207,70	132,16	5,53%	117,12	47,73	2,74%
Diplopoda	233,14	101,02	4,79%	146,70	114,53	3,88%	511,39	412,78	13,62%	599,09	308,54	14,02%
Diptera, larvas	41,86	27,30	0,86%	32,12	17,02	0,85%	80,12	70,48	2,13%	53,41	34,78	1,25%
Formicidae (part.)	411,06	237,53	8,45%	413,95	215,96	10,95%	299,18	257,90	7,97%	304,23	152,34	7,12%
Gryllidae	0,00	0,00	0,00%	0,00	0,00	0,00%	17,32	0,00	0,46%	0,00	0,00	0,00%
Isopoda	109,71	51,54	2,25%	18,95	8,18	0,50%	114,40	44,91	3,05%	243,24	152,34	5,69%
Isoptera	1.146,02	368,96	23,55%	520,41	276,82	13,76%	262,73	288,76	7,00%	369,20	396,05	8,64%
Mollusca	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%	0,36	1,02	0,01%
Trichoptera	31,40	27,96	0,65%	11,73	8,33	0,31%	10,47	8,30	0,28%	5,77	8,02	0,14%
total	**2.109,57**	**490,86**	**43,35%**	**1.302,54**	**431,80**	**34,45%**	**1.514,50**	**437,38**	**40,33%**	**1.700,73**	**889,50**	**39,81%**

herbivores	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**
Coleoptera (part.)	0,00	0,00	0,00%	1,66	1,97	0,04%	4,20	6,72	0,11%	0,86	1,62	0,02%
Diptera ad.	222,31	204,69	4,57%	173,41	85,92	4,59%	207,51	169,64	5,53%	158,07	116,12	3,70%
Embioptera	3,43	5,17	0,07%	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%
Formicidae (part.)	70,92	52,62	1,46%	89,68	101,76	2,37%	51,14	37,29	1,36%	81,92	94,04	1,92%
Hemiptera	30,59	16,92	0,63%	60,00	32,18	1,59%	32,30	10,88	0,86%	29,77	18,05	0,70%
Homoptera	57,29	34,75	1,18%	63,61	40,14	1,68%	25,26	22,90	0,67%	114,95	81,99	2,69%
Hymenoptera	38,07	33,39	0,78%	22,20	13,87	0,59%	23,46	23,63	0,62%	29,23	21,13	0,68%
Lepidoptera	0,36	0,67	0,01%	0,54	1,53	0,01%	0,00	0,00	0,00%	0,36	1,02	0,01%
total	**422,87**	**302,62**	**8,69%**	**411,10**	**203,10**	**10,87%**	**343,87**	**196,90**	**9,16%**	**415,17**	**182,18**	**9,72%**

others	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**
Coleoptera (part.)	4,57	4,92	0,09%	2,48	2,55	0,07%	2,31	3,53	0,06%	0,00	0,00	0,00%
Formicidae (part.)	36,81	58,99	0,76%	65,32	39,36	1,73%	156,27	375,23	4,16%	118,01	91,06	2,76%
total	**41,38**	**57,18**	**0,85%**	**67,80**	**40,46**	**1,79%**	**158,58**	**374,40**	**4,22%**	**120,74**	**91,78**	**2,83%**
Macrofauna total	4.866,14	1.603,97	100,00%	3.780,96	1.182,52	100,00%	3.755,66	1.396,59	100,00%	4.272,06	1.745,83	100,00%

Mean macrofauna biomass (mg/m²) over all 8 sampling events

Functional groups of macrofauna

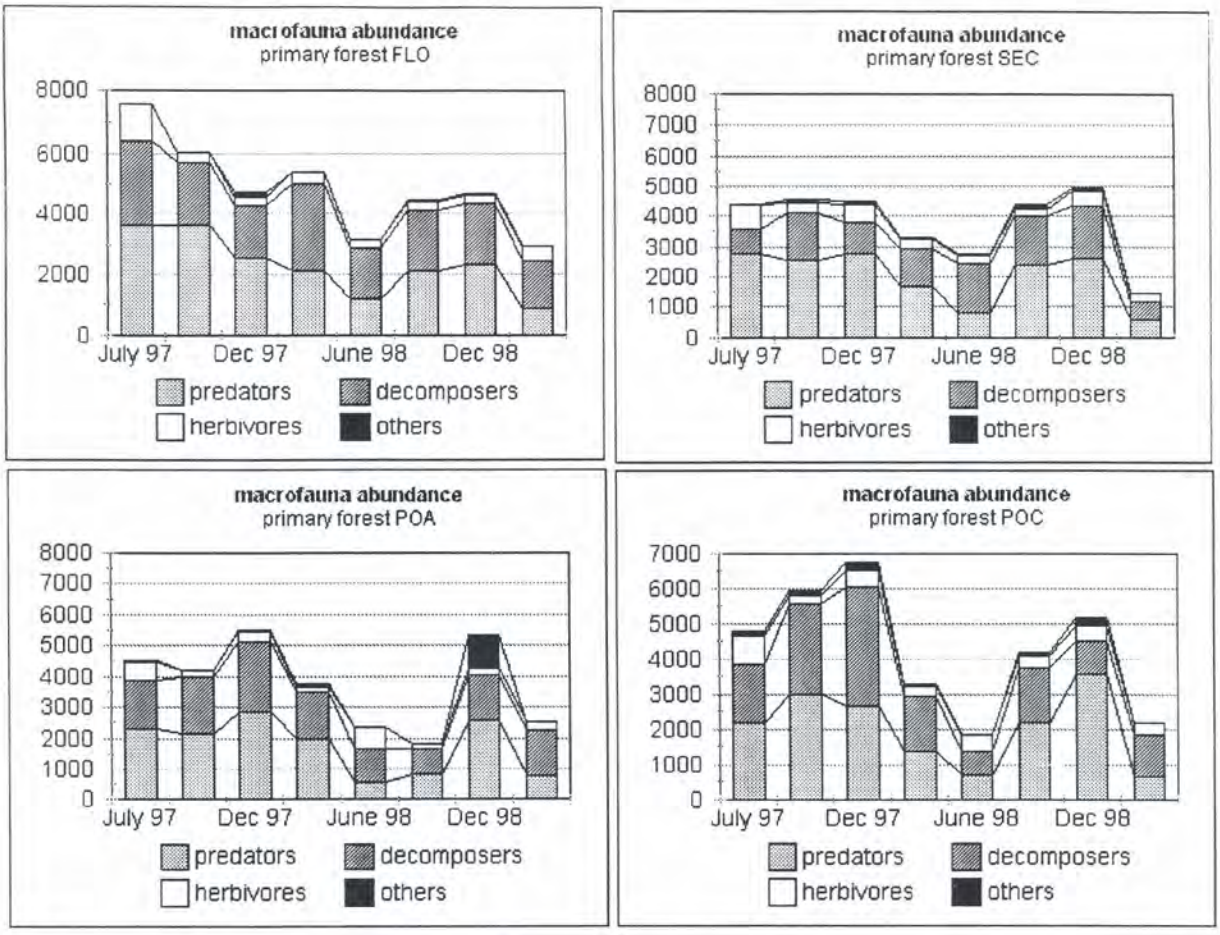
	FLO			SEC			POA			POC		
predators	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**
Araneae	58,47	68,61	2,18%	46,80	59,17	3,40%	7,59	3,56	0,56%	40,45	88,71	1,77%
Chilopoda	434,18	511,92	16,21%	503,46	754,25	36,52%	183,58	142,92	13,50%	167,53	168,93	7,32%
Coleoptera (part.)	72,70	27,45	2,71%	60,70	28,29	4,40%	41,41	19,77	3,04%	58,15	64,31	2,54%
Dermaptera	6,95	14,35	0,26%	7,94	10,39	0,58%	0,00	0,00	0,00%	3,97	7,35	0,17%
Diplura	3,50	1,81	0,13%	8,37	3,94	0,61%	11,26	7,89	0,83%	8,42	4,28	0,37%
Formicidae (part.)	145,21	86,21	5,42%	68,52	30,37	4,97%	26,03	8,25	1,91%	62,33	30,81	2,72%
Opilionida	3,13	1,38	0,12%	0,09	0,13	0,01%	0,21	0,23	0,02%	1,61	1,42	0,07%
Palpigradi	3,09	2,23	0,12%	0,23	0,23	0,02%	0,40	0,69	0,03%	0,81	2,04	0,04%
Pseudoscorpionida	62,28	46,95	2,33%	61,63	32,24	4,47%	33,70	22,03	2,48%	55,51	32,74	2,43%
Ricinulei	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%
Scorpionida	223,20	424,17	8,34%	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%
Uropygi	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%
total	1012,71	898,21	37,82%	757,74	794,92	54,97%	304,19	156,12	22,37%	398,78	203,57	17,43%

Decomposers	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**
Blattodea	111,08	214,60	4,15%	1,94	2,59	0,14%	7,94	11,54	0,58%	15,07	27,36	0,66%
Coleoptera (part.)	99,36	45,57	3,71%	39,35	16,20	2,85%	67,56	57,29	4,97%	35,01	19,35	1,53%
Diplopoda	219,63	187,33	8,20%	107,10	77,53	7,77%	247,08	171,11	18,17%	275,89	163,90	12,06%
Diptera, Larvae	33,49	21,84	1,25%	25,69	13,62	1,86%	64,09	56,38	4,71%	41,57	22,80	1,82%
Formicidae (part.)	22,85	12,28	0,85%	10,40	4,44	0,75%	12,12	6,75	0,89%	8,12	4,70	0,36%
Gryllidae	0,16	0,23	0,01%	0,06	0,10	0,00%	0,07	0,19	0,00%	0,00	0,00	0,00%
Isopoda	287,16	189,90	10,72%	33,69	22,70	2,44%	227,03	174,16	16,69%	993,72	800,97	43,44%
Isoptera	654,43	158,56	24,44%	305,99	134,96	22,20%	108,66	121,19	7,99%	303,64	405,59	13,27%
Mollusca	140,52	363,44	5,25%	10,61	30,01	0,77%	251,02	391,08	18,46%	93,68	242,92	4,10%
Trichoptera	17,07	43,17	0,64%	9,53	22,39	0,69%	11,43	25,22	0,84%	9,61	25,63	0,42%
total	**1585,74**	**442,90**	**59,22%**	**544,36**	**141,00**	**39,49%**	**997,00**	**395,96**	**73,31%**	**1776,31**	**1032,72**	**77,65%**

Herbivores	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**
Coleoptera (part.)	0,00	0,00	0,00%	0,45	0,65	0,03%	1,35	2,41	0,10%	0,16	0,31	0,01%
Formicidae (part.)	13,20	9,47	0,49%	5,07	4,84	0,37%	4,18	4,77	0,31%	13,24	23,76	0,58%
Hemiptera, adults	13,64	11,23	0,51%	17,70	10,65	1,28%	12,13	9,07	0,89%	28,31	39,58	1,24%
Hemiptera, larvae	3,37	2,30	0,13%	11,04	9,08	0,80%	4,68	2,95	0,34%	2,97	2,93	0,13%
Homoptera, adults	14,81	17,74	0,55%	12,52	9,85	0,91%	5,94	4,91	0,44%	18,47	27,00	0,81%
Homoptera, larvae	11,17	3,16	0,42%	15,12	13,90	1,10%	5,33	6,90	0,39%	26,06	16,11	1,14%
Lepidoptera, larvae	12,15	9,39	0,45%	8,93	10,85	0,65%	20,01	24,44	1,47%	12,89	23,11	0,56%
Thysanoptera	0,65	0,31	0,02%	1,20	0,77	0,09%	1,33	1,24	0,10%	1,28	1,11	0,06%
other Orthoptera	0,00	0,00	0,00%	0,27	0,78	0,02%	0,00	0,00	0,00%	0,31	0,89	0,01%
total	**68,98**	**33,47**	**2,68%**	**72,30**	**38,43**	**5,24%**	**54,93**	**38,47**	**4,04%**	**103,70**	**76,67**	**4,63%**

Other Groups	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**	**mean**	**stds**	**in %**
Coleoptera (part.)	3,73	5,16	0,14%	0,26	0,42	0,02%	0,24	0,48	0,02%	1,56	4,00	0,07%
Formicidae, adults (part.)	6,70	12,73	0,25%	3,82	2,59	0,28%	3,61	6,99	0,27%	7,27	6,92	0,32%
total	**10,42**	**14,30**	**0,39%**	**4,09**	**2,71**	**0,30%**	**3,86**	**6,93**	**0,28%**	**8,83**	**9,06**	**0,39%**

Macrofauna total	**2677,86**	**995,60**	**100,00%**	**1378,48**	**871,35**	**100,00%**	**1359,97**	**379,37**	**100,00%**	**2287,62**	**565,76**	**100,00%**



Taxonomic composition, functional groups (abundance and biomass)

Predators

Macropredators consisted mainly of 12 arthropod groups. Most of them belonged to the Arachnida (Araneae, Opilionida, Palpigradi, Pseudoscorpionida, Ricinulei, Scorpionida and Uropygi (including the Schizomida).

Among the insects most of the ants and six beetle families were considered predatory. Carabids, Pselaphids, Scydmaenids were their important representatives. Some staphylinids were predators. Others could be considered as decomposers. Because of the high dominance of predatory species, all staphylinids were treated as predators. Dytiscids and Hysterids were generally rare. Among the chilopods the Geophilomorpha group dominated over Scolopendromorpha and Lithobiomorpha. With exception of the scorpions, chilopods and Uropygi all groups were represented mostly by species, which had a small to a very small body size, including such groups which were commonly considered as large arthropods, like spiders and carabids. Most frequent in all areas were ants of the genera Solenopsis (subfam. Myrmicinae) and Hypoponera (subfam. Ponerinae). The predatory species of Hypoponera represented the biggest part of ant biomass in all areas (20-33%), whereas the very abundant mostly tiny species (< 2mm) of Solenopsis made up only 1,4 – 3,9% of the ant biomass. Carnivory was the principal foraging strategy in some soil dwelling ants (e.g. Ponerinae and Ecitoninae). In all studied areas the genera Solenopsis and Hypoponera were most frequent. Hypoponera species are known by its predatory habit whereas the biology of Solenopsis is poorly known. They might be predominantly acting as predators including on brood of other ant species , but there might be also a lot of scavenging on dead animals (decomposing activity). Among the many predatory species were a good number that as far as known are highly specialized in their type of prey, e.g. *Thaumatomyrmex* (polyxenid millipedes), *Cylindromyrmex*, *Acanthostichus, Centromyrmex* (termites) *Discothyrea* (arthropod eggs) or *Smithistruma* and *Strumigenys* (mainly collembolans). These specialized predators were more than twice frequent in primary and secondary forests than in polycultures. Army ants have been registered in samples only in the forests, but have been observed occasionally in the polycultures.

Abundance. Macropredators constituted a high portion of the macrofauna, attaining high dominances (FLO: 47 %; SEC: 53 %; POA: 46 %; POC: 48 %; percentages related to 100% of predators). Their total abundance did not differ largely between the study sites (FLO: 2992 ind./m^2; SEC: 2000 ind./m^2; POA: 1739 ind./m^2; POC: 2035 ind./m^2). Formicids and Pseudoscorpions were the most abundant predators in the four study sites, followed by diplura, spiders and beetles. Pseudoscorpions were similarly abundant in FLO (775 ind./m^2), SEC (866 ind./m^2), POA (603 ind./m^2) and POC (948 ind./m^2) and correspondingly the difference of dominance was not accentuated between the study sites, ranging from 34 % in FLO to 46 % in POC (percentages related to 100% of predators). Predatory ants were much more abundant, having a higher dominance in FLO (804 ind./m^2; 35 %) than in SEC (297 ind./m^2; 15 %) and in the polycultures (POA: 119 ind./m^2; 7 %); POC: 275 ind./m^2; 13 %). Similar differences of abundance and dominance were registered for the chilopods, beetles, opilionids, palpigrads and Uropygi. Indeed, the diplura had the lowest abundance in the primary forest. In the secondary forest and in the polycultures they represented the secondmost dominant group, whereas the ants filled the third or even the fifth rank (in POA) among the predators.

Biomass. The biomass of the predators was highest in FLO (1012 mg/m^2), but about 25 % lower in SEC (758 mg/m^2) and even about 60 % lower in the polycultures (POA: 304 mg/m^2; POC: 399 mg/m^2). Chilopods were the most dominant predators in all four study sites (FLO: 43 %; SEC: 66 %; POA: 60 %; POC: 42 %; percentages related to 100% of predators). Their biomass was high in FLO and SEC, attaining 434 mg/m^2 and 503 mg/m^2 respectively, whereas biomass was more than 50 % lower in POA (184 mg/m^2) and POC (168 mg/m^2). In FLO scorpions followed the chilopods, attaining 22 % (223 mg/m^2). The high dominance of chilopods may be overestimated, because of their very few large individuals but very low abundance. Ants, pseudoscorpions and beetles filled the second, the third or the fourth rank in the different study sites, followed by the spiders and dipluras. The biomass of ants attained high values in FLO (145 mg/m^2), but their biomass was comparatively low in SEC (69 mg/m^2), POA (26 mg/m^2) and POC (62 mg/m^2).

There was a contrast between the dominance of biomass and species richness of the different groups of predators. There were very few large chilopods, which determined the biomass of predators, whereas spiders, beetles and ants were much more rich in small species, which did not affect strongly the predators biomass. Due to their small body sizes, many of them may predate more on mesofauna than on other macroarthropods.

All the other groups, mostly Arachnida, were rare, having low abundances and low biomass. They inhabited mainly the primary forest.

Mean macropredator abundance (ind./m²) and biomass (mg/m²) over all 8 sampling events
Taxonomic groups of predators

Abundances (ind./m²)	FLO			SEC			POA			POC		
predators	mean	stds	in %	mean	stds	in %	mean	stds	in %	mean	stds	in %
Araneae	221,05	63,75	9,64%	178,64	84,93	8,93%	184,42	73,39	10,61%	158,79	93,49	7,80%
Chilopoda	64,96	24,46	2,83%	28,33	15,64	1,42%	45,47	48,13	2,62%	36,81	19,26	1,81%
Coleoptera (part.)	157,15	47,25	6,86%	179,34	55,52	8,97%	189,89	93,04	10,92%	148,66	78,37	7,30%
Dermaptera	1,26	2,61	0,06%	1,44	1,89	0,07%	0,00	0,00	0,00%	0,72	1,34	0,04%
Diplura	187,12	81,24	8,16%	431,45	202,89	21,58%	580,32	406,92	33,38%	434,16	220,63	21,33%
Formicidae (part.)	803,71	399,23	35,06%	296,84	192,11	14,85%	119,31	43,68	6,86%	274,64	184,79	13,49%
Opilionida	46,56	12,84	2,03%	4,51	5,80	0,23%	4,33	5,56	0,25%	19,85	16,14	0,98%
Palpigradi	31,40	27,96	1,37%	11,73	8,33	0,59%	10,47	8,30	0,60%	5,78	8,02	0,28%
Pseudoscorpionida	775,38	511,56	33,83%	865,97	498,05	43,31%	603,06	386,92	34,68%	948,43	623,04	46,60%
Ricinulei	2,71	2,37	0,12%	1,26	1,20	0,06%	1,44	1,54	0,08%	7,58	7,23	0,37%
Scorpionida	0,90	1,71	0,04%	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%
Uropygi	26,53	33,41	1,16%	5,96	5,09	0,30%	2,17	5,06	0,12%	0,72	1,34	0,04%
total	2.292,21	1.004,66	100,00%	1.999,52	886,43	100,00%	1.738,71	898,46	100,00%	2.035,42	1.057,63	100,00%

Biomass (mg/m²)	FLO			SEC			POA			POC		
predators	mean	stds	in %	mean	stds	in %	mean	stds	in %	mean	stds	in %
Araneae	58,47	68,61	5,77%	46,80	59,17	6,18%	7,59	3,56	2,50%	40,45	88,71	10,14%
Chilopoda	434,18	511,92	42,87%	503,46	754,25	66,44%	183,58	142,92	60,35%	167,53	168,93	42,01%
Coleoptera (part.)	72,70	27,45	7,18%	60,70	28,29	8,01%	41,41	19,77	13,61%	58,15	64,31	14,58%
Dermaptera	6,95	14,35	0,69%	7,94	10,39	1,05%	0,00	0,00	0,00%	3,97	7,35	1,00%
Diplura	3,50	1,81	0,35%	8,37	3,94	1,10%	11,26	7,89	3,70%	8,42	4,28	2,11%
Formicidae (part.)	145,21	86,21	14,34%	68,52	30,37	9,04%	26,03	8,25	8,56%	62,33	30,81	15,63%
Opilionida	3,13	1,38	0,31%	0,09	0,13	0,01%	0,21	0,23	0,07%	1,61	1,42	0,40%
Palpigradi	3,09	2,23	0,31%	0,23	0,23	0,03%	0,40	0,69	0,13%	0,81	2,04	0,20%
Pseudoscorpionida	62,28	46,95	6,15%	61,63	32,24	8,13%	33,70	22,03	11,08%	55,51	32,74	13,92%
Ricinulei	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%
Scorpionida	223,20	424,17	22,04%	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%
Uropygi	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%
total	1012,71	898,21	100,00%	757,74	794,92	100,00%	304,19	156,12	100,00%	398,78	203,57	100,00%

Decomposers

Arthropods and molluscs

Decomposers comprised all trophic groups, which interacted more or less directly within the decomposition process of organic matter residues, like saprophages, detritophages, fungivores, xylophages and coprophages. Besides the earthworms, 10 taxonomic groups of macrofauna have been identified as being important decomposers and for which biomass have been determined. Molluscs (snails and slugs) were considered too.

Abundance. The abundance of macrodecomposers was highest in the primary forest (2110 ind./m^2) and lowest in the secondary forest (1303 ind./m^2) (Table...). In all sites the portion of abundance was lower than that of predators. The relative abundance of macrodecomposers was highest in FLO (43 %) and lowest in SEC (35 %). By contrast, their dry weight biomass was higher than that of the predators, ranging from 59 % in FLO to 73 % in POC. In SEC only 39 % of the macrofauna belonged trophically to the macrodecomposers. The biomass was similarly high in POC (1776 mg/m^2) and FLO (1586 mg/m^2), but lower in POA (997 mg/m^2).

At all sites the most important macrodecomposers in abundance and biomass were diplopods, isopods, termites (Isoptera), ants (Formicidae) and beetles (Coleoptera) and to a lower degree cockroaches (Blattodea), larvas of diptera and molluscs (snails and slugs). At least 47 families of beetles have been registered in the Berlese samples. 62 % (29 families) were considered as macrodecomposers. At least 14 orders and families of diplopods participated in the decomposition process. Because of the small body size of most species of beetles and diplopods, both groups were abundant. But their total biomass was comparatively low. Isopods were much less rich in species. Small Philosciidae dominated in the primary forest, whereas in the polycultures, one large species of Circoniscus sp. (Scleropactidae) was much more abundant. 15 genera of termites were recorded in total. The largest number of genera was recorded in FLO (13), followed by SEC and POA/POC in that order. The most important genera were the Apicotermitinae (humus-feeding) and Heterotermes of

Rhinotermitidae (wood-feeders), in FLO also Syntermes (large leaf-feeding termites) and Cylindrotermes (wood-feeders). Their abundance was high in FLO (1146 ind./m^2; 54 %). They were much less abundant and dominant in SEC (520 mg/m^2; 40 %) and in the polycultures POA (263 ind./m^2; 17 %) and POC (369 ind./m^2; 21 %). In all sites, the number of termites in the soil samples (0-5mm depth) was higher than in the litter samples. The reduction of genus diversity to SEC and FLO points to a possible reduction in functional diversity. The reduction in termite genus diversity from FLO over SEC to the polycultures was more or less accompanied by the reduction in their abundance and biomass.
In FLO and SEC the Formicidae were the second most abundant taxonomic group. Although large cockroaches were typical arthropods and often observed, their abundance was generally very low, when compared to other arthropods. The interpretation of soil termite and soil ant data from soil core extraction was difficult because of the clumped distribution pattern of these social insects. Soil fauna assessments tended to underestimate the size of the whole populations of both groups, with all its functional fractions.

Biomass. In the primary forest termites dominated (654 mg/m^2; 41 %), followed by isopods (287 mg/m^2; 18 %), and diplopods (220 mg/m^2; 14 %), whereas the ants (23 mg/m^2; 1,4 %) and beetles (99 mg/m^2; 6 %) and cockroaches (111 mg/m^2; 7 %) were less important. Because the few molluscs had a large body size, they attained a slightly higher biomass than beetles and cockroaches.
Large differences existed between decomposers of the primary forest and the other three plots. In the secondary forest and in the polycultures, termites had much a lower biomass (from 306 mg/m^2 in SEC to 108 mg/m^2 in POA). In SEC termites attained 56 %, but in POA and POC only 11 and 17 % respectively. By contrast, in the polycultures diplopods and isopods were the most important decomposers, both groups together attaining 56 % in POA and even 71 % POC. The biomass of isopods was especially high in POC (994 mg/m^2), due to the high abundance of large individuals of Circoniscus sp. Indeed, the biomass of isopods was very low in SEC (34 mg/m^2).

Mean macrodecomposer abundance (ind./m²) and biomass (mg/m²) over all 8 sampling events
Taxonomic groups of predators

Abundances (ind./m²)	FLO			SEC			POA			POC		
decomposers	mean	stds	in %	mean	stds	in %	mean	stds	in %	mean	stds	in %
Blattodea	15,16	7,98	0,72%	11,19	6,63	0,86%	11,19	12,29	0,74%	8,30	7,31	0,49%
Coleoptera (part.)	121,22	58,76	5,75%	147,49	59,75	11,32%	207,70	132,16	13,71%	117,12	47,73	6,89%
Diplopoda	233,14	101,02	11,05%	146,70	114,53	11,26%	511,39	412,78	33,77%	599,09	308,54	35,23%
Diptera, larvas	41,86	27,30	1,98%	32,12	17,02	2,47%	80,12	70,48	5,29%	53,41	34,78	3,14%
Formicidae (part.)	411,06	237,53	19,49%	413,95	215,96	31,78%	299,18	257,90	19,75%	304,23	152,34	17,89%
Gryllidae	0,00	0,00	0,00%	0,00	0,00	0,00%	17,32	0,00	1,14%	0,00	0,00	0,00%
Isopoda	109,71	51,54	5,20%	18,95	8,18	1,45%	114,40	44,91	7,55%	243,24	152,34	14,30%
Isoptera	1.146,02	368,96	54,32%	520,41	276,82	39,95%	262,73	288,76	17,35%	369,20	396,05	21,71%
Mollusca	0,00	0,00	0,00%	0,00	0,00	0,00%	0,00	0,00	0,00%	0,36	1,02	0,02%
Trichoptera	31,40	27,96	1,49%	11,73	8,33	0,90%	10,47	8,30	0,69%	5,77	8,02	0,34%
total	2.109,57	490,86	100,00%	1.302,54	431,80	100,00%	1.514,50	437,38	100,00%	1.700,73	889,50	100,00%

Biomass (mg/m²)	FLO			SEC			POA			POC		
decomposers	mean	stds	in %	mean	stds	in %	mean	stds	in %	mean	stds	in %
Blattodea	111,08	214,60	7,00%	1,94	2,59	0,36%	7,94	11,54	0,80%	15,07	27,36	0,85%
Coleoptera (part.)	99,36	45,57	6,27%	39,35	16,20	7,23%	67,56	57,29	6,78%	35,01	19,35	1,97%
Diplopoda	219,63	187,33	13,85%	107,10	77,53	19,67%	247,08	171,11	24,78%	275,89	163,90	15,53%
Diptera, Larvae	33,49	21,84	2,11%	25,69	13,62	4,72%	64,09	56,38	6,43%	41,57	22,80	2,34%
Formicidae (part.)	22,85	12,28	1,44%	10,40	4,44	1,91%	12,12	6,75	1,22%	8,12	4,70	0,46%
Gryllidae	0,16	0,23	0,01%	0,06	0,10	0,01%	0,07	0,19	0,01%	0,00	0,00	0,00%
Isopoda	287,16	189,90	18,11%	33,69	22,70	6,19%	227,03	174,16	22,77%	993,72	800,97	55,94%
Isoptera	654,43	158,56	41,27%	305,99	134,96	56,21%	108,66	121,19	10,90%	303,64	405,59	17,09%
Trichoptera	17,07	43,17	1,08%	9,53	22,39	1,75%	11,43	25,22	1,15%	9,61	25,63	0,54%
Mollusca	140,52	363,44	8,86%	10,61	30,01	1,95%	251,02	391,08	25,18%	93,68	242,92	5,27%
Total Decomposers	1585,74	442,90	100,00%	544,36	141,00	100,00%	997,00	395,96	100,00%	1776,31	1032,72	100,00%

Earthworms

Earthworms were known to be the most important group of soil animals in temperate regions of the world but their contribution to ecosystem soil functions, especially litter decomposition, in the humid tropics remains largely unexplored. Therefore, the species composition, abundance and biomass of these organisms were determined in two plots of a polyculture forestry plantation and in plots of nearby secondary and primary forest . This chapter will concentrate on the species level.

Species number and composition. Considering the differences like vegetation cover and anthropogenic influence in the four plots, the number of species seems to be slightly higher (approximately 9; Table 1) than the normal range reported from rainforests (6.5 $\pm$ 1.3; Fragoso & Lavelle 1992). All of them belong to the mainly neotropical family Glossoscolecidae. The most conspicuous (since up to 110 cm long) belong to the genus *Rhinodrilus*. Besides some species widely distributed in Amazonia *(A. amazonius*, *U. brasiliensis*; Righi 1990), at least two of them seem to be endemic to the Manaus region (*R. contortus*, *R. priollii*). Both species were found for the first time since they have been described scientifically in 1938 and 1967, respectively. Very rarely and only in Berlese samples two small species were found *(P. vandersleeni, C. righii*; Zicsi et al. 2000). The peregrine species (i.e. circumtropical*) Pontoscolex corethrurus* was found on all plots except FLO. Another small peregrine species, *Dichogaster bolaui* (Octochaetidae) occurred in another plantation plot nearby.

Table 1: List of earthworm species (family Glossoscolecidae) found at the four Embrapa plots

Genus	Species	Author
Andiorrhinus	*amazonicus*	Michaelsen, 1918
Andiorrhinus	*venezuelanus tarumanis*	Righi et al. 1976
Cirodrilus	*righii*	Zicsi et al., 2000
Pontoscolex	*corethrurus*	(Müller, 1857)
Pontoscolex	*vandersleeni*	Michaelsen, 1933
Rhinodrilus	*contortus*	Cernosvitov, 1938
Rhinodrilus	*priollii*	Righi, 1967
Urobenus (Rhinodrilus)	*brasiliensis*	(Benham, 1887)
Tuiba	*dianaea*	Righi et al. 1976

This list was not complete since taxonomic work on some of the earthworms found in additional samples (both on the four study plots as well as nearby) was not finished yet.

Earthworm number and biomass. The abundance of earthworms in the four plots was low in comparison to many other tropical lowland rain forest sites. Concerning the mean abundance, no differences between the four plots were indicated – despite the fact that no worms were found at all on POA at two sampling times (September 1997 and 1998; Fig. 1). In various other polyculture plots nearby higher mean earthworm numbers were found (approximately by a factor of 3 to 4; Araujo, pers. comm.). However, these values were based on less sampling dates, mainly in the wet season.
Since most of the species living on the investigation plots were very large, the amount of biomass found at one point of time was very high (up to 35 g FW m^{-2}). Considering the results from FLO, the results were within the normal range reported from tropical rain forests (Fragoso & Lavelle 1992).
The average number of earthworms in the four plots seems to be more or less the same, showing a maximum in the rainy season (March 1998 and March 1999; Fig. 1). However, due to the very low number, these data were highly variable. On average, the earthworm biomass was highest in the primary forest and lowest in the secondary forest, whereas the plantation plots were somewhere in between (POC resembles more FLO and POA more SEC; Fig. 2). The extreme climatic conditions, partly induced by the open tree rows, might be responsible for the variability in the plantation plots which was clearly higher than in the two forests. In addition it was notable that only on POA no or nearly no earthworms were found in the dry season (September to December). The data gained so far have not been compared statistically due to their high variability in time, but it seems that the difference between the FLO and the SEC plot (and maybe the plantation plots too) was not accidental.

When looking at the individual species, the composition at the four sites was quite similar (Table 2). For example, the percentage *of A. amazonicus* oder *Rh. priollii* differed only between 25 to 33 % or 5

to 12 %, respectively. Only in few cases one species was completely missing (e.g. *Rh. contortus* on POA) or clearly more or less abundant than on the other plots (e.g. *U. brasiliensis* on POC). Two issues should be highlighted: concerning their species composition FLO and SEC seem to be more similar than the two polyculture plots; the percentage of the only peregrine species (*P. corethrurus*) was increasing steadily from FLO (0 %) to SEC (2 %), POC (5 %) and POA (12 %).
In general, the species composition indicates a closer relationship between the two forest sites in comparison to the two polyculture sites.

Table 2: Percentage of the most important earthworm species at the four study plots at the EMBRAPA site based on individual numbers

Species	FLO	SEC	POA	POC
A. amazonicus	11 %	10 %	12 %	22 %
P. corethrurus	0 %	2 %	12 %	5 %
Rh. contortus	31 %	17 %	0 %	14 %
Rh. priollii	6 %	5 %	12 %	5 %
U. brasiliensis	20 %	34 %	33 %	10 %
T. dianaea	25 %	28 %	30 %	33 %
Rest	7 %	6 %	1 %	11 %

When investigating the species composition based on biomass values, the differences between the four plots were even smaller: The large *Rhinodrilus* species (especially *Rh. priollii*) were responsible for 88 (SEC), 92 (POC), 94 (POA) and 97 (FLO) % of the total biomass, respectively. Within this genus it seems that Rh. priollii was more adapted to the polyculture situation since on FLO and SEC it showed a percentage similar to that of Rh. contortus, whereas on POC and, especially, on POA it was highly dominant. This leaded to an extremely steep dominance rank curve on POA. No other species reached more than 5 %. Only on POA *P. corethrurus* had a measurable biomass (1 %).

Juvenile/adult age ratio. If all earthworms were assessed together, the juvenile to subadult to adult ratio was 72 to 13 to 15 % based on numbers and 28 to 14 to 58 % based on biomass, indicating the much higher weight of the adult worms Table 3). Despite the fact that biomass was the ecologically more important parameter, for reasons of convenience (comparability with literature data) only results based on numbers were presented here. However, the average numbers were quite different when the various species (not distinguished between study plots) were compared individually. These numbers reflected probably different life strategies and maybe methodological problems (e.g. the relatively small juveniles of P. corethrurus might be underestimated since they were more abundant in the "macro-sonda" - large corer - samples than in the formalin samples presented here).

Table 3: Percentage of the three age stages for the most important earthworm species found at the four EMBRAPA plots so far

Species	Juvenil	Subadult	Adult
A. amazonicus	66 %	8 %	26 %
P. corethrurus	40 %	0 %	60 %
Rh. contortus	72 %	14 %	14 %
Rh. priollii	52 %	4 %	44 %
U. brasilienswas	44 %	1 %	55 %
T. dianaea	91 %	4 %	5 %

Concerning the age ratio at the four study plots, it seems that the juvenile number (including subadults) was higher on FLO and POC compared to POA and SEC. The same tendency was already found concerning biomass. Except of FLO (where the total biomass of juveniles seems to be higher in the wet season (November – April)) no correlation between number and biomass of age classes and climatic variables was visible.

The most important results gained so far when investigating the earthworms of the four EMBRAPA plots can be summarised as follows (cf. Table 4):

Table 4: Summary of the most important data describing the earthworm biocoenosis at the EMBRAPA site (* = data including the values from macro-sonda samples)

Parameter	FLO	SEC	POA	POC
Abundance [Ind/m^2] *	2.8 (16.2)	1.6 (11.7)	1.1 (12.0)	2.5 (14.5)
Variance	80 %	85 %	81 %	115 %
Biomass [FW/m^2]	15.6	2.6	4.0	9.6
Variance	68 %	79 %	205 %	122 %
Number of species	7	8	5	8
Juvenile/adult ratio [%]	81 : 19	64 : 36	67 : 33	77 : 23
Endemic/peregrine species ratio [%]	100 : 0	98 : 2	88 : 12	95 : 5

The reasons for the observed distribution pattern in time and space were not yet clear. However, the high biomass of earthworms, which can be as high as that of all other soil invertebrates together, indicated that they play a key role in ecological soil functions at the EMBRAPA sites. The low biomass values (partly together with the changed species composition) indicate that this role might be impeded on SEC and, especially, POA plots.

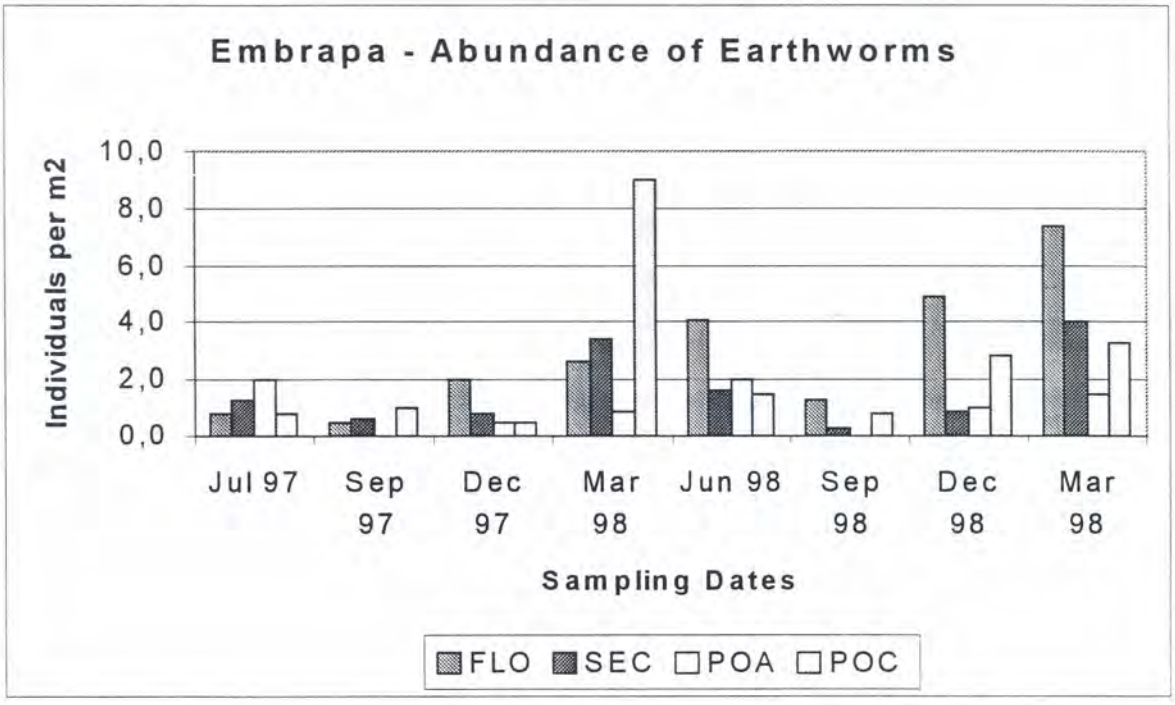


Fig. 1: Abundance [ind/m^2] of earthworms in the four study plots (FLO, SEC, POA, POC) at the eight sampling dates

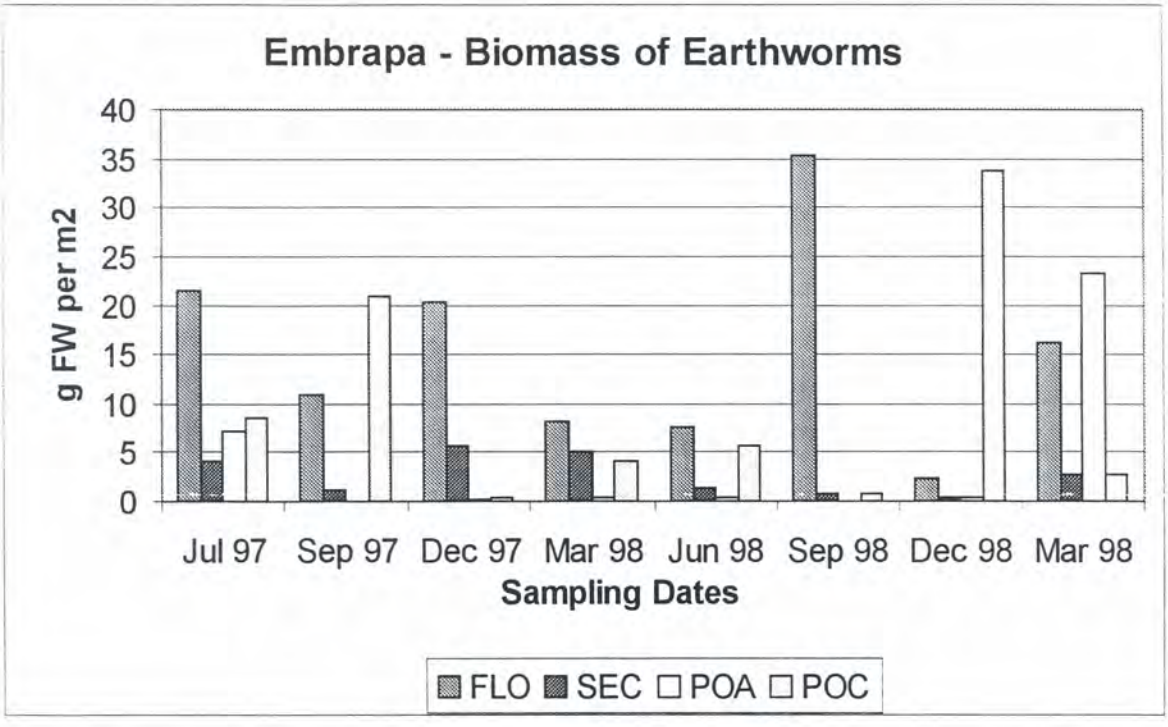


Fig. 2: Biomass (g/m²) of earthworms in the four study plots (FLO, SEC, POA, POC) at the eight sampling dates

Diversity of taxons and indicator groups

Our results showed strong shifts of composition even at the level of higher taxonomic groups. Strong shifts were recognized at the level of orders, families and genera. Species richness and the diversity of higher taxons was lower in all three anthropogenic forest sites (secondary forest and polycultures) than in the primary forest. The differences between the study sites may be even much more accentuated at species level. There are strong arguments, that such shifts may be correlated with functional shifts, which may affected the decomposition processes. Some results (examples) are presented in the following.

Arachnids. Among the arachnids several groups showed large differences of abundance and biomass between the study sites (Table 1). For example the Palpigradi were registered exclusively in the primary forest. Opilionids, Schizomida, Uropygi and Pseudoscorpions were predominantly abundant in FLO but less dominant in SEC, POA and POC.

Spiders were the most diverse taxon of arachnids. 23 families have been registered in all sites. Family diversity was highest in the primary forest. Of 23 families 19 inhabited the primary forest, 16 the secondary forest and 16 and 14 families in POA and POC respectively. The Oonopidae were the family most dominant by abundance in all study sites, and additionally by biomass in POA. However, the Mygalomorphae filled the first rank by biomass in FLO, whereas the Ctenidae filled this rank in SEC and POC (Table 2).

Table 1: Total number of individuals of arachnids found in Berlese samples

Taxon	FLO	SEC	POA	POC	Total
	160 samples	160 samples	80 samples	80 samples	480 samples
Araneae	794	512	266	269	1841
Scorpionida	4	0	0	0	1
Opilionida	170	10	8	41	229
Palpigradi	83	0	0	0	83
Pseucoscorpionida	450	317	125	172	1064
Ricinulei	12	6	4	21	43
Schizomida	52	29	4	0	85
Uropygi	7	2	0	1	10
Total	1572	876	407	504	3359

Diplopods. At the level of orders and families large differences were also detected in diplopods (Table 3 and 4). For example the orders Siphonophorida and Stemmiulida had a much higher biomass (sum of fresh weight of four sampling events) in the primary forest than in the other study sites. Indeed, several other diplopods dominated in POA (Chelosdesmidae, Fuhrmannodesmidae, Cyrtodesmidae, Paradoxosomatidae) and in POC (Pyrgodesmidae, Cryptodesmidae, Glomeridesmida). In both polycultures Polyxenida had a much higher biomass than in FLO and SEC. Taking in to account the abundances, the results were different (Table 4). The sum of total biomass (of four sampling events) was similar in FLO (663 mg/m²), POA (695 mg/m²) and POC (742 mg/m²)(Table 3), while it was about 60 % lower in SEC (285 mg/m²). Indeed, abundance was about 50 % lower in FLO (154 ind./m²) and SEC (125 ind./m²) than in POA (363 ind./m²) and POC (303 ind./m²)
(Table 4).

In the course of our field studies at least 5 exotic diplopod species were registered at the Embrapa station, which originated from Asia (*Trigoniulus corallinus* (Gervais, 1947); *Rhinotus purpureus* (Pocock, 1894); *Asiomorpha coarctata* (Saussure, 1860)) or were introduced by man probably from other neotropical regions (*Epitrigoniulus cruentatus* (Brolemann, 1902); *Xenolobus carnifex*). A few individuals of these species invaded accidentally the polycultures, but never the primary forest. Exotic diplopod species were especially numerous outside the forest like in pastures, other agroforestry systems and in house gardens.

Isopods. Strong shifts of species composition and dominance were also recorded from isopods. Isopods were abundant on FLO and POC and less abundant in POA and SEC. In the primary forest Philosciidae dominated, whereas the genus *Circoniscus* (Scleropactidae) was rare. This scleropactid isopod dominated in abundance and biomass in POA and especially in POC (Table 5). It was especially abundant in many other antropogenic habitats, being one of the most important species among the decomposers in man-made landscapes.

Table 2: List of spider families, their abundance and biomass in the study plots

	Primary forest		Secondary forest		Polyculture A		Polyculture C		Polycultures A + C	
	No. ind.	Biomass dry [mg]	No. ind.	Biomass dry [mg]	No. ind.	Biomass dry [mg]	No. ind.	Biomass dry [mg]	No. ind.	Biomass dry [mg]
Amaurobiidae					1	0,33			1	0,33
Anapidae	2	0	1	0,02	2	0,03			2	0,03
Araneidae	1	0,16	2	1,05	2	0,03	2	1,58	4	1,61
Caponiidae	1	3,11								
Clubionidae					2	0,4	10	0,59	12	0,99
Corinnidae	2	0,23	12	2,77	6	1,65	1	0,02	7	1,67
Ctenidae	7	137,27	9	124,12	2	0,03	5	91,53	16	91,66
Gnaphosidae	32	15,42	10	3,64	2	0,35	12	0,53	14	3,94
Heteropodidae	2	0,76								
Indet.	79	2,11	62	1,39	7	0,01	47	0,44	54	0,45
Linyphiidae	14	0,43	10	0,31	7	0,15	2	0,08	9	0,23
Mygalomorphae	334	226,00	7	72,41			4	2,16	5	2,16
Nesticidae			1	0,16						
Ochyroceratidae	109	1,75	18	0,26	5	0,1	18	0,56	23	0,66
Oecobiidae					1	0,06			1	0,06
Oonopidae	432	16,45	652	22,72	833	15,1	236	10,62	823	25,73
Palpimanidae	5	5,89					1	0,16	1	0,16
Pholcidae	10	0,5								
Salticidae	72	5,55	30	24,84	10	1,09	5	0,37	15	1,46
Scytodidae	10	1,27	6	0,1						
Symphytognathidae	64	0,12	79	0,14	29	0,05	96	0,24	125	0,29
Theridiidae	19	0,47	16	0,44	13	0,27	3	0,08	16	0,35
Zodariidae	11	3,86	13	3,69	8	1,58			8	1,58
Total	1208	425,51	935	259,39	936	21,23	435	112,05	923	133,28
No. of families	19	19	16	16	19	16	14	14	16	13
% dominant group	35,82%	53,27%	70,48%	47,65%	89,44%	71,13%	52,51%	81,69%	87,34%	68,70%
Dominant group	Oonopidae	Mygalomorphae	Oonopidae	Ctenidae	Oonopidae	Oonopidae	Oonopidae	Ctenidae	Oonopidae	Ctenidae

Table 3: Total fresh weight (mg/m²) of diplopod taxa; with indication of potential indicator groups for primary forest (FLO) and plantations (POA and POC)

Fresh weight (mg)/m² **Taxon**	**FLO**	**SEC**	**POC**	**POA**
FLO				
Siphonophorida	**279,5**	29,1	1,9	0,0
Stemmiulida	**170,9**	36,4	75,0	86,1
POC				
Pyrgodesmidae	86,8	95,8	**250,0**	42,5
Cryptodesmidae	0,0	0,0	**63,5**	2,3
Glomeridesmida	17,8	7,0	**33,5**	4,6
POA				
Chelodesmidae	0,0	8,9	102,7	**214,9**
Fuhrmannodesmidae	19,9	44,7	99,5	**155,1**
Cyrtodesmidae	54,4	48,7	68,3	**103,0**
Paradoxosomatidae	2,1	4,1	0,0	**63,7**
POA + POC				
Polyxenida	3,5	0,5	**20,7**	**13,6**
Polyzoniida	0,0	0,0	**0,2**	**0,9**
Rest				
Haplodesmidae	22,0	2,6	17,3	0,0
Polydesmida, indet.	0,7	0,7	7,9	1,6
Oniscodesmidae	0,0	0,0	1,8	0,0
Platyrhacidae	5,2	6,0	0,0	5,8
unidentified	0,5	0,4	0,0	0,3
Sum	663,3	284,9	742,3	694,5

Table 4: Total abundance (ind./m²) of diplopod taxons; with indication of potential indicator groups for primary forest (FLO) and plantations (POA and POC)

Abundance/m²	**FLO**	**SEC**	**POC**	**POA**
FLO				
Cyrtodesmidae	**36,3**	9,0	9,4	8,3
POC				
Pyrgodesmidae	24,9	22,9	**48,4**	13,0
POA				
Cryptodesmidae	0,0	0,0	0,7	**1,4**
Chelodesmidae	0,0	0,4	0,4	**1,4**
POA + POC				
Fuhrmannodesmidae	45,8	60,1	**117,3**	**121,3**
Polyxenida	17,7	2,7	**148,0**	**113,0**
Polyzoniida	0,0	0,5	**4,7**	**11,9**
Rest				
Glomeridesmida	12,8	8,1	13,0	5,1
Polydesmida	9,6	14,8	17,3	19,5
Stemmiulida	2,7	3,1	1,1	3,3
Siphonophorida	0,9	0,9	1,1	0,0
Paradoxosomatidae	0,4	1,3	0,0	1,8
Oniscodesmidae	0,0	0,0	0,7	0,0
Platyrhacidae	0,2	0,2	0,0	0,4
Haplodesmidae	0,2	0,9	1,1	0,0
Polydesmida, indet.	2,4	0,4	0,0	2,5
Sum	153,7	125,2	363,0	302,8

Table 5: Abundance/m^2 of *Circoniscus* sp. (Scleropactidae) and other Isopoda

Abundance/m^2			
	Circoniscus sp.	Isopoda (others)	Relationship
FLO	0,72	**66,40**	(1 : 92)
SEC	7,22	10,10	(1 : 1,4)
POC	**70,01**	9,38	(1 : 0,13)
POA	**44,03**	16,60	(1 : 0,38)

Body sizes of arthropods

Body lengths of several macroarthropod taxa (Coleoptera, Diplopoda, Arachnida) have been measured. The results showed that most of the individuals of these taxa had very small body sizes.

A total of 47 beetles families have been identified (Table 1). The adults of 19 families had a mean body size larger than 2 mm, whereas the adults of 28 families had a smaller mean body length. Mean body length of all beetle families was 2,2 mm. Following Van der Drift's classification (1951), a great portion of the beetle fauna could be considered as mesofauna. Individuals with large body sizes (> 4 mm body length) were generally very rare. Scarabaeidae, Staphylinidae, Platypodidae and Curculionidae were slightly larger than other taxa. Carabids are commonly considered as large predators. They are viewed as essential elements of the soil macrofauna. Indeed, in our study areas, the mean body length of 301 individuals taken from Berlese samples were 1,9 mm, having a maximum length of 11,5 mm and a minimum length of 0,9 mm. A high portion of the carabid species belonged to the very small Bembidiini (Tachyina and Anillina, Erwin 1984) with body lengths between 0,9 to 1,1 mm or to small Scaritini species (2,0 mm).

The results of data evaluation of the body lengths of Arachnida were similar to that of the beetles (Table 2). Araneae and Opilionida (adults and juveniles) were even smaller than the mean body size of the beetles, having a mean body length of 1,4 mm (Araneae) and 1,5 mm (Opilionida). They were slightly larger than Pseudoscorpionida (1,2 mm).

Other arthropod taxa of the soil fauna, like the Diplopoda and Formicidae, were also comparatively small (Table 3 and 4). Most of the diplopod families (adults and juveniles) had mean body sizes smaller than 10 mm and the maximum lengths indicated that most of the groups were represented by small adults. Large individuals and species had generally a very low abundance. It is remarkable, that small diplopod species, mainly the Micropolydesmida, dominated in the studied areas.

Therefore, it might not be surprising, that abundance of many macropredators and macrodecomposers seems to be high compared to their biomass.

Table 1: Body lengths (mm) of litter and soil beetle families, based on 480 Berlese samples from FLO, SEC POA and POC

Family	No. of individuals	Max. length (mm)	Mean length (mm)	Min. length (mm)
Scarabaeidae	21	14,0	5,1	2,1
Euglenidae	1	3,9	3,9	3,9
Staphylinidae	446	42,0	3,2	0,4
Platypodidae	33	4,3	3,2	2,2
Curculionidae	31	5,0	2,9	1,4
Endomychidae	5	9,3	2,9	1,1
Nitidulidae	14	4,3	2,7	1,6
Tenebrionidae	22	6,6	2,6	1,2
Histeridae	7	3,9	2,5	1,8
Hydrophilidae	4	3,4	2,5	1,6
Heteroceridae	3	2,6	2,5	2,3
Notiopygidae	1	2,5	2,5	2,5
Bostrichidae	1	2,3	2,3	2,3
Lyctidae	1	2,3	2,3	2,3
Chrysomelidae	14	3,5	2,2	1,4
Mordellidae	3	2,8	2,2	1,3
Dytiscidae	6	3,8	2,1	1,4
Scirtidae	2	2,5	2,1	1,7
Troscidae	1	2,1	2,1	2,1
Cholevidae	3	2,1	2,0	1,8
Languriidae	2	2,5	2,0	1,5
Silvaniidae	1	2,0	2,0	2,0
Scolytidae	383	2,7	1,9	0,7
Carabidae	301	11,5	1,9	0,9
Colydiidae	19	6,3	1,9	1,0
Elmidae	9	2,1	1,9	1,1
Aderidae	1	1,9	1,9	1,9
Sphaeridae	1	1,9	1,9	1,9
Anthicidae	7	2,1	1,8	1,4
Rhizophagidae	2	1,8	1,8	1,8
Laemophloeidae	1	1,8	1,8	1,8
Byrrhidae	7	1,9	1,7	1,4
Scaphidiidae	5	2,2	1,6	1,1
Mycetophagidae	1	1,6	1,6	1,6
Pselaphidae	171	3,3	1,5	0,8
Leiodidae	71	2,3	1,5	0,9
Lathridiidae	8	1,5	1,5	1,3
Cucujidae	6	1,8	1,4	1,0
Cerylidae	1	1,4	1,4	1,4
Corylophidae	10	1,8	1,3	0,7
Erotylidae	1	1,2	1,2	1,2
Salpingidae	1	1,2	1,2	1,2
Scydmaenidae	476	13,0	1,1	0,4
Clambidae	1	1,1	1,1	1,1
Lagriidae	1	0,9	0,9	0,9
Ptiliidae	304	4,8	0,8	0,5
Dasyceridae	1	0,4	0,4	0,4
Coleoptera, larvae	1302	38,0	2,9	0,5
indet.	22	3,5	1,1	0,4
Total	3741	42,0	2,2	0,4

Table 2: Body lengths (mm) of litter and soil Arachnida, based on 480 Berlese samples from FLO, SEC, POA and POC

Taxon	No. of individuals	Max. length (mm)	Mean length (mm)	Min. length (mm)
Araneae	1841	16,0	1,4	0,4
Scorpionida	4	5,0	4,3	3,0
Opilionida	229	6,0	1,5	0,5
Palpigradi	83	1,0	1,0	1,0
Pseudoscorpionida	1064	3,0	1,2	1,0
Ricinulei	43	6,0	2,8	1,0
Schizomida	85	4,0	2,3	0,5
Uropygi	10	13,0	8,8	5,0
Total	3359	16,0	1,4	0,4

Table 3: Body lengths (mm) of litter and soil diplopods, based on 480 Berlese samples taken from FLO, SEC, POA and POC

Taxon	No. of individuals	Max. length (mm)	Mean length (mm)	Min. length (mm)
Chelodesmidae	7	30,0	18,4	9,0
Siphonophorida	13	48,0	13,9	2,3
Platyrhachidae	3	13,7	12,4	10,5
Stemmiulida	44	32,0	10,9	4,0
Haplodesmidae	9	22,0	8,4	3,4
Cryptodesmidae	6	25,0	8,1	4,0
Paradoxosomatidae	14	22,0	7,3	3,5
Pyrgodesmidae	434	19,0	5,5	0,7
Polyzoniida	49	11,0	5,1	1,2
Oniscodesmidae	2	6,5	4,9	3,3
Cyrtodesmidae	300	19,0	4,6	1,0
Glomeridesmida	166	12,0	3,2	0,5
Fuhrmannodesmidae	1248	9,5	3,0	0,5
Polyxenida	835	4,5	1,7	0,5
Polydesmida (indet.)	232	9,5	1,6	0,6
Total	3362	18,9	7,3	3,0

Table 4: Body length categories of litter and soil ants, based on 480 Berlese samples taken from FLO, SEC, POA and POC

Genus	class of body length (mm)
Carebara	1,0
Erebomyrma	1,5
Solenopsis	2,0
Acanthostichus	2,0
Acropyga	2,0
Cyphomyrmex	2,0
Hylomyrma	2,0
Paratrechina	2,0
Quadristruma	2,0
Rhopalotrix	2,0
Rogeria	2,0
Smithistruma	2,0
Strumigenys	2,0
Tapinoma	2,0
Wasmannia	2,0
Discothyrea	2,0
Hypoponera	2,5
Proceratium	2,5
Crematogaster	2,5
Mycocepurus	2,5
Apterostigma	3,0
Trachymirmex	3,0
Zacryptocerus	3,0
Pheidole	3,0
Pseudomyrmex	3,0
Centromyrmex	4,0
Anochaetus	4,0
Azteca	4,0
Megalomyrmex	4,0
Acromyrmex	4,5
Gnamptogenys	5,0
Camponotus	5,0
Pachycondyla	6,0
Cylindromyrmex	7,0
Atta	8,0
Dolichoderus	8,0
Odontomachus	9,0
Ectatoma	10,0
Hypoponera	>5
Hypoponera	3 to 5

Bait-lamina- feeding rates

Two different approaches were used: In parallel to the quarterly basic sampling program, five blocks of bait-lamina sticks (each consisting of 16 individual sticks) were exposed on each plot (FLO, SEC, POA and POC) for four days. In addition, four "paired" experiments (one on each plot) were performed to determine the impact of the litter layer on the feeding activity in periods between the quarterly samplings (June (POA), July (SEC) and September (POC, FLO) 1998). Ten blocks of bait-lamina sticks (each consisting of 16 individual sticks) were exposed on subplots where the litter layer was removed by hand. Ten additional blocks, exposed on subplots immediately besides the other ones but without any litter removal served as controls. The exposure time (about four days) has been determined in a pre-test in June 1997, when bait-lamina sticks were exposed on all plots for 14 days.

Results and Discussion. In general, the measurement of the functional endpoint "feeding activity" using bait-lamina sticks at the EMBRAPA site was possible without problems. No adaptation to tropical conditions except a shortage in exposure time was necessary.

In Table 1, average values for the total feeding rate at the four study plots are given for all four sampling dates. Despite the fact that the absolute amount is different it seems that the feeding activity on the two plantation plots is twice as high as on the two forest plots (SEC and FLO). This difference seems to be caused mainly by a decrease of feeding activity in the uppermost soil layer. The standard deviation is more than twice as high on POA and POC in comparison to FLO and SEC. Due to the high variability within the individual blocks, no statistical significant differences between the four plots could be identified.

Table 1: Average amount of the feeding rate at the four study plots in percent of the total number of bait lamina holes

Date:	FLO	SEC	POA	POC
12/97	9	7	14	24
06/98	17	20	36	35
09/98	19	16	43	43
12/98	11	11	27	05
Mean	14	14	30	27
Std.-Dev.	± 4.8	± 5.7	± 12.5	± 16.5

Comparison between control and treatments (litter removal study)

In the case of the litter removal study, all data gained so far are presented in Table 2. They seem to support the impression that the feeding activity is higher at POA and POC. On all investigation plots, the number of fed holes is higher for the controls than for the treated blocks. However, this difference is only small in the case of FLO and not very high in the case of POA and POC. Only at SEC the results are statistically different. Again, the standard deviation is much higher on the polyculture plots in comparison to the forest sites. It seems that the vertical distribution has changed accordingly (i.e. at the top layer more holes are fed; Fig. 5 and 6).

Table 2: Average amount of the feeding rate of control and litter removal plots at the four study plots in percent of the total number of bait lamina holes

Manipulation	FLO	SEC	POA	POC
Control	12.5	22.8	46.3	38.5
Std.-Dev.	10.9	14.8	18.3	26.6
Treatment	10.1	7.5	37.5	23.6
Std.-Dev.	9.4	4.2	21.9	21.3

Note: Only in SEC the difference is statistically significant.

Often the data evaluation was hindered by the fact that individual blocks were influenced by factors which could not be controlled: e.g. ants build their nest between the sticks of one block, eating nearly

all holes. If things like this happened on some blocks which by chance belonged to the treated group, this could influence the overall assessment considerably.

The bait-lamina test is a simple test with a „yes" or „no" answer. Despite the fact that not all data are evaluated it seems that this method can give important information on the function of the soil biocoenosis.

Conclusions. The most important results gained so far when using bait-lamina sticks on the four EMBRAPA plots can be summarised as follows:

- The feeding activity is always lower on FLO and SEC than on POA and POC, but these differences are statistically not significant.
- The removal of litter (= treatment) leads to a decrease of the feeding activity but with the exception of SEC these differences are statistically not significant.
- In both cases, the variability of the results is much higher on the polyculture plots compared to the forest plots, indicating mainly the different abiotic conditions at the various plots.

Respiration rates of soil fauna

Invertebrates are an important structural component of the soil compartment and fulfill essential functions within the ecosystem. The soil fauna is of major importance for litter decomposition and thus for the cycling of carbon (and other nutrients) in tropical forest systems as it has been demonstrated by litterbag experiments within the project SHIFT ENV 52. It could also be shown for the temperate zone in various other investigations published in the literature. Mineralization of organic matter and release of CO_2 from the soil and litter, however, is mainly attributed to the activity of the soil microflora, which in turn is thought to be enhanced by faunal feeding activity. The aim of the study reported here was to measure the amount of carbon that is directly respired by the soil fauna. Therefore an instrument to measure the respiration of small soil invertebrates was developed, based on an infrared gas analyser (IRGA) designed to measure photosynthesis.

Results and discussion. All animals survived the measurements without any visible damage. Respiration rates, measured as the increase in CO_2 –concentration over a time period of 10 minutes were almost linear. The base-line drift of the system during measurements of the tropical fauna was up to 2.1 ppm/min. Therefore respiration rates were corrected for the drift. The results are given in Table 1. The values represent mixed respiration activity of animals active and at rest except for the tropical diplopod (Platyrhacidae) that was actively moving throughout the measurements.

The lowest observed CO_2 -production of the examined taxa from the tropical forest was 26.8 µL CO_2 h^{-1} g^{-1} for a beetle (Passalidae) at rest. The respiration increased to 191.2 µL when the beetle was active. Assuming a respiratory quotient of RQ = 1 the values for a Passalidae reported by Bartholomew & Casey (1977) were higher, ranging from 213 µL at rest to 551-3495 µL when active.

The highest single value was found for a true bug with 1141.8 µL CO_2 per gram biomass. It can be assumed that the CO_2 –production also depends on the quality of the food (Nunes et al. 1997). Many true bugs feed on phloem liquid which is rich in sugars that can easily be respired.

Grasshoppers (Orthoptera) always produced high amounts of CO_2 per biomass with an average of 672.3 µL.

Lower average CO_2 –production was found for isopods 291.3 µL and diplopods 240.1 µL.

Respiration rates of the tropical diplopods were in the range found for diplopods from the temperate zone (Schallnaß, 1989). The respiration of the tropical isopods was slightly higher compared to176.1 µL CO_2 h^{-1} g^{-1} for Isopods from the temperate zone (Förster unpublished data).

The respiration rate found for earthworms seemed to decrease with increasing biomass. Bolton (1970) measured the respiration of the earthworm species *D. rubida* and *L. castaneus* at 10° C and found values between 75 and 100 µL CO2 h-1 g-1 .

Table 1: Respiration rates of some tropical soil invertebrates from Amazonia

Taxa (No. of individual group or specimen measured)	No. of animals in the cuvette	Total Biomass fresh weight [g]	Respiration (mean) [µL CO_2 h^{-1} g^{-1} biomass]
Woodlice (Isopoda)			
(1)* Gen. sp.	10	0.306	245.2
(2)	10	0.465	308.9
(3)	10	0.650	290.8
(4)	10	0.539	273.7
(5)	5	0.293	282.7
(6)	5	0.294	303.7
(7)	10	0.584	334.4
Millipedes (Diplopoda)			
(1) Trigoniulus lumbricinus	1	0.665	214.9
(2)	1	0.603	253.4
(3)	1	0.535	368.7
(4)	1	0.703	195.7
(5)	1	0.607	128.9
(6)	1	0.699	208.5
(7)	1	0.616	266.0
(8)	1	0.767	268.6
(9)	1	0.531	202.1
(1) Asiomorpha coarctata	5	0.251	352.7
(1) Plusioporus setiger	1	0.689	185.7
(2)	1	0.615	117.9
(1) Platyrhacidae Gen. sp. (active)	1	1.424	199.5
(1) Chelodesmidae Gen.sp.	1	0.167	258.4
(2)	1	0.258	203.3
(3)	1	0.253	306.1
(4)	1	0.256	351.7
Cockroach (Blattodea)			
(1) Gen.sp.	1	0.215	404.5
(2)	1	0.204	534.0
Beetle (Passalidae)			
(1) Gen. sp. (active)	1	1.620	191.2
(1) Gen. sp. (at rest)	1	1.620	26.8
Spiders (Opilionida)			
(1) Gen.sp.	5	0.246	363.3
Grasshoppers (Orthoptera)			
(1) Gen.sp.	1	0.842	697.5
(2)	1	0.405	994.6
(3)	1	0.242	408.1
(4)	1	0.144	767.3
(5)	1	0.182	494.0
True bugs (Heteroptera)			
(1) Gen.sp.	1	0.185	1141.8
Earthworms (Glossoscolecidae)			
(1) Gen. sp.	1	1.344	172.4
(2)	1	1.061	170.3
(3)	1	27.3	106.1
(4)	1	71.4	48.5
(5)	1	76.7	43.8

Soil fauna and ecosystem function

Relationships between fauna and abiotic components
Climate and soil macrofauna

Please refer to separate report (Microclimate).

Litter quantity and abundance of macroarthropods

Litter is an important ecosystem resource. Litter feeds the decomposer food chain and thus initiates the nutrient cycles. At the same time the litter layer forms a structured space which serves as a habitat for the soil fauna.
This chapter refers to the question, if litter quantity (litter stock) and its different fractions may determine total macrofauna abundance and that of functional groups, like predators (spiders, pseudoscorpions, chilopods, opilionids), decomposers (diplopods, isopods) and social insects (ants, termites).
The data of litter stock and macrofauna abundance were taken from the same Berlese samples. Data of six sampling events were considered (from December 1997 to March 1999). The litter samples were separated into five fractions: Leafs (sieve mesh width >5mm), wood and twigs of > 1cm diameter and of < 1cm diameter, fine organic matter (fine litter, sieve mesh width < 5mm) and roots. Litter quantity was given in grams of oven dried (65° C) material.
For data processing Sygmaplot 4.0 and Statistica has been used, applying Power regression and Spearman Rank Ordered Correlation.

Results. The evaluation of 348 Berlese samples (one extreme value of FLO has been eliminated) from FLO, SEC, POA and POC indicated a significant association between total litter quantity and total litter macrofauna abundance. However the correlation coefficients were low (R= 0,406, R^2= 0,165, p = <0,0001) (Fig. 1, Table 1). Total litter quantity correlated with total litter and soil fauna to an even lower degree (R= 0,134, R^2 = 0,018, p = 0,0124). The high value of Press-Statistic (Predicted Residual Error Sum of Squares) and the low F-values confirmed that the independent variable (litter quantity) contributed to a low degree to the prediction of the dependent variable. Significant correlations existed between total litter stock and total litter macrofauna in the study sites FLO, SEC and POA, but not in POC, when samples of all 6 sampling events were evaluated. The degree of significance differed, when seasonal data were examined. Total litter macrofauna abundance correlated also significantly with leaf and leaf & fine litter quantity to a higher degree, than with other litter fractions (Table 2 and 3).
Predators, decomposers and social insects reacted differently to litter quantity. The abundance of dominant predators (spiders, pseudoscorpions) was correlated to a higher degree with total litter quantity than that of dominant decomposers (diplopods, isopods) and social insects (formicids, termites. The degree of correlation and their level of significance varied seasonally and and both were also site dependent. This may indicate that some correlations must be interpreted as "pseudocorrelations" by chance.

Conclusions. The high levels of significance (p-values) indicated that total litter stock and some litter fractions, especially leaf litter as well as leaf & fine litter fractions may have an certain positive effect on macrofauna abundance. The taxa and functional groups responded in a different manner. For predators (spiders, pseudoscorpions) litter quantity may express a relationship with structural habitat complexity, which determines much more their abundance than that of decomposers and social insects.
However, the low correlation coefficients and the low F-values showed that there were low predictive associations between the independent variable (litter stock) and the dependent variable (fauna abundance). The high values of Press statistic confirmed in most of the cases also a low predictive ability of the models.

The results may show that litter stock is only one factor of several others, which affect soil fauna. Other factors like spatial variation of litter quality, soil moisture and air humidity of microspaces, temperature, the intensity of insolation and climatic seasonality may have temporarily a stronger influence on soil fauna than the quantity of litter. Other factors that have to taken into account may be e.g. the local predation of migratory arthropod hunters (e.g. *Eciton* sp., Formicidae), different seasonality of reproduction of the species and their sociability, as well as the competition between arthropods and fungi.

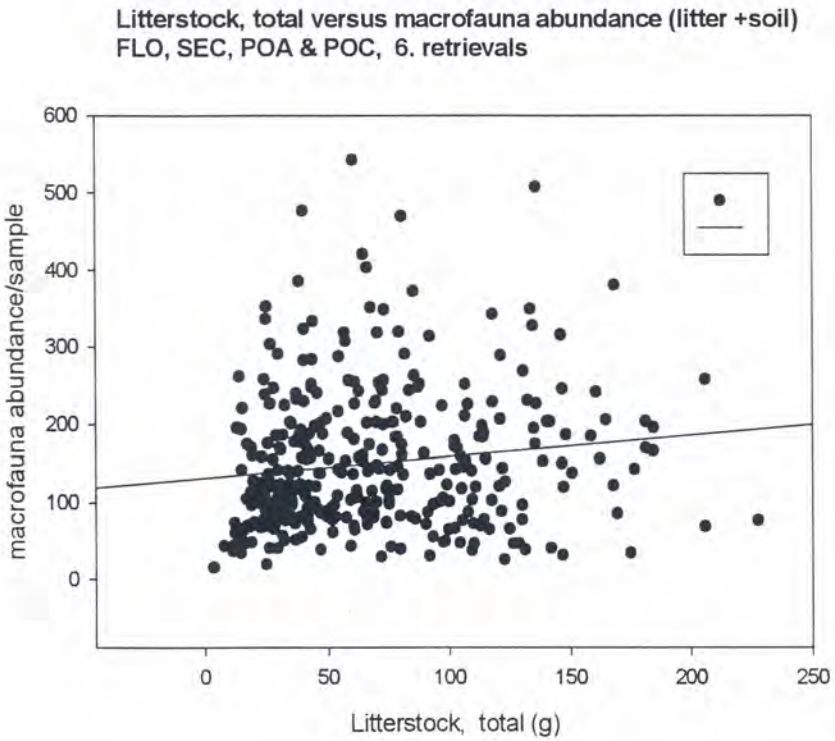


Figure 1 Correlation between litterstock and litter and soil macrofauna abundance from all study sites and 6 sampling events

Table 1: Correlations of total litterstock versus total litter macrofauna, 6 sampling events (Sigmaplot Power regression)

Site	R	R^2	Adj. R^2	P-value	F-value	PRESS-value
All sites (*)						
Lit+soil (+)	0,101	0,010	0,007	,0059	3,59	5.572.846,8
Lit+soil (-)	0,134	0,018	0,015	,0124	6,32	2.723.501,5
Lit (+)	0,347	0,121	0,118	<,0001	47,56	1.662.842,4
Lit (-)	0,406	0,165	0,162	<,0001	68,13	881.773,9
Single sites (**)						
FLO	0,441	0,195	0,187	<,0001	25,85	1.088.977,1
SEC	0,394	0,155	0,148	<,0001	21,70	393.674,2
POA	0,579	0,336	0,324	<,0001	29,33	99.928,4
POC	0,435	0,189	0,175	<,0005	13,52	183,884,0

(*) Lit + soil: sum of litter and soil macrofauna
(+) extreme values included
(-) extreme values excluded
Lit: only litter macrofauna considered
(**) FLO (N= 109 samples), SEC (N= 120), POA (N=60),
POC (N=60): litter macrofauna, extreme values excluded)

Table 2: Values of Spearman Rank Ordered Correlation coefficients R and p-values (* significant at $p < 0,05$), N = 349 samples from FLO, SEC, POA & POC, n.s. = no significance

Fauna	Leafs	Wood >1cm	Wood <1cm	Flow, seeds & fruits	Fine litter	Roots	Total litter
Total macrofauna	0,28* p=,000*	0,18* p=,001*	n.s.	0,32* p=,000*	0,28* p=,000*	0,29* p=,000*	0,35* p=,000*
Predators							
Araneae	0,37* p=,000*	n.s.	0,12* p=,026*	0,14* p=,012*	0,42* p=,000*	0,44* p=,000*	0,45* p=,000*
Pseudoscorp.	0,34* p=,000*	n.s.	n.s.	0,23* p=,000*	0,29* p=,000*	0,24* p=,000*	0,34* p=,000*
Chilopoda	n.s.	n.s.	n.s.	n.s.	0,13* p=,015*	0,11* p=,042*	0,12* p=,030*
Opilionida	n.s.	n.s.	n.s.	n.s.	0,17 p=,002*	n.s.	n.s.
Decomposers							
Diplopoda	n.s.	n.s.	n.s.	n.s.	0,16* p=,003*	n.s	0,13* p=,019*
Isopoda	n.s.	n.s.	n.s	n.s.	n.s.	n.s.	n.s.
Social insects							
Formicidae	0,17* p=,001*	0,16* p=,002*	0,12 p=,021*	n.s.	0,15* p=,004*	0,17* p=,001*	0,21* p=,000*
Isoptera	n.s.	0,18* p=,001*	n.s.	0,27* p=,000*	n.s.	0,15* p=,005*	0,11* p=,033*
Others							
Coleoptera, adults	0,18* p=,001*	n.s.	0,12* p=,030*	0,29* p=,000*	0,29* p=,000*	0,15* p=,005*	0,27* p=,000*
Coleoptera, larvae	n.s.	n.s.	n.s.	0,22* p=,000*	0,19* p=,000*	0,11* p=,044*	0,18* p=,001*

Table 3: Levels of significance of Spearman Rank Ordered Correlations between litter stock fractions, total macrofauna and functional groups

Site	Trophic group	Leafs	Wood >1cm diameter	Wood <1cm diameter	Flowers, seeds & fruits	Fine litter	Roots	Leafs & fine litter	Wood, total	Total litter
FLO-Total	Total macrofauna	0,0148	0,0060	n.s.	n.s.	n.s.	n.s.	0,0161	0,0007	0,0011
POA-Total	Total macrofauna	0,0108	n.s.	n.s.	0,0128	0,0015	n.s.	0,0019	n.s.	0,0012
POC-Total	Total macrofauna	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
SEC-Total	Total macrofauna	0,0073	n.s.	0,0161	0,0004	n.s.	0,0317	0,0075	n.s.	0,0082
FLO-Total	Predators	0,0112	0,0156	n.s.	n.s.	n.s.	n.s.	0,0286	0,0305	0,0064
POA-Total	Predators	0,0338	n.s.	n.s.	0,0016	0,0019	0,0063	0,0023	n.s.	0,0007
POC-Total	Predators	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
SEC-Total	Predators	0,0104	n.s.	0,0376	0,0011	n.s.	n.s.	0,0271	n.s.	0,0329
FLO-Total	Decomposers	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0,0122	n.s.
POA-Total	Decomposers	0,0064	n.s.	n.s.	0,0101	0,0010	0,0377	0,0012	n.s.	0,0003
POC-Total	Decomposers	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
SEC-Total	Decomposers	0,0073	0,0320	n.s.	0,0241	n.s.	n.s.	0,0042	n.s.	0,0054
FLO-Total	Social insects	n.s.	0,0318	n.s.	n.s.	n.s.	n.s.	n.s.	0,0211	0,0236
POA-Total	Social insects	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
POC-Total	Social insects	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
SEC-Total	Social insects	n.s.	n.s.	n.s.	n.s.	0,0331	0,0492	0,0186	n.s.	0,1921

Relationships between decay rates, litterstocks and fauna biomass.

Correlation of soil fauna with decomposition rates in litterbags

During the 21 months when 8 fauna sampling events were realized two series of litterbags were exposed and correlations between soil fauna biomass and decay rates can be made using data from always 4 fauna sampling events from the period of the respective litterbag series or from all 8 events and both series significant positive correlations with decay rates were calculated for decomposers biomass (including macrofauna arthropods and earthworms) for the first and over both series ($p < 0,001$), earthworms for the second and over both series and total macrofauna for the first series ($p < 0,007$).

Multiple regression analyses on possible factors affecting the dry weight loss of the periods between the retrievals showed significance of weight loss in FLO and SEC fine mesh litterbags for termite occurrence.

Correlations of soil fauna biomass with decay rates and litter stocks

To answer one of our central questions, if mesofauna and macrofauna does have the same role in decomposition processes, the correlation between the different components of soil fauna, based on biomass and decay coefficients from the different plots and between the soil fauna and litterstock quantity was tested.

From August 1997 to February 1999 litter production was measured weekly and litterstock was taken monthly (Martius et al., see this report). From monthly values of litter stocks and total monthly litter production, the decomposition or decay coefficient was calculated for each month.

The decomposition coefficient was, on average, highest for FLO (0,059), lower for POC (0,042) and POA (0,040) and lowest for SEC (0,024); in short, very slow decomposition processes. The decay coefficients of the polyculture systems were between the primary forest and SEC.

Litterstock on the forest floor were highest in SEC (24,70 t ha^{-1}), followed by POC (16,19 t ha^{-1}) and POA (15,06 t ha^{-1}); they were lowest in the primary forest (FLO: 11,98 t ha^{-1}).

These data were correlated with the averages and median values of the total biomass of the decomposer fauna and their compartments (mesodecomposers, macrodecomposers, earthworms etc.).

Results. The correlation test with Sigmaplot, using a polynomial regression equation ($y = ax+b$; y = decay coefficient or litterstock (t ha^{-1}), x = fauna biomass (mg/m^2) resulted, that there are higher correlations (R^2) between the soil fauna biomass and the decay coefficients, than between fauna biomass and standing litterstock. The relationships were stronger using median values for fauna biomass than biomass averages. Although no significant correlations have been registered, the high correlation coefficients indicate, that there is a positive relationship between fauna biomass and decay rates and a negative one between fauna biomass and litterstock (Table 1 and 2). Clear differences can be recognized between the correlations of the mesodecomposers and macrodecomposers and the decay rates and litter stocks

Table 1: Correlations between fauna biomass and litterstock, based on averages of fauna biomass, decay rates and litterstocks

Correlation between decay coefficient and:	Coeff. a	Coeff. b	R^2	p-value
Mesodecomposers	0,0000	0,0532	0,0051	0,7749
Macroarthropods	0,0000	0,0169	0,6084	0,2200
Earthworms	0,0000	0,0064	0,8429	0,0819
Total Macrodecomposers	0,0000	0,0178	0,7921	0,1100
Total Meso- and Macrodecomposers	0,0000	0,0090	0,8304	0,0887

Correlation between litter stock and:	Coeff. a	Coeff. b	R^2	p-value
Total Mesodecomposers	-0,0034	18,7992	0,0081	0,9101
Macroarthropds	-0,0074	0,0440	0,5899	0,2320
Earthworms	-0,0070	22,5288	0,5711	0,2443
Total Macrodecomposers	-0,0040	24,9537	0,6355	0,2028
Total Meso- and Macrodecomposers	-0,0045	28,5041	0,7349	0,1427

Table 2: Correlations between fauna biomass and litterstock, based on median values of fauna biomass and averages of decay rates and litterstocks

Correlation between decay coefficient and:	Coeff. a	Coeff. b	R^2	p-value
Mesoarthropods	-0,0001	0,0924	0,2525	0,4975
Enchytraeidae	0,0005	0,0109	0,2333	0,5170
Total Mesodecomposers	-0,0001	0,0977	0,1975	0,5556
Macroarthropods	0,0000	0,0156	0,6322	0,2049
Earthworms	0,0000	0,0312	0,6100	0,1634
Total Macrodecomposers	0,0000	0,0188	0,8681	0,0683
Total Meso- and Macrodecomposers	0,0000	0,0103	0,8922	0,0554

Correlation between litter stock and:	Coeff. a	Coeff. b	R^2	p-value
Mesoarthropods	0,0161	9,2469	0,0400	0,8000
Enchytraeidae	-0,9660	22,9741	0,0628	0,7493
Total Mesodecomposers	0,0145	9,0916	0,0267	0,8366
Macroarthropods	-0,0084	27,1752	0,6881	0,1705
Earthworms	-0,0049	19,7451	0,3637	0,3969
Total Macrodecomposers	0,0041	24,3227	0,6438	0,1976
Total Meso- and Macrodecomposers	-0,0044	27,287	0,6836	0,1732

The biomass of mesodecomposers (arthropods; arthropods and enchytraeids) and decay coefficients or litterstocks, respectively was not correlated, indicated by the low values of correlation coefficients R^2 (Table 1 and 2). Much higher correlation coefficients resulted between the biomass of the macroarthropods, the sum of total macrodecomposers (arthopods and earthworms), and the total biomass of meso- and macrodecomposers versus the both litter variables (decay coefficient or litter stock). Applying the median values of macrofauna biomass the correlation values were always over R^2 = 0,6000, attaining 0,8681 (p = 0,0683) when total macrodecomposers versus decay rates were calculated, and 0,8922 (p = 0,0554), when total meso- and macrodecomposers versus the decay coefficients were calculated.
Because of some extreme values of the biomass (caused mainly by the social insects, like termites and ants) and that of litter stocks (occasionally high portions of wood fractions), the original data will treated by exclusion of such extreme values. The actual results fit well with our basic hypotheses that macrodecomposers have a key function in the decomposition processes rather higher than mesodecomposers.

Conclusions: The litterbag experiments as well as the evaluation of the biomass versus decay rates and litterstock showed, that there are strong arguments, that macrodecomposers, among them both, arthropods and earthworms, have a key function in the decomposition process of organic residues. The principal function of the macrodecomposers may be to crush up the organic residues. Only when the organic matter is reduced to small pieces or transformed to excrements and therefore physically and chemically altered, then the mesofauna (and microorganisms) can intervene efficiently within the decay process. This model fits well with our findings, that litter stock was low and the calculated decay coefficient was high, when the macrodecomposers biomass was high in a study plot. This can be shown in the figures 1and 2.
Considering the age of the four study plots, they could be ordered as a successional sequence. POA and POC are the youngest plots, carrying a 5 years old and still low secondary vegetation, and SEC about 12 year old one, and medium sized secondary forest, which seems to be actually in a transitional succession phase. The primary forest may be several hundred years old. It seems, that during the succession sequence litter stock is accumulated on these nutrient poor and highly meteorisized soils, because the decomposition processes may be not enough effective due to lower biomass of the macrofauna. Only when the secondary forest succession reaches a vegetation structure, species composition and microclimatical conditions comparable to that of the primary forest, the decomposition processes may be enhanced, leading to a reduction of litter stock, then attaining during the transformation to the primary forest similar or even slightly higher decomposition rates than they prevail in FLO.

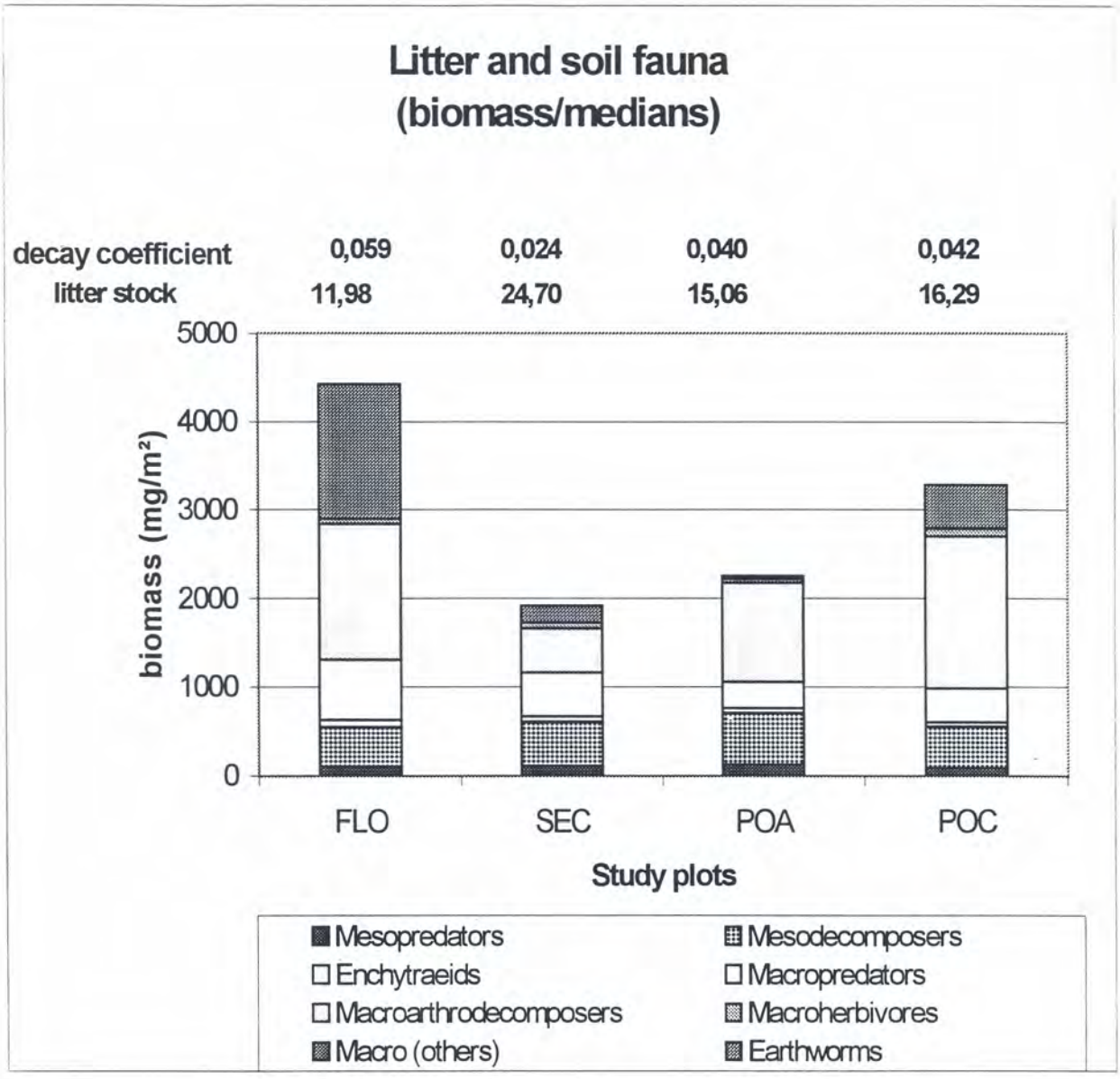


Figure 1: Median values of soil fauna biomass and indication of decay coefficients and litter stocks (t ha^{-1}) of the study plots

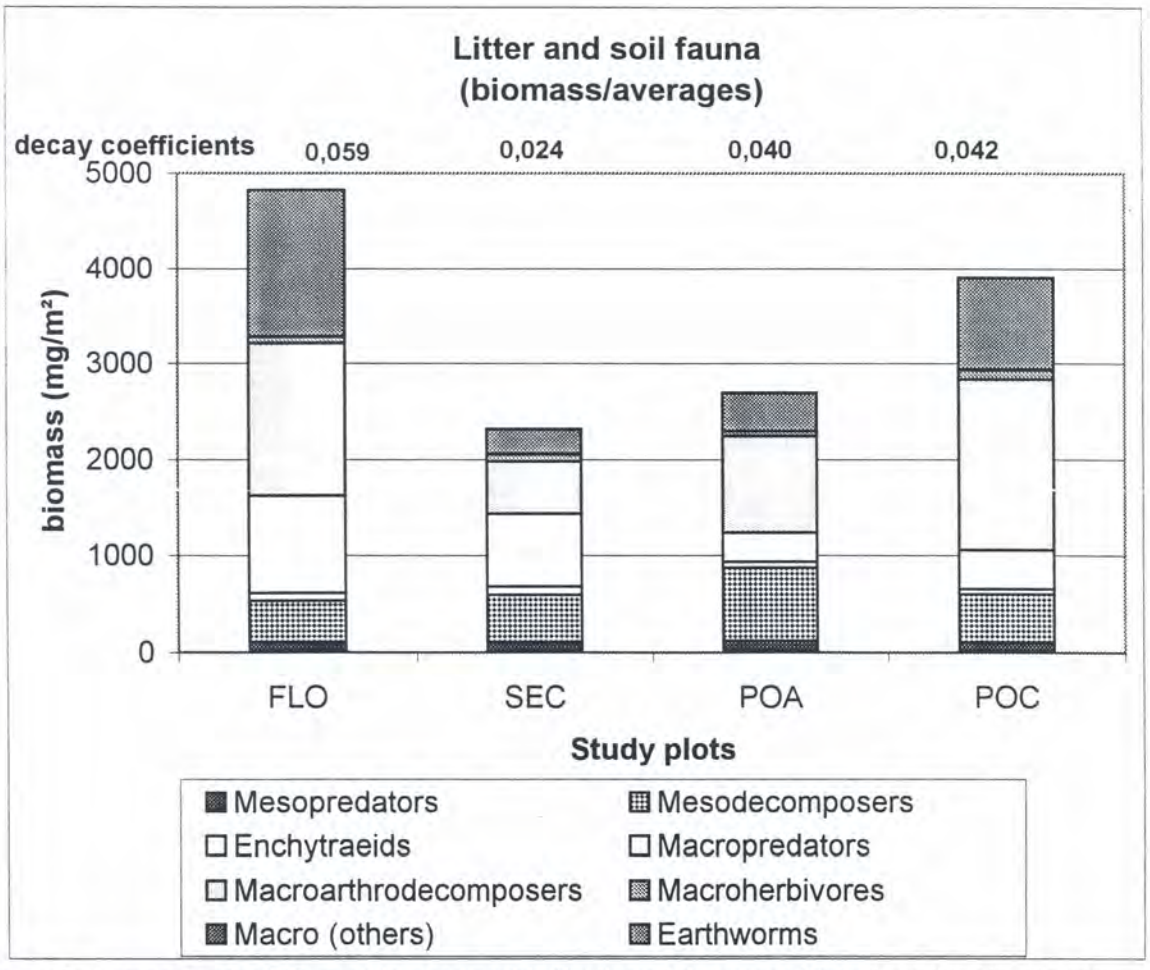


Figure 2: Averages of soil fauna biomass and indication of decay coefficients in the study plots

4. General conclusions

- The assessment of the macrofauna showed a substitution of faunal (taxonomic) and functional groups between the sites. In the primary forest, social insects (mainly termites) and earthworms had large individual numbers and biomass, whereas in the polycultures, other decomposer groups like isopods and diplopods had higher abundances and biomass.
- Strong shifts of species composition and of even higher taxonomic level (at the level of orders and families) have been recognised and species richness of several predator and decomposer groups was lower in the polyculture systems and the secondary forest, compared to the primary forest.
- Such shifts in species composition and in the reduction of number of species in the polycultures and secondary forest were paralleled to a change of the decomposition processes and correlated to an altered efficiency of decomposition of organic matter, leading to an increasing accumulation of litter from the polycultures to the secondary forest, when compared to the primary forest.
- High macrofauna biomass (including the arthropods and the earthworms) was correlated to high decay rates and low litter stocks. Corresponding results have been obtained in litterbag experiments, where decay rates were higher in litterbags when macroarthropods were not excluded.
- Mesofauna biomass was not correlated strongly with decay rates and litterstocks, indicating, that these functional groups did have other role in decomposition than the macrodecomposers, p.e. to crush up large organic materials like leaves and wood.

- Correlations were highest between total meso- and macrodecomposer biomass and decay rates, indicating, that both contribute to the decay of organic residues, but as the other test show in different manner.
- Viewing the polycultures, the secondary forest and the primary forest as a successional sequence, the results showed, that litterstocks increased from younger plots (polycultures) to the secondary forest, parallel to a decreasing decay rate. One can assume, that in more advanced successional phases (than the phase of the secondary forest), decay rate may increase again due to the increase of efficiency of decomposition of the macrofauna. Such dynamics may be characteristic for acid poor nutrient soils in the tropics and in temperate zones.

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6. Annex

Functional groups of macrofauna

Primary forest Litter & soil **Biomass (mg/m²)** **Macrofauna biomass**

Taxon	Jul'97	Sep'97	Dec'97	Mar'98	Jun'98	Sep'98	Dec'98	Mar'99	over all data			
predators	**mg/m²**	**mg/m²**	**mg/m²**	**mg/m²**	**mg/m²**	**mg/m²**	**mg/m²**	**mg/m²**	**sum**	**mean**	**stds**	**median**
Araneae	82,08	24,71	28,48	35,63	13,25	33,49	29,42	220,70	467,752	58,47	68,61	31,45
Chilopoda	218,89	142,42	1660,15	385,44	129,47	265,83	504,33	166,88	3473,422	434,18	511,92	242,36
Coleoptera (part.)	107,70	109,29	78,65	44,81	77,04	77,04	52,46	34,63	581,629	72,70	27,45	77,04
Dermaptera	0,00	0,00	0,00	0,00	15,88	39,70	0,00	0,00	55,575	6,95	14,35	0,00
Diplura	3,81	5,54	5,57	3,39	1,68	3,05	4,56	0,39	28,004	3,50	1,81	3,60
Formicidae (part.)	244,13	189,50	113,43	94,35	81,18	74,74	293,70	70,63	1161,671	145,21	86,21	103,89
Opilionida	1,98	3,33	1,07	3,59	3,02	3,29	5,85	2,87	25,001	3,13	1,38	3,15
Palpigradi	6,06	5,76	0,61	2,32	1,01	4,85	3,23	0,91	24,756	3,09	2,23	2,78
Pseudoscorpionida	76,29	99,90	154,04	46,11	17,99	51,32	41,59	11,01	498,238	62,28	46,95	48,71
Ricinulei	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,000	0,00	0,00	0,00
Scorpionida	0,00	714,24	1071,37	0,00	0,00	0,00	0,00	0,00	1785,610	223,20	424,17	0,00
Uropygi	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,000	0,00	0,00	0,00
Total	**740,93**	**1294,71**	**3113,37**	**615,65**	**340,51**	**553,32**	**935,14**	**508,03**	**8101,657**	**1012,71**	**898,21**	**678,29**

Decomposers	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	sum	mean	stds	median
Blattodea	3,71	226,18	606,38	1,75	0,00	3,69	46,71	0,19	888,612	111,08	214,60	3,70
Coleoptera (part.)	135,08	105,87	52,11	147,28	57,86	158,30	98,08	40,26	794,846	99,36	45,57	101,97
Diplopoda	426,45	235,17	114,33	47,87	572,78	114,59	184,55	61,33	1757,066	219,63	187,33	149,57
Diptera, Larvae	13,86	48,50	9,24	20,79	71,60	53,12	27,72	23,10	267,914	33,49	21,84	25,41
Formicidae (part.)	13,36	47,96	14,56	25,69	15,94	18,57	33,15	13,56	182,793	22,85	12,28	17,26
Gryllidae	0,00	0,15	0,07	0,00	0,42	0,00	0,61	0,00	1,240	0,16	0,23	0,03
Isopoda	250,39	196,89	181,10	694,57	114,97	390,61	134,94	333,82	2297,301	287,16	189,90	223,64
Isoptera	864,80	525,15	684,51	925,86	519,23	588,37	537,70	589,81	5235,430	654,43	158,56	589,09
Mollusca	0,00	0,00	0,00	0,00	1039,32	28,29	28,29	28,29	1124,198	140,52	363,44	14,15
Trichoptera	123,85	5,08	0,00	0,64	1,59	2,54	1,91	0,95	136,555	17,07	43,17	1,75
Total	**1831,50**	**1390,95**	**1662,29**	**1864,44**	**2393,71**	**1368,09**	**1093,65**	**1091,33**	**12685,955**	**1585,74**	**442,90**	**1626,62**

Herbivores	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	sum	mean	stds	median
Coleoptera (part.)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,000	0,00	0,00	0,00
Formicidae (part.)	24,05	9,54	28,56	10,29	14,37	2,83	1,32	14,60	105,565	13,20	9,47	12,33
Hemiptera, adults	38,80	13,10	4,85	18,92	12,13	9,70	7,28	4,37	109,129	13,64	11,23	10,91
Hemiptera, larvae	3,55	2,84	7,81	0,95	2,13	4,26	4,73	0,71	26,988	3,37	2,30	3,20
Homoptera, adults	57,29	13,25	8,57	15,98	2,73	10,13	7,02	3,51	118,482	14,81	17,74	9,35
Homoptera, larvae	11,07	17,82	10,53	11,34	8,64	7,29	12,69	9,99	89,348	11,17	3,16	10,80
Lepidoptera, larvae	2,86	17,15	28,58	11,43	2,86	20,01	11,43	2,86	97,176	12,15	9,39	11,43
Thysanoptera	1,15	0,75	0,72	0,78	0,52	0,61	0,58	0,06	5,168	0,65	0,31	0,66
other Orthoptera	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,000	0,00	0,00	0,00
Total	**138,78**	**74,44**	**89,63**	**69,69**	**43,37**	**54,83**	**46,04**	**36,09**	**551,856**	**68,98**	**33,47**	**62,26**

Other Groups	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	mg/m²	sum	mean	stds	median
Coleoptera (part.)	15,23	0,00	6,71	3,05	0,00	2,64	0,21	1,98	29,828	3,73	5,16	2,31
Formicidae, adults (part.)	0,14	0,86	36,18	0,00	0,21	2,07	13,38	0,73	53,564	6,70	12,73	0,80
Total	**15,37**	**0,86**	**42,89**	**3,05**	**0,21**	**4,71**	**13,59**	**2,71**	**83,393**	**10,42**	**14,30**	**3,88**

Macrofauna total	2728,58	2760,97	4908,17	2552,83	2777,80	1970,95	2087,42	1638,16	21422,861	2677,86	995,60	2039,70

Table 3: Percentage of the most important earthworm species at the four study plots at the EMBRAPA site based on individual numbers (for details see Table 4 in the Annex)

Species	FLO	SEC	POA	POC
A. amazonicus	11 %	10 %	12 %	22 %
P. corethrurus	0 %	2 %	12 %	5 %
Rh. contortus	31 %	17 %	0 %	14 %
Rh. priollii	6 %	5 %	12 %	5 %
U. brasiliensis	20 %	34 %	33 %	10 %
T. dianaea	25 %	28 %	30 %	33 %
Rest	7 %	6 %	1 %	11 %

When investigating the species composition based on biomass values (Table 5 in the Annex; Fig. 3 - 6), the differences between the four plots are even smaller: The large *Rhinodrilus* species (especially *Rh. priollii*) are responsible for 88 (SEC), 92 (POC), 94 (POA) and 97 (FLO) % of the total biomass, respectively. Within this genus it seems that *Rh. priollii* is more adapted to the polyculture situation since on FLO and SEC it shows a percentage similar to that of *Rh. contortus*, whereas on POC and, especially, on POA it is highly dominant. This leads to an extremely steep dominance rank curve on POA. No other species reaches more than 5 %. Only on POA *P. corethrurus* had a measurable biomass (1 %).

Juvenile/adult age ratio

If all earthworms are assessed together, the juvenile to subadult to adult ratio is 72 to 13 to 15 % based on numbers and 28 to 14 to 58 % based on biomass, indicating the much higher weight of the adult worms (Fig. 7 and 8). Despite the fact that biomass is the ecologically more important parameter, for reasons of convenience (comparability with literature data) only results based on numbers are presented here. However, the average numbers are quite different when the various species (not distinguished between study plots) are compared individually (Table 6). These numbers reflect probably different life strategies and maybe methodological problems (e.g. the relatively small juveniles of *P. corethrurus* might be underestimated since they are more abundant in the macro-sonda samples than in the formalin samples presented here).

Table 6: Percentage of the three age stages for the most important earthworm species found at the four EMBRAPA plots so far

Species	Juvenil	Subadult	Adult
A. amazonicus	66 %	8 %	26 %
P. corethrurus	40 %	0 %	60 %
Rh. contortus	72 %	14 %	14 %
Rh. priollii	52 %	4 %	44 %
U. brasiliensis	44 %	1 %	55 %
T. dianaea	91 %	4 %	5 %

Concerning the age ratio at the four study plots (Table 7; Fig. 9 - 12) it seems that the juvenile number (including subadults) is higher on FLO and POC compared to POA and SEC. The same tendency was already found concerning biomass. Except of FLO (where the total biomass of juveniles seems to be higher in the wet season (November – April)) no correlation between number and biomass of age classes and climatic variables is visible.

Correlation between climatic data and earthworm biomass

Based on an idea of C. Martius, the biomass of the all earthworms on the four study plots was correlated with rainfall, humidity, soil temperature and litter temperature 3, 5, 10 and 30 days before the actual sampling dates (Table 8 in the Annex). Nearly no correlation was found: Only the rainfall immediately (i.e. three days) before sampling on POA and soil temperature at any time (increasing coefficient from 3 to 30 days) again on POA seems to be positively correlated with earthworm biomass. This result is explainable due to the relative homogenous climatic conditions on the other plots (especially FLO) and, more important, due to the long life-cycle, large body size and high mobility of these organisms.

4. Conclusions and outlook

The most important results gained so far when investigating the earthworms of the four EMBRAPA plots can be summarised as follows (cf. Table 8):

- the earthworm biocoenosis of the primary forest (FLO) is comparable to those described from other (neotropical) rain forest sites
- some of the species seem to be confined to the region of Manaus, whether others are widely distributed in Amazonia
- the number at all four sites is quite low whereas the biomass is in the expected range
- the variability is high, especially on the two polyculture sites (POA, POC)
- in general, the four sites are not completely different concerning their earthworm biocoenosis (e.g. the species number is comparable):
  - the biomass on FLO (and partly POC) is higher than on POA and SEC
  - the same tendency is visible concerning the juvenile/adult ratio;
  - the species composition is more similar on FLO / SEC than on POA / POC
- the amount of peregrine species (*P. corethrurus*) is 0 % on FLO and 12 % on POA with POC and SEC in between
- a correlation between climatic parameters (litter temperature and, partly, rainfall) and earthworm biomass was only found (as expectable) on POA.

Table 8: Summary of the most important data describing the earthworm biocoenosis at the EMBRAPA site (* = data including the values from macro-sonda samples)

Parameter	FLO	SEC	POA	POC
Abundance [Ind/m^2] *	2.8 (16.2)	1.6 (11.7)	1.1 (12.0)	2.5 (14.5)
Variance	80 %	85 %	81 %	115 %
Biomass [FW/m^2]	15.6	2.6	4.0	9.6
Variance	68 %	79 %	205 %	122 %
Number of species	7	8	5	8
Juvenile/adult ratio [%]	81 : 19	64 : 36	67 : 33	77 : 23
Endemic/peregrine species ratio [%]	100 : 0	98 : 2	88 : 12	95 : 5

The reasons for the observed distribution pattern in time and space are not yet clear. However, the high biomass of earthworms, which can be as high as that of all other soil invertebrates together, indicates that they play a key role in ecological soil functions at the EMBRAPA sites. Similar conclusions have already been drawn by Römbke & Verhaagh (1992) and Fragoso & Lavelle (1995) who emphasised their important (direct or indirect) influence on the decomposition process. In contrary, the low biomass values (partly together with the changed species composition) indicate that this role might be impeded on SEC and, especially, POA plots. The intermediate situation at POC is probably due to two facts:

- this plot is separated from the primary forest only by a unpaved road;
- due to the closed BLÄTTERDACH the abiotic conditions are more favourable.

There are still some open questions which have to be assessed when all data are availabie:

- the taxonomic investigation has to be completed
- the various species have to be classified according to their ecological role
- the correlation between earthworm biomass and litter stock and/or decomposition rates should be clarified in detail
- in order to clarify the role of earthworms their respiration has been measured but the data is still under investigation

Finally, these data will be used to model the specific contribution of these organisms to the decomposition of the organic matter, and on the importance of these processes for the nutrient supply to the plants.

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Acknowledgements
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6. Annex
See following pages

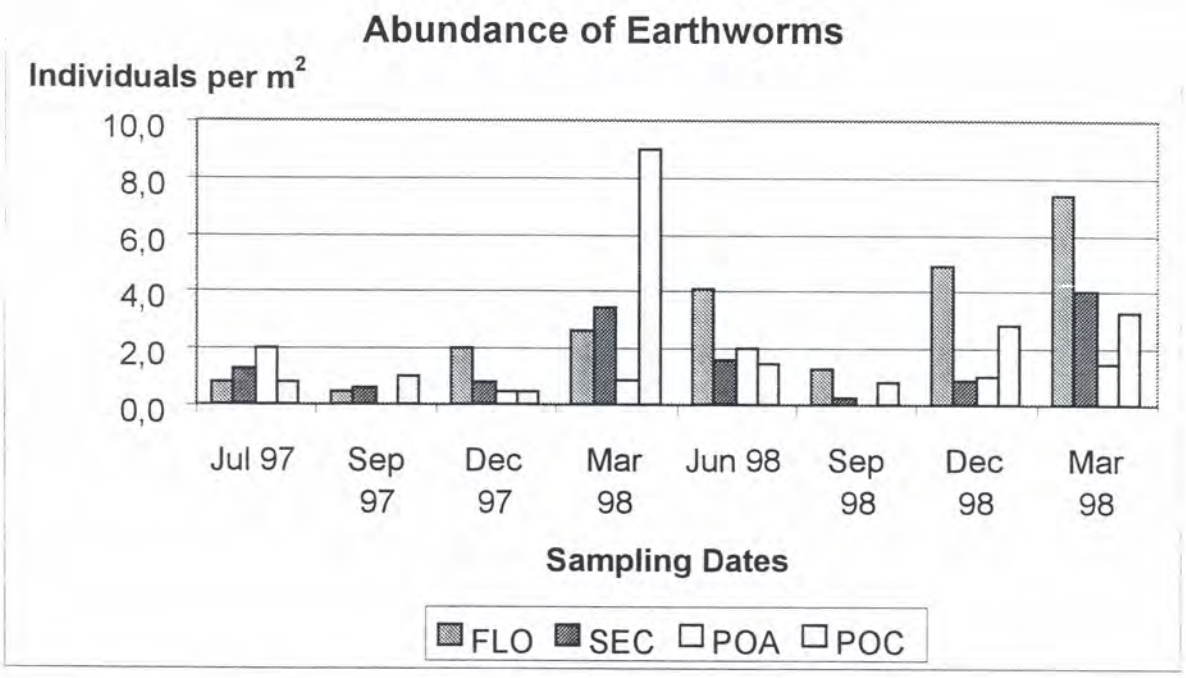

Fig. 1: Abundance [ind/m^2] of earthworms in the four study plots (FLO, SEC, POA, POC) at the eight sampling dates

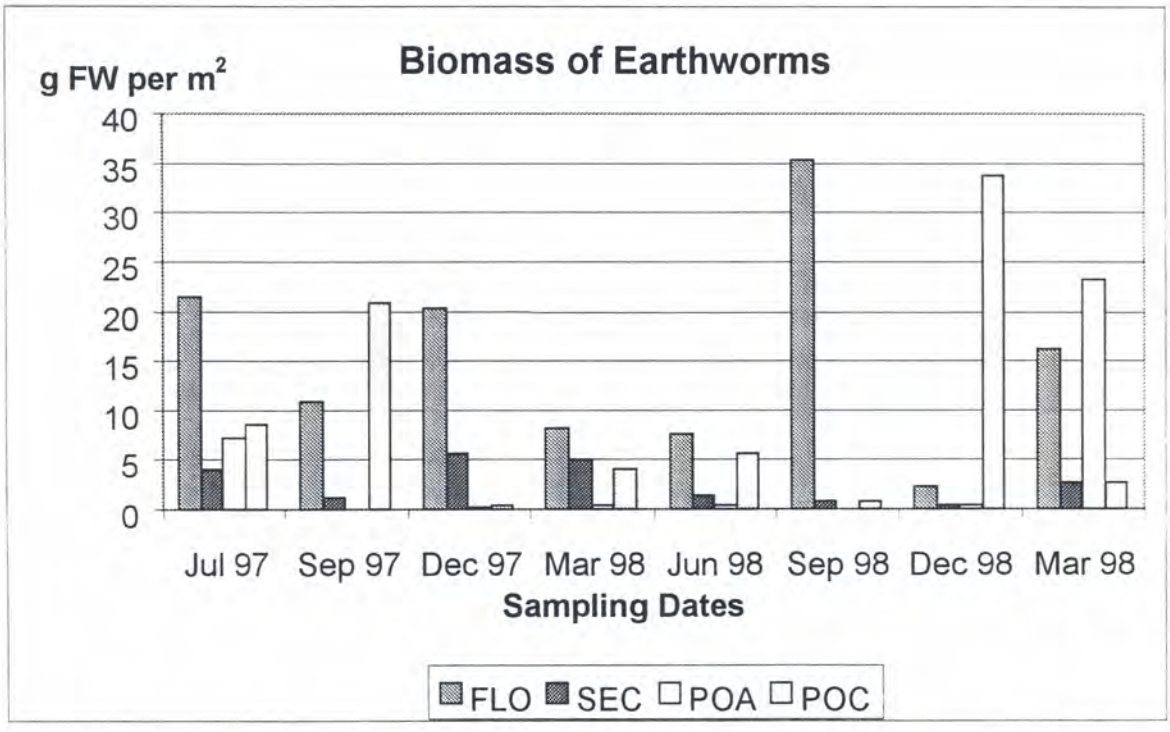

Fig. 2: Biomass [g fresh weight /m^2] of earthworms in the three study plots (FLO, SEC, POA, POC) at the eight sampling dates

Table 4: Percentage of the earthworm species based on numbers on the four study plots

FLO	Individuals	Individuals/m²	%
R. contortus	50.00	6.25	31%
T. dianaea	41.00	5.13	25%
U. brasiliensis	32.00	4.00	20%
A. amazonius	17.00	2.13	11%
R. priollii	10.00	1.25	6%
Andiorrhinus sp.	7.00	0.88	4%
Rhinodrilus sp.	4.00	0.50	2%
P. corethrurus	0.00	0.00	0%
Total	161.00	20.13	100%

POA	Individuals	Individuals/m²	%
U. brasiliensis	11.00	2.75	33%
T. dianaea	10.00	2.50	30%
A. amazonius	4.00	1.00	12%
P. corethrurus	4.00	1.00	12%
R. priollii	4.00	1.00	12%
R. contortus	0.00	0.00	0%
Rhinodrilus sp.	0.00	0.00	0%
Andiorrhinus sp.	0.00	0.00	0%
Total	33.00	8.25	100%

POC	Individuals	Individuals/m²	%
T. dianaea	24.00	6.00	33%
A. amazonius	16.00	4.00	22%
R. contortus	10.00	2.50	14%
U. brasiliensis	7.00	1.75	10%
Andiorrhinus sp.	5.00	1.25	7%
P. corethrurus	4.00	1.00	5%
R. priollii	4.00	1.00	5%
Rhinodrilus sp.	3.00	0.75	4%
Total	73.00	18.25	100%

SEC	Individuals	Individuals/m²	%
U. brasiliensis	34.00	4.25	34%
T. dianaea	28.00	3.50	28%
R. contortus	17.00	2.13	17%
A. amazonius	10.00	1.25	10%
R. priollii	5.00	0.63	5%
P. corethrurus	2.00	0.25	2%
Rhinodrilus sp.	2.00	0.25	2%
Andiorrhinus sp.	1.00	0.13	1%
Total	99.00	12.38	100%

Table 5: Percentage of the earthworm species based on biomass on the four study plots

FLO	FW	FW/m²	%
R. contortus	237,68	59,42	48%
R. priollii	207,29	51,82	42%
Rhinodrilus sp.	33,98	8,49	7%
T. dianaea	8,03	2,01	2%
U. brasiliensis	4,71	1,18	1%
A. amazonius	1,32	0,33	0%
Andiorrhinus sp.	0,12	0,03	0%
P. corethrurus	0,00	0,00	0%
Total	493,13	123,28	100%

POA	FW	FW/m²	%
R. priollii	119,57	29,89	94%
U. brasiliensis	3,11	0,78	2%
T. dianaea	2,70	0,68	2%
P. corethrurus	0,82	0,20	1%
A. amazonius	0,74	0,18	1%
R. contortus	0,00	0,00	0%
Rhinodrilus sp.	0,00	0,00	0%
Andiorrhinus sp.	0,00	0,00	0%
Total	126,93	31,73	100%

POC	FW	FW/m²	%
R. priollii	191,44	47,86	62%
Rhinodrilus sp.	47,15	11,79	15%
R. contortus	47,06	11,77	15%
T. dianaea	12,09	3,02	4%
U. brasiliensis	6,39	1,60	2%
A. amazonius	2,74	0,69	1%
P. corethrurus	1,19	0,30	0%
Andiorrhinus sp.	0,04	0,01	0%
Total	308,10	77,02	100%

SEC	FW	FW/m²	%
R. contortus	32,18	8,04	39%
R. priollii	25,17	6,29	30%
Rhinodrilus sp.	15,95	3,99	19%
T. dianaea	4,08	1,02	5%
U. brasiliensis	4,03	1,01	5%
A. amazonius	1,07	0,27	1%
P. corethrurus	0,09	0,02	0%
Andiorrhinus sp.	0,00	0,00	0%
Total	82,57	20,64	100%

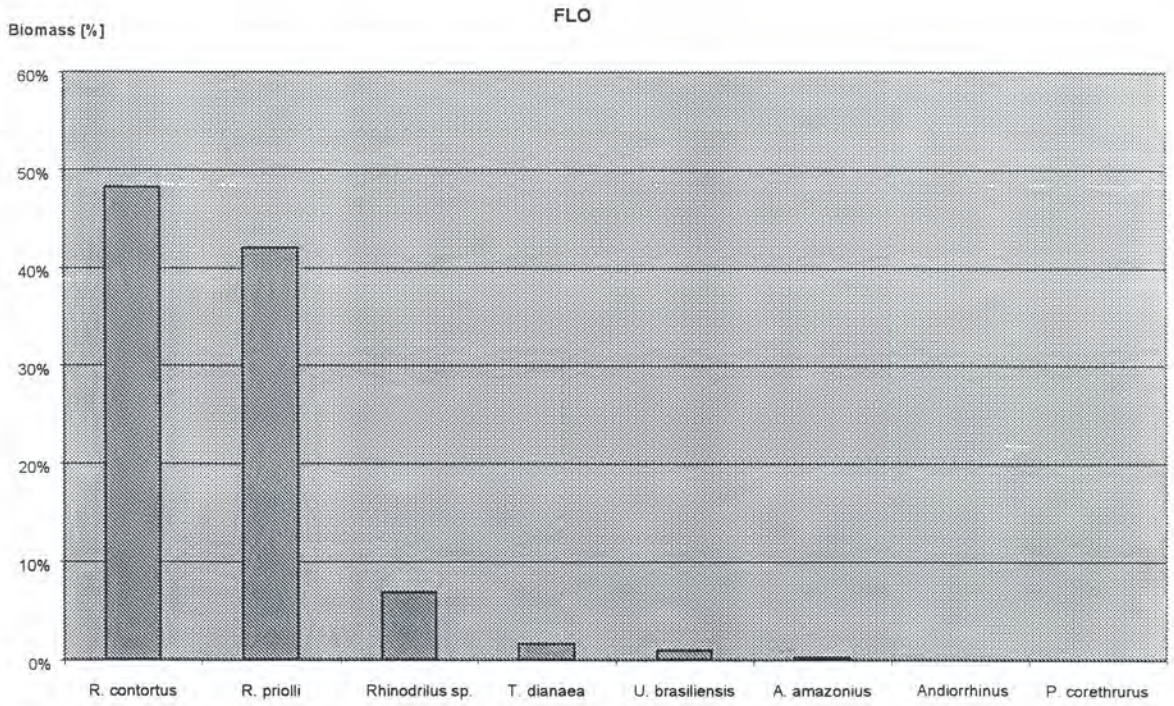

Fig. 3: Percentage of the earthworm species at the FLO study plot based on biomass data

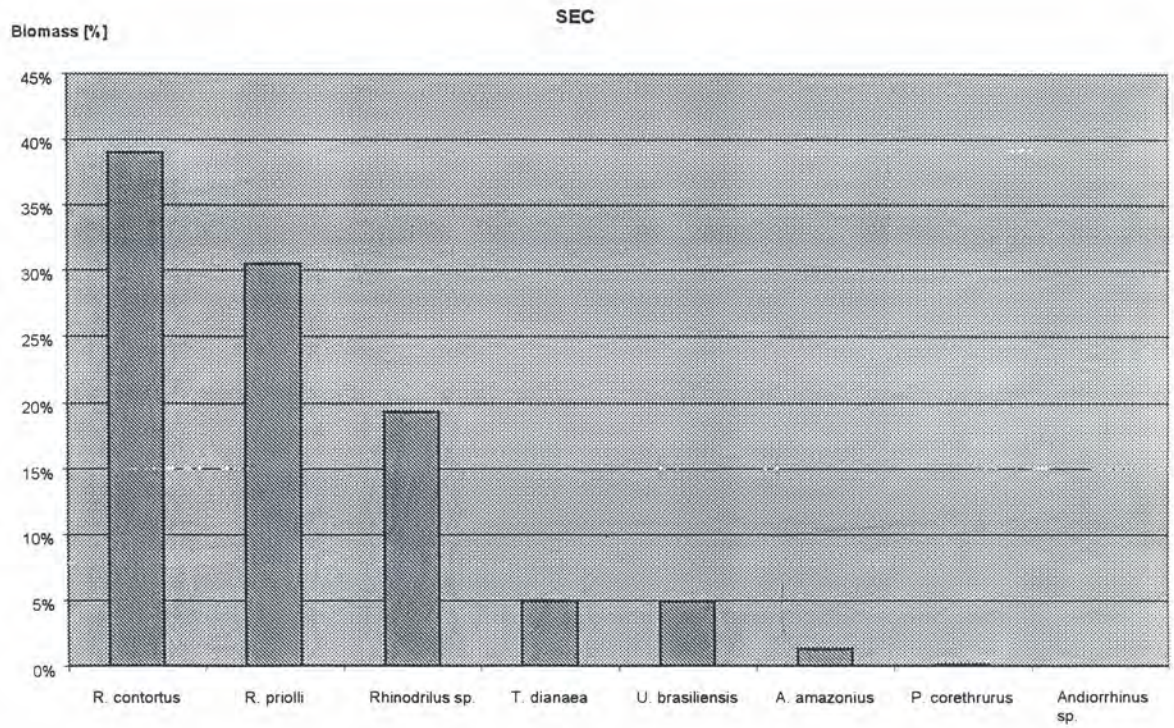

Fig. 4: Percentage of earthworm species at the SEC study plot based on biomass data

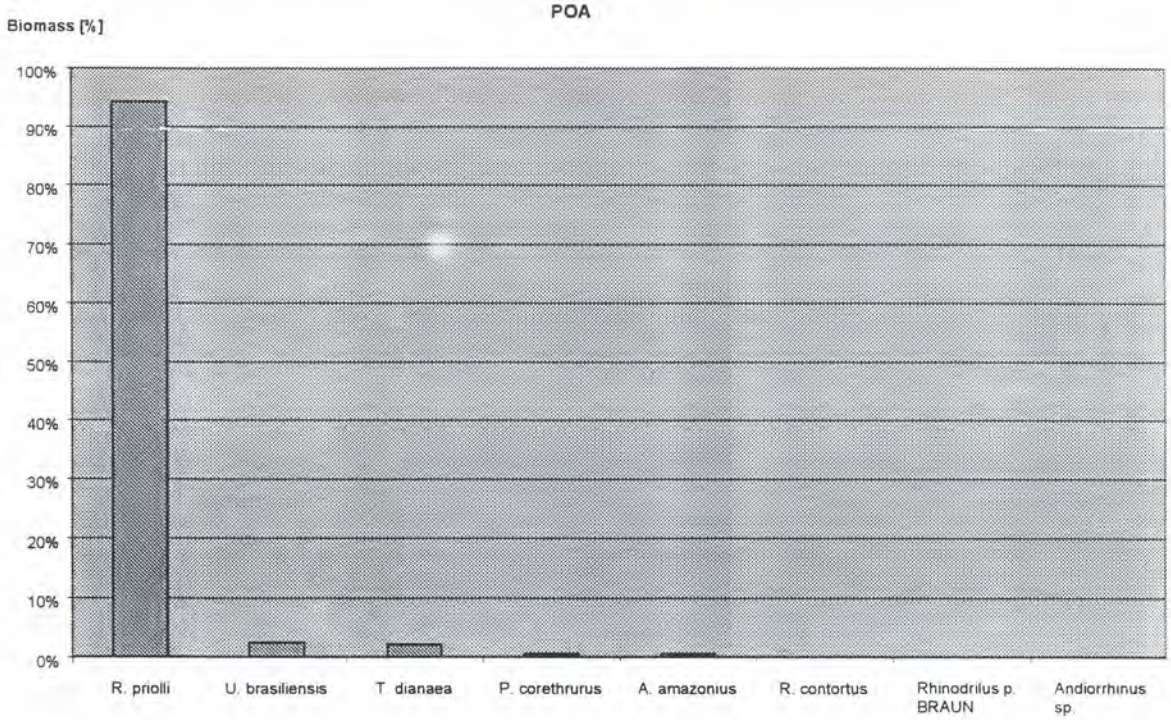

Fig. 5: Percentage of earthworm species at the POA study plot based on biomass data

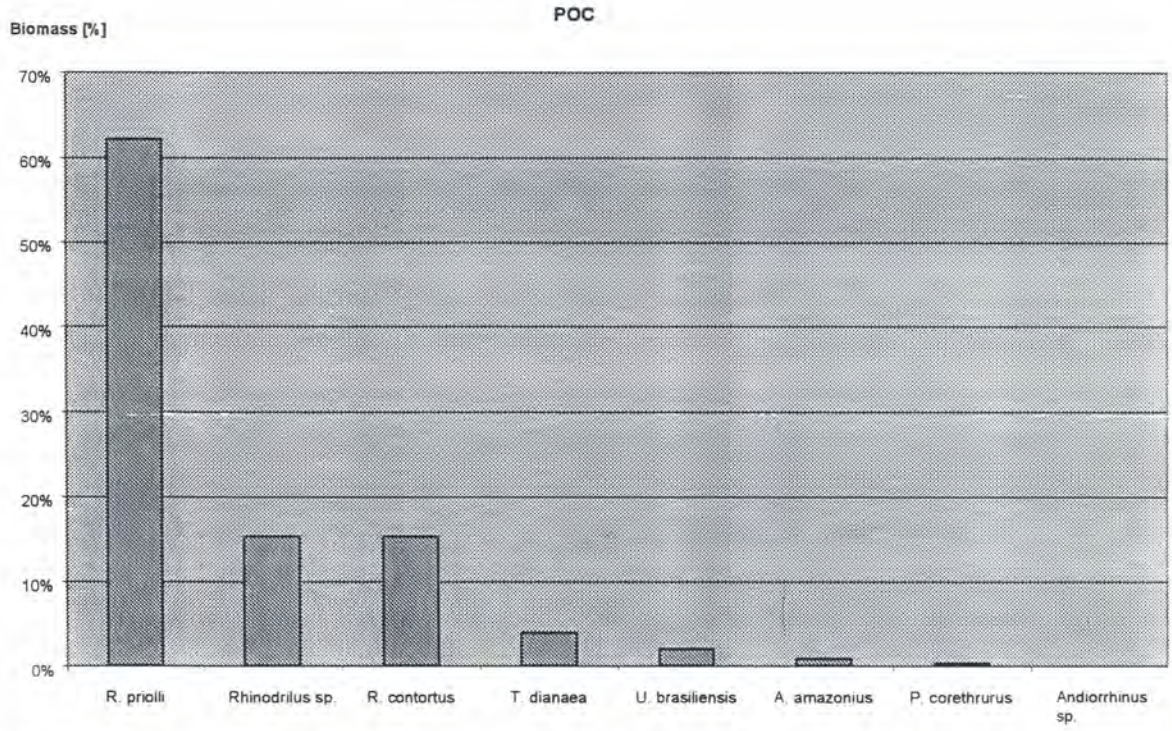

Fig. 6: Percentage of earthworm species at the POC study plot based on biomass data

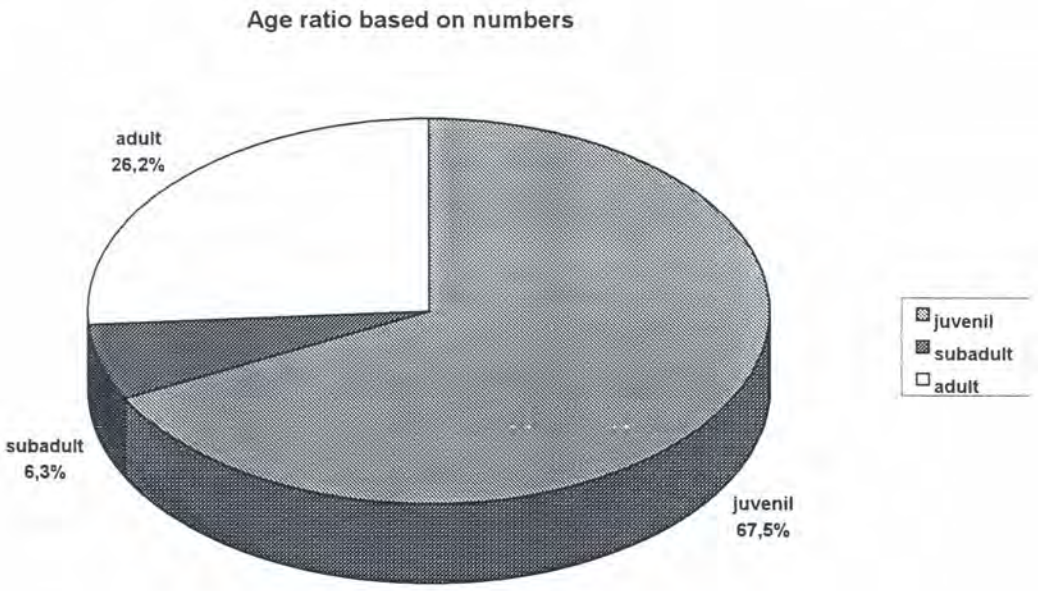

Fig. 7: Age ratio of all earthworms in the four study plots (FLO, SEC, POA, POC) at the eight sampling dates based on numbers

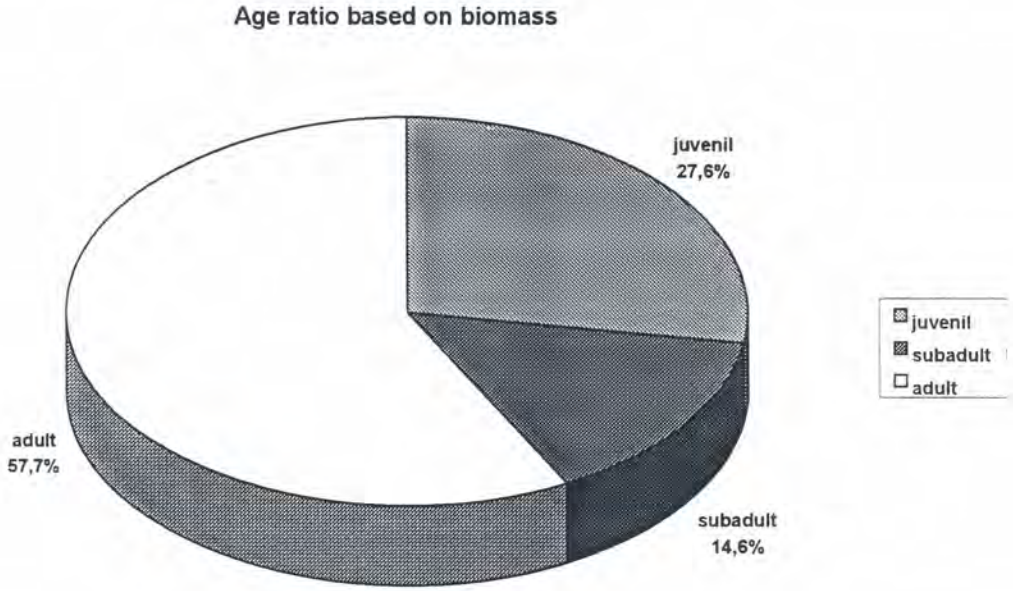

Fig. 8: Age ratio of all earthworms in the four study plots (FLO, SEC, POA, POC) at the eight sampling dates based on biomass

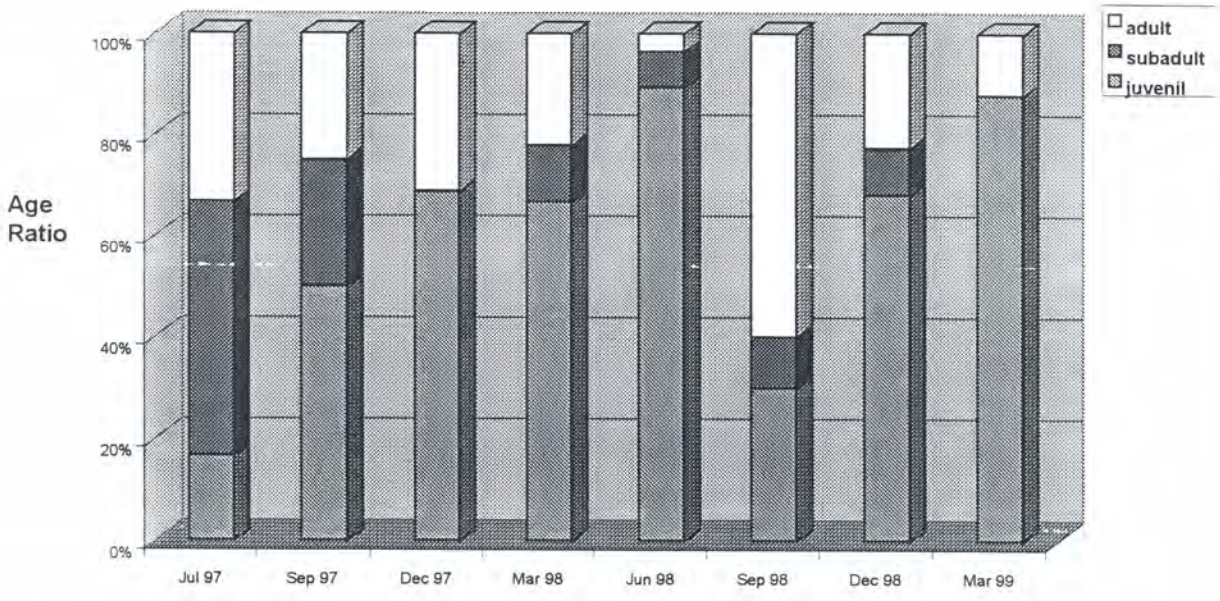

Fig. 9: Age ratio of all earthworms in plot FLO at the eight sampling dates based on numbers

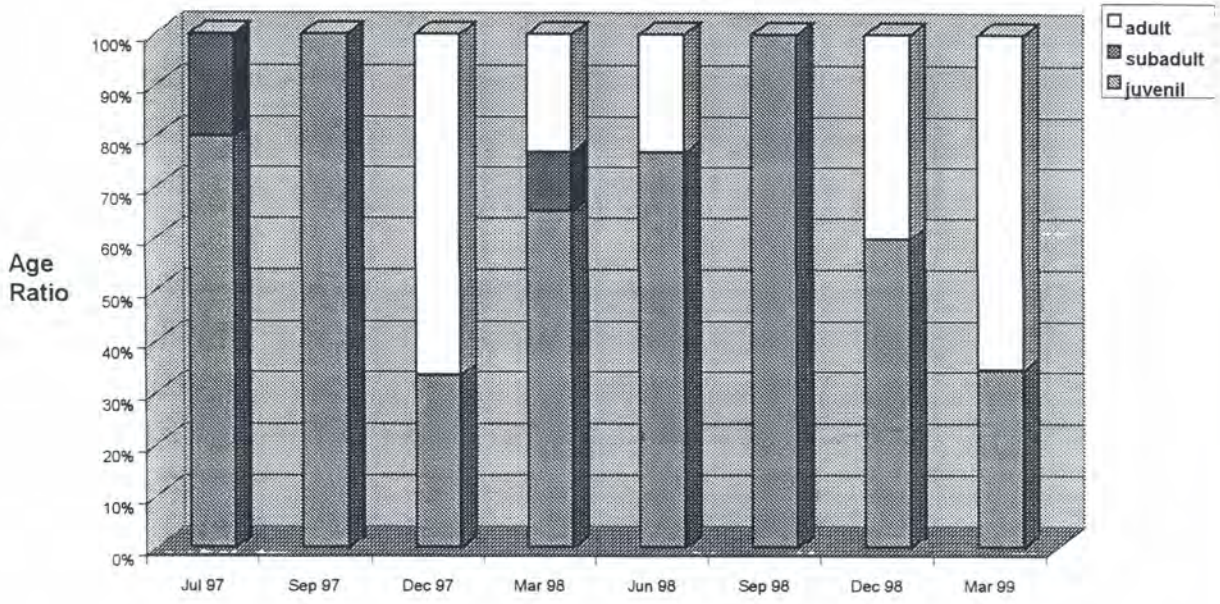

Fig. 10: Age ratio of earthworms in plot SEC at the eight sampling dates based on numbers

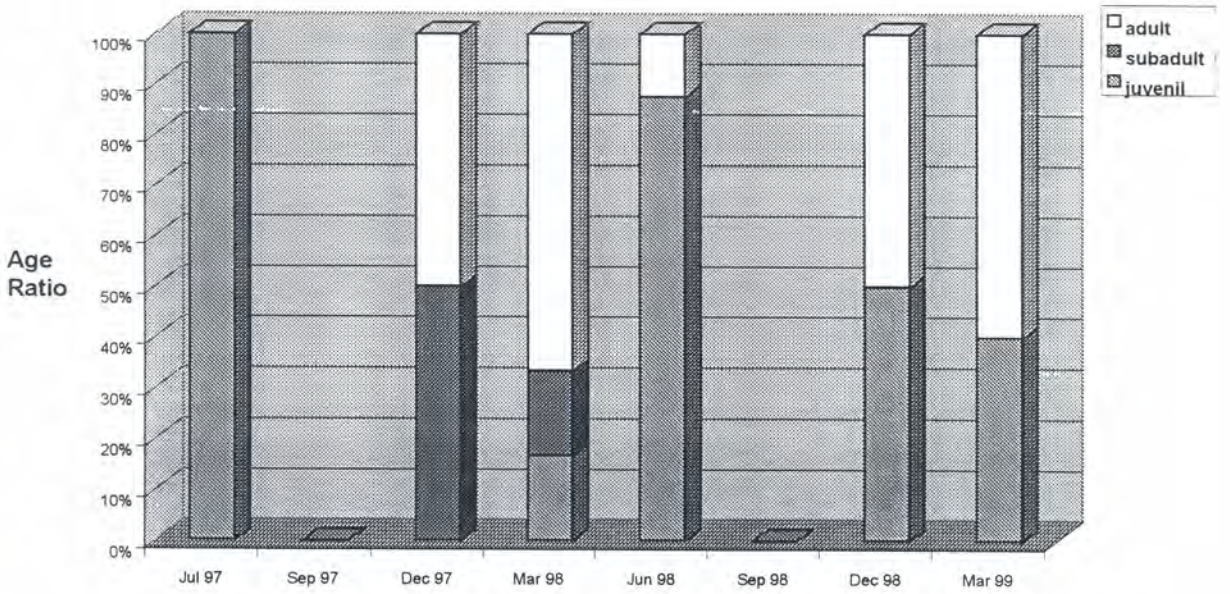

Fig. 11: Age ratio of earthworms in plot POA at the eight sampling dates based on numbers

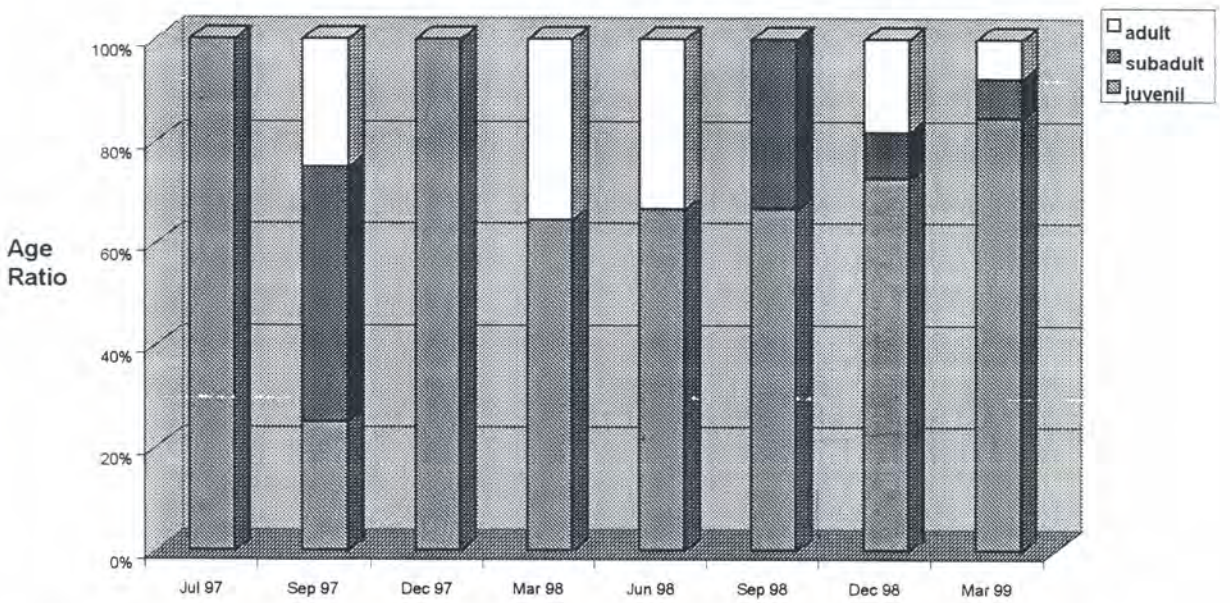

Fig. 12: Age ratio of earthworms in plot POC at the eight sampling dates based on numbers

Table 8: Correlation factors between various climatic parameters and earthworm biomass at the four study plots.

rainfall

correlation coefficient

days before sampling	3	5	10	30
FLO	0,221	0,006	-0,348	-0,318
POA	**0,722**	0,622	0,454	0,510
POC	-0,294	-0,053	0,302	-0,079
SEC	-0,361	-0,462	-0,271	0,119

humidity

correlation coefficient

days before sampling	3	5	10	30
FLO	0,293	0,502	0,504	0,499
POA	0,109	0,460	0,513	0,422
POC	0,616	0,616	0,621	0,394
SEC	-0,350	-0,135	-0,156	-0,419

soil temperature

correlation coefficient

days before sampling	3	5	10	30
FLO	0,036	0,131	0,189	-0,058
POA	-0,687	**-0,774**	**-0,872**	**-0,888**
POC	0,257	0,046	-0,041	0,438
SEC	0,310	0,223	0,282	0,396

litter temperature

correlation coefficient

days before sampling	3	5	10	30
FLO	-0,172	-0,076	0,140	-0,158
POA	-0,483	-0,493	-0,521	-0,638
POC	0,245	0,146	-0,146	-0,130
SEC	0,288	0,192	0,263	0,489

Microdrili: Enchytraeidae, Naididae and Tubificidae

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1. Introduction

Enchytraeidae are known to be an important group of soil animals in temperate regions of the world but their contribution to ecosystematic soil functions, especially litter decomposition, in the humid tropics remains largely unexplored. Therefore, as part of the SHIFT project ENV 52 "Soil Fauna and Litter Decomposition" the species composition, abundance and biomass of these organisms have *been determined in a polyculture forestry plantation* and in plots of nearby secondary and primary forest in central Amazonia since 1997. The aim of the project is to study the regeneration and better use of already degraded areas, to diminish the human impact on primary rain forest in Amazonia. The basic hypothesis of all investigations within this project is that soil fauna (e.g. enchytraeids) and micro-organisms are extremely important for the maintenance of „healthy" (functional) nutrient cycles at these plots. In particular the following questions were investigated:

- number of species and species composition of the microdrilid biocoenosis
- number and biomass of these worms of the four study plots
- juvenile/adult age ratio
- the correlation between various climatic data and enchytraeid biomass.

Some results of these investigations have been published already (Römbke & Meller 1999). Originally the studies focussed only on enchytraeids since other microdrilid families like Naididae or Tubificidae were not expected to occur in these terrestrial habitats (they were considered to be aquatic). Due to their frequent occurrence and high species number they were included in the project, but the microdrilid data are not fully assessed yet.

2. Study sites and methods

Study sites

Study sites were four plots of three different forest systems - one plot of 40 x 40 m in a primary forest (FLO), one plot of 40 x 40 m in a nearby secondary forest (growing since 1984, SEC) and two plots of 32 x 48 m large polycultures (POA, POC), where 4 different tree species of commercial use have been planted in rows. In the polyculture plots the tolerated secondary vegetation (mainly *Vismia* spp., Guttiferae) still dominated the stand and especially the litter production (Beck et al. 1998; Höfer et al. 1999).

Microdrilid sampling, determination and biomass measurement

Microdrilids were sampled quarterly within the standard sampling program of the main project using a soil corer (diameter: 6.4 cm). In the field the samples were differentiated in 2 depth (litter-layer including the root-map and soil 0 - 5 cm). In total, 120 samples were taken per date: POA and POC 10 samples each; SEC and FLO 20 samples each. The microdrilids were collected from litter or soil by a wet-extraction-method (developed by Graefe; Römbke 1995). Subsequently the enchytraeids were identified in vivo immediately whereas naidids and tubificids were determined after fixation in EtOH.

Since up to now nearly no ecological studies on microdrilids have been performed in the tropics, some methodological details will be given here. In general, sampling and extraction is quite similar in comparison to ecological studies in temperate regions. In case a laboratory (including air condition) is provided within a short distance from the study site nearly no differences occur. But even if such a laboratory is not at hand, the investigation of microdrilids is possible. In such a case, a temperature range of 15 – 25 °C has to be secured during the transfer of the cooled samples to a laboratory. For example, in this project cooled samples were sent to Germany twice, but since such a transport takes only four to six days a normal treatment (extraction and species determination) was performed. Cooled samples should be stored not longer than one week. Microdrilids from the EMBRAPA site where the soil temperature fluctuates usually between 20 and 30 °C are very sensitive against temperatures below approximately 10 and above 30°C.

Usually, a soil corer (the diameter should be between approximately 5 and 7 cm), a plastic-hammer (especially in the dry season), a knife, labelled plastic bags (1 L) and a cooling container is all what was needed in the field. Due to the extreme climatic conditions a well organised preparation (e.g. pre-labelling) was necessary to minimise the time between taking the samples and storing them in the cooling device.

The wet extraction was started as quick as possible. As a first step the fresh weight of all litter samples was determined. Afterwards, the samples were filled into sieves which were placed into bowls containing water. The samples in the sieves were completely under the water surface, but the bottom of the sieves should not reach the bottom of the bowls. To ensure a high recovery of microdrilids from the samples, the extraction time of soil was approximately 3 days at 22 ± 3 °C (20 – 22 °C is optimal). The time could be modified if, e.g. in the dry season, the overall number of individuals in a sample was close to zero. At the end of the extraction time a small amount of water together with the suspended soil was transferred to a petri dish. After a waiting period of a few minutes up to one hour the suspended particles had been settled down and the water was clear. The microdrilids were collected out of the petri dish under a binocular using a softsteel forceps. The microscopic identification of the enchytraeids (including separation of the other families) were done within hours, because the animals died relatively quickly in water. If the worms moved to fast on the slide, they could be anaesthetised with CO_2 (using a drop of mineral water). Microdrilids can be preserved for further studies (e.g. species descriptions) in 70% EtOH. However, in the case of enchytraeids the preservation is accompanied by a loss of visible morphological details. Selected animals can be coloured and mounted individually on object slides, but this procedure is very time-laborious and no detailed description is available in the literature (Beylich, pers. comm.).

In addition to the soil and litter samples microdrilids were extracted from litterbags using a Berlese extraction apparatus. In general, the litterbag samples were handled in the same way as samples coming from a soil corer (see Chapter 4). Nearly no microdrilids were found in other samples (e.g. in macro-sonda or Berlese samples) due to the small size of these worms.

Identification of the microdrilids followed a site-specific key, prepared for the EMBRAPA site based on information from the literature and the INPA collection. No review on microdrilid taxonomy from the Manaus region (or any other humid tropical site) is available, despite the fact that several individual species were described (e.g. Righi 1978). Currently some of the enchytraeid species are reviewed taxonomically (Schmelz & Römbke 2000). In addition, several new naidid and tubificid species were described recently (Collado & Schmelz 2000a,b,c). In order to facilitate this taxonomic work, several enchytraeid and naidid species are bred in laboratory cultures (mainly at the University of Osnabrück, Germany; partly at ECT GmbH, Flörsheim, Germany). Due to these uncertainties, most of the ecological results presented here will focus on the genus level. In the case of naidids and tubificids, no distinction beyond the total number will be made. Type material of all newly described species will be stored in the collection of INPA (Manaus). All other worms extracted from the soil and litter samples were discarded.

The determination of the biomass of these very small and quickly dehydrogenated worms is very difficult. Therefore, the following procedure was performed (only for enchytraeids): some of the larger individuals (especially adult worms of the genus *Guaranidrilus*) were weighed directly. The biomass of all other enchytraeid species was estimated by using values previously determined for European species of the same size. Finally, the fresh weight was converted to dry weight by using the factor of 15 % (Axelsson et al. 1984). Statistical calculations, partly done using Excel, are not finished yet..

Results and Discussion

Species number and composition

After eight sampling dates in the period from July 1997 to March 1999, the following results can be presented: The number of microdrilid species appears to be relatively high (approx. 30; Table 1). Most of the enchytraeid species belong to the mainly neotropical genera *Guaranidrilus* (5) and *Hemienchytraeus* (5). Species of genera known from the Northern Hemisphere like *Achaeta sp.* (4) and *Enchytraeus sp.* (2) were also found. Unfortunately, the type material of the only enchytraeid species described from the region of Manaus (an inundation forest (Varzea)), *H. solimoensis* (Righi 1978), was destroyed during storage in the collection of the INPA (Manaus). At least one species could not assigned to an established genus so far. With one (or two ?) exceptions, none of the species found at the site have been described scientifically. The enchytraeid fauna seems to be

relatively divers in comparison to soils of temperate regions. Unfortunately, no data from tropical sites are available in such detail (some Indian studies are not checked so far).
At least twelve species of other microdrile oligochaete families (mainly from the genus *Pristina* (Naididae) as well as several Tubificidae) were found in the four study plots (Collado & Schmelz 2000a,b,c). Only three of them were known to science before. This finding is very surprising because species of these families are considered to be confined to aquatic habitats (or at least like *Dero multibranchiata* to semi-aquatic sites like inundation forests; Irmler 1989). Except of some isolated information like the occurrence of the naidid species *Pristinella jenkinae* (Coates & Stacey 1994) in a Peruvian rain forest nearly nothing is known about naidid and tubificid species in tropical soils.

Table 1a: List of enchytraeid species found at the four Embrapa plots so far

Genus	Species	Author
Enchytraeidae		
Achaeta	*sp. A*	new
Achaeta	*sp. B*	new
Achaeta	*sp. C*	new
Achaeta	*sp. F*	new
Enchytraeus	*sp.*	new ?
Enchytraeus	*sp. Frag*	new ?
Guaranidrilus	*sp. A*	new
Guaranidrilus	*sp. SV*	new
Guaranidrilus	*sp. Dg*	new
Guaranidrilus	*sp. Dk*	new
Guaranidrilus	*"Amp"*	new
Hemienchytraeus	*stephensoni*	Cognetti 1927
Hemienchytraeus	*solimoensis* ?	Righi 1978
Hemienchytraeus	*patriciae*	new
Hemienchytraeus	*siljae*	new
Hemienchytraeus	*tanjae*	new
"Marionina	*"hell"*	new
Oligochaeta	*"dark"*	new

Table 1b: List of other microdrilid species found at the four Embrapa plots so far

Genus	Species	Author
Tubificidae:		
Bothrioneurum	*righii*	Collado & Schmelz 2000c
Oligochaeta		
????	*hamata*	new
????	*rhabdochaeta*	new

Table 1c: List of naidid species found at the four Embrapa plots so far

Genus	Species	Author
Naididae		
Pristina	*bifurcata*	new
Pristina	*diaphora*	new
Pristina	*fulva*	new
Pristina	*jenkinae*	Stephenson 1937
Pristina	*marcusi*	Collado & Schmelz 2000b
Pristina	*notopora*	Cernosvitov 1937
Pristina	*silvicola*	Collado & Schmelz 2000a
Pristina	*sima*	(Marcus 1944)
Pristina	*terrena*	Collado & Schmelz 2000a
Dero (Allodero)	*crassifaucis*	Collado & Schmelz 2000c

This list is not complete since taxonomic work on nearly all microdrilid worms found (both on the four study plots as well as nearby) is not finished yet.

Number and biomass

The mean abundance of enchytraeids in the four plots (on average 4.300 – 6.200 ind/m^2) is low in comparison to many temperate regions but higher than the (very few) numbers reported from other tropical rain forest sites (Table 2 and 3). The abundance data are differentiated according to the two layers (litter and soil) in Fig. 1 – 4. Very often the litter layer is less inhabited than the soil layer but this ration can change at certain dates. However, on POA and POC the litter layer is significantly less inhabited than the soil layer whereas the ration on FLO and SEC is close to equal. Whereas the

abundance is not very different on the four plots, the biomass on the two polyculture plots is lower than in the two forest sites. In both cases the variability in time (especially due to the different climatic situation in 1997 and 1998) is so high that these differences are statistically not significant. No distinct population dynamics, e.g. correlated with the rainy or dry season, is observable. In both years number and biomass were quite low in September and relatively high after the rainy season (June/July). However, due to the complex climatic situation in 1997 (one of the dryest years recorded so far in the Manaus region) the only conclusion which can be drawn for sure is that the average number on all four plots is higher in 1998/99 than in 1997/98. Due to the fact that the biomass dynamics follow with very few exceptions the abundance curve biomass graphics are not presented.

Table 2: Number (AB: Ind/m^2 * 1000) and biomass (BM: mg FW/m^2) of Enchytraeidae from the four study areas and at different sampling dates (for details see Fig. 1 – 4)

	FLO		SEC		POA		POC	
Date:	**AB**	**BM**	**AB**	**BM**	**AB**	**BM**	**AB**	**BM**
07/97	5.5	412	7.0	554	2.5	194	3.9	314
09/97	2.4	153	2.7	234	3.3	250	2.1	158
12/97	1.7	119	1.8	167	1.9	133	2.1	170
03/98	3.3	309	3.0	290	6.3	566	3.7	314
06/98	8.1	903	9.9	871	9.9	792	6.6	453
09/98	5.8	669	3.9	301	1.8	146	2.3	303
12/98	10.4	668	8.7	796	6.7	517	7.0	523
03/99	7.3	875	12.5	1350	8.6	653	6.5	672
Mean	5.6	513	6.2	570	5.1	406	4.3	363

Table 3: Overview on ecological studies: Enchytraeids in tropical rain forests (Species ? = Have the species been identified ?)

Study site	**Method**	**Individuals/m^2**	**Species ?**	**Reference**
Various	Various	Up to 1000	No	Swift et al. 1979
Honshu, Japan	Nielsen, 7 replicates	10.100	No	Kitazawa 1971
Sepilok, Malaysia	Nielsen, 1 replicate	1.000	No	Kitazawa 1971
Pasoh, Malaysia	O´Connor 20 replicates	2.000 – 23.000	No	Chiba et al. 1976
Various	Various	approx. 1000	No	Petersen & Luxton 1982
Panguana, Peru	Wet extraction, 2 replicates	4.000 – 5.000	No	Römbke unpubl.
Manaus, Brazil	Wet extraction, 10 replicates	1.000 – 10.000	Yes	This study

When looking at the individual species, species number and composition at the four sites based on individual numbers is quite similar whereas the dominance spectrum is different (Table 4). On the genus level, most of the differences found are not very pronounced, except of two cases:

- Species of the genus *Hemienchytraeus* are much more abundant in at FLO, whereas member of the genus *Guaranidrilus* are clearly dominant on the other three plots.
- The number of naidids (including some tubificids) decreases from FLO to SEC and POC and is lowest on POA. This finding is probably correlated with the increasing influence of litter temperature and moisture fluctuations.

In Fig. 5 – 8, the dominance spectrum of enchytraeids on the four plots is given in detail. Two issues might be confusing:

- the species names are partly preliminary and will be replaced after completion of the species description;

- not only species but also those juveniles which are determined only on the genus level are included.

Due to these reasons it is not possible to clarify whether the enchytraeid biocoenosis of the four plots is different concerning dominance rank. However, it seems that the there is no correlation between the steepness of the curve and the abiotic conditions of a plot (in the case of earthworm biomass, the curve was much steeper on POA and POC than on FLO and SEC).

The dominance spectrum based on biomass values will not be presented since due to the relatively small differences in individual weights the outcome would be quite similar to the picture presented in Table 4. In general, the species composition indicates a clear difference between the primary forest on the one side and the other three plots on the other hand.

In contrast to the earthworm biocoenosis, no distinction between endemic and peregrine species is possible in the case of the microdrilid worms. Maybe some of these species found at the EMBRAPA site are circumtropically distributed already (e.g. the enchytraeid species *Hemienchytraeus stephensoni* has been recorded from Burma, India, Argentine and Brazil), but our knowledge is not sufficient to draw any conclusion from these isolated findings.

Table 4: Percentage of the most important microdrilid genera at the four study plots at the EMBRAPA site based on individual numbers (for details see Fig. 5 - 8)

Species	FLO	SEC	POA	POC
Achaeta sp.	4 %	4 %	2 %	1 %
Enchytraeus sp.	6 %	4 %	9 %	2 %
Guaranidrilus sp.	39 %	71 %	61 %	72 %
Hemienchytraeus sp.	45 %	14 %	18 %	20 %
Other genera	6 %	7 %	10 %	5 %

Litter / soil ratio

The average values of the depth distribution as given in Table 7 reflect the influence of climatic factors at the four plots: at the two forest sites, the worms are more or less evenly distributed between the two layers. In the two polyculture plots, however, approximately only one third of all worms are found in the litter layer (cf. Fig. 1 – 4). In many litter samples during the dry season no worms were found at all. When interpreting these results it must be remembered that due to pre-tests the number of enchytraeids is decreasing very rapidly with depth. In other words: if the moisture is sufficient, the worms prefer the litter layer. Only during periods of climatic stress they retreat to deeper layers. The same but even more pronounced behaviour is true for the other microdriles.

Juvenile/adult age ratio

On average (i.e. all plots and sampling dates together), 71 % of enchytraeids were juveniles and 29 % adult – a ratio which is in the normal range known from ecological studies in temperate regions. Interestingly, nearly no differences of this ratio were found between the four plots (Table 7): 69 to 74 % of all enchytraeids were juvenile. Even more surprising is the fact that this ratio is quite stable during the whole study period on all four plots (Fig. 9 - 12). In other words, the influence of climatic changes (i.e. the difference between dry and wet season) is not reflected in the reproductive cycles of these worms. Due to the problematic taxonomic situation and the fact that often juveniles can only be determined to the genus level no data on the juvenile/adult ratio for the individual species are presented here.

Correlation between climatic data and enchytraeid biomass

Based on an idea of C. Martius, the biomass of the all enchytraeids on the four study plots was correlated with rainfall, humidity, soil temperature and litter temperature 3, 5, 10 and 30 days before the actual sampling dates (Table 6 in the Annex). Very often these parameters were (positively or negatively) correlated:

- a positive correlation between rainfall and biomass was found on FLO, SEC and POC three to ten days before sampling
- the humidity was positively correlated with enchytraeid biomass more on less on all time points on POA and POC
- soil and litter temperature were clearly negatively correlated with the enchytraeid biomass on all

- not only species but also those juveniles which are determined only on the genus level are included.

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- a positive correlation between rainfall and biomass was found on FLO, SEC and POC three to ten days before sampling
- the humidity was positively correlated with enchytraeid biomass more on less on all time points on POA and POC
- soil and litter temperature were clearly negatively correlated with the enchytraeid biomass on all

plots (except POA) at all time points three to ten days before sampling.
These results indicate that the number of enchytraeids depends clearly on the climatic properties mainly three to ten days before sampling. This result was expectable due to the life-form of these small worms: Most of them live in close contact with the litter and soil pore water. Additionally, it is known that enchytraeids are very sensitive against high temperatures which occur regularly in the litter layer of all study plots. It is surprising that the last statement is also true for the primary forest (FLO) three to five days before sampling, since this plot should have a well-balanced micro-climate. In addition, it is not clear why temperature on POA is not correlated with enchytraeid biomass. The consequences these findings might have for further sampling strategies need to be discussed.

4. Microdrilid colonisation of litterbags
Method description
Microdrilids were collected routinely out of litterbags in order to assess their contribution to the process of litter decomposition. In total, 13 samplings have been performed: seven from the first series of bags and six from the second series. Only the total number of microdrilids was counted so far, but a distinction on the family level is planned for the near future. A preliminary examination of some samples revealed a relationship between enchytraeids and naidids of 1 : 1 in the coarse litterbags and 1 : 2 to 1 : 4 in the fine litterbags. No further taxonomic determination is planned due to practical reasons. It should be stressed that less than 1 % of the checked samples contained nematods, which indicates that the counting work was done very exactly. All worms were stored in 70 % EtOH immediately after extraction.

Additionally, the number could not corrected for the actual amount of dry weight of litter in the respective litterbag, since these values were measured only at two sampling dates. Therefore, the numbers reported here should be recalculated to a standard unit (e.g. 100 g dry weight) using the mean values for each series of litterbags at a given date.

At each sampling date, usually two bags with the same mesh-width are taken from the FLO and SEC areas except the first date (November 1997), where only one bag was used. In POA and POC always just one bag per area was taken, respectively. Again, in November 1997 only POA was sampled. In February 1998, erroneously both bags per mesh-width were taken from POC whereas no bag was used from POA. In autumn 1998, an additional study was initiated comparing the number of enchytraeids and naidids in litterbags filled with mixed leaf material coming originally from the FLO and SEC areas. The results will be interpreted in relation to feeding experiments in the laboratory (Augustsson, pers. comm.).

Results and discussion
The data gained so far from the first litterbag series are summarised in Table 5. In general, only in litterbags from FLO considerable numbers of microdrilids were found (in total: 1857 worms on FLO, 115 on SEC, 2 on POA and 33 on POC). Despite the fact that only the first three sampling dates of the second series is assessed, the same ratio between the four plots is visible. It seems that under certain favourable conditions (e.g. in January and, partly, in May 1998) worms can enter the SEC litterbags. With very few exceptions nearly no worms were ever found in POA and only very few in *POC litterbags. Probably this situation is caused by the unfavourable abiotic conditions in litterbags* which are exposed on the soil surface, e.g. very high temperatures. Even if they consist for only a few hours, all worms will be killed or are driven out of the litter back into the soil.

As indicated earlier, the worms counted belong mainly to two annelid families, differing strongly in size. Most adult naidids are only up to one mm long. Since they can reproduce mainly by fragmentation, the "juveniles" are around 100 - 500 µm long and much less in width. This explains, at least partly, why they are so abundant, especially in the fine litterbags, leading to the situation that the overall number in all three mesh-widths of FLO litterbags is practically the same (in tendency even more in the fine bags). However, an open question remains: How can Enchytraeidae enter a fine litterbag? Some might do it as a cocoon (egg), which of course are small enough to fall through the mesh. In some other cases, the bags may have holes due to animal (termite ?) activities. Despite these open questions and the overall small amount of data gained so far, it can be expected that the microdrilid influence on litter decomposition is low except on the FLO plot.

Table 5: Number of microdrilid worms (Enchytraeidae and Naididae) per bag in litterbags with three

mesh-widths from the 4 study areas and sampling dates (in 11/97 and 2/98 not all bags were taken)

Date:	FLO			SEC			POA			POC		
	Coar.	Med.	Fine	Coar.	Med.	Fine	Coar.	Med.	Fine	Coar.	Med.	Fine
11/97	25	55	155	5	0	0	0	0	0	-	-	-
12/97	5	4	0	0	0	0	0	0	0	1	1	0
01/98	24	112	9	37	38	1	0	0	0	0	2	1
02/98	25	3	49	0	0	0	-	-	-	0	1	0
04/98	144	64	15	25	0	0	1	0	0	1	0	5
07/98	93	192	268	0	0	0	0	0	0	4	0	6
10/98	not assessed yet			not assessed yet			not assessed yet			not assessed yet		

5. Conclusions and outlook

The most important results gained so far when investigating the microdrilid worms of the four EMBRAPA plots can be summarised as follows (Table 7), taking into consideration that the study described here is the first ecological investigation of microdrilids in a (neotropical) rain forest:

- slightly modified methods routinely used in temperate regions are also useful in the tropics
- the number of enchytraeids of the primary forest seems to be comparable to those few described from other rain forest sites; however, the data basis is very small
- nothing is known about enchytraeid biocoenosis of tropical secondary forest or agroforestry sites, so, a comparison with own data is not possible
- the number at all four sites is quite similar whereas the biomass is lower on POA and POC than in FLO and SEC
- the variability of data between replicates is very high, but the variance of the mean values per plot over time is relatively low for all plots
- no correlation between weight/volume of samples and enchytraeid numbers was found
- no clear annual population dynamics was observed, but the dry conditions in 1997 had a negative influence on their number and biomass
- in general, the four sites are similar concerning species number (high in comparison to forest sites in temperate regions) and composition, but the dominance spectrum was different (e.g. the dominant genus is *Hemienchytraeus* on FLO and *Guaranidrilus* on all other plots)
- the juvenile/adult ratio is very similar on all plots and at all sampling dates
- the litter layer is significantly less inhabited on POA and POC than on FLO and SEC
- nothing can be said so far concerning the ratio between endemic and peregrine species since the taxonomic assessment is not completed
- distinct correlations between climatic parameters (positively: rainfall, humidity; negatively: soil and litter temperature) with enchytraeid biomass were found; some exceptions (especially on POA) cannot be fully explained.
- Naidids (and partly tubificids) were regularly found in terrestrial samples of a tropical rain forest for the first time; their species number is extremely high (only about one quarter is known to science so far)
- Based on the results of litterbag samples, microdrilids (especially naidids) can reach very high numbers under favourable conditions (especially the permanent moist litter layer of FLO)
- The same distribution pattern was found when assessing the soil-core samples: naidids are quite abundant on FLO, rare on SEC and practically not living on POA and POC.

Based on these results, it seems that the microdrilid biocoenosis indicates a clear distinction between FLO (and partly SEC) in comparison to POA and POC.

Table 7: Summary of the most important data describing the microdrilid biocoenosis at the EMBRAPA site

Parameter	FLO	SEC	POA	POC
Abundance [Ind/m^2]	5.600	6.200	5.100	4.300
Variance	54 %	63 %	62 %	50 %
Biomass [mg FW/m^2]	513	570	406	363
Variance	60 %	72 %	63 %	48 %
Number of species	ca. 18	ca. 17	ca. 18	ca. 19
Juvenile/adult ratio [%]	69 : 31	71 : 29	74 : 26	75 : 25
Litter/soil ratio [%]	41 : 59	58 : 42	33 : 67	27 : 73
Number of naidids and tubificids in litterbags	very much	many	very few	few

There are still some open questions which have to be assessed when all data are available:
- the taxonomic investigation has to be completed
- the correlation between microdrilid biomass and litter stock and/or decomposition rates has to be determined
- the role of naidids has to be assessed further (including laboratory tests on feeding habits and respiration; Augustsson, pers. comm.)

Finally, these data will be used to model the specific contribution of these organisms to the decomposition of the organic matter. Since it is not expectable that the direct influence of these small worms (taking their relatively low biomass into account) on decomposition is very high, further assessment should concentrate on their potential role as indicators, e.g. for anthropogenic effects.

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7. Annex
See following pages

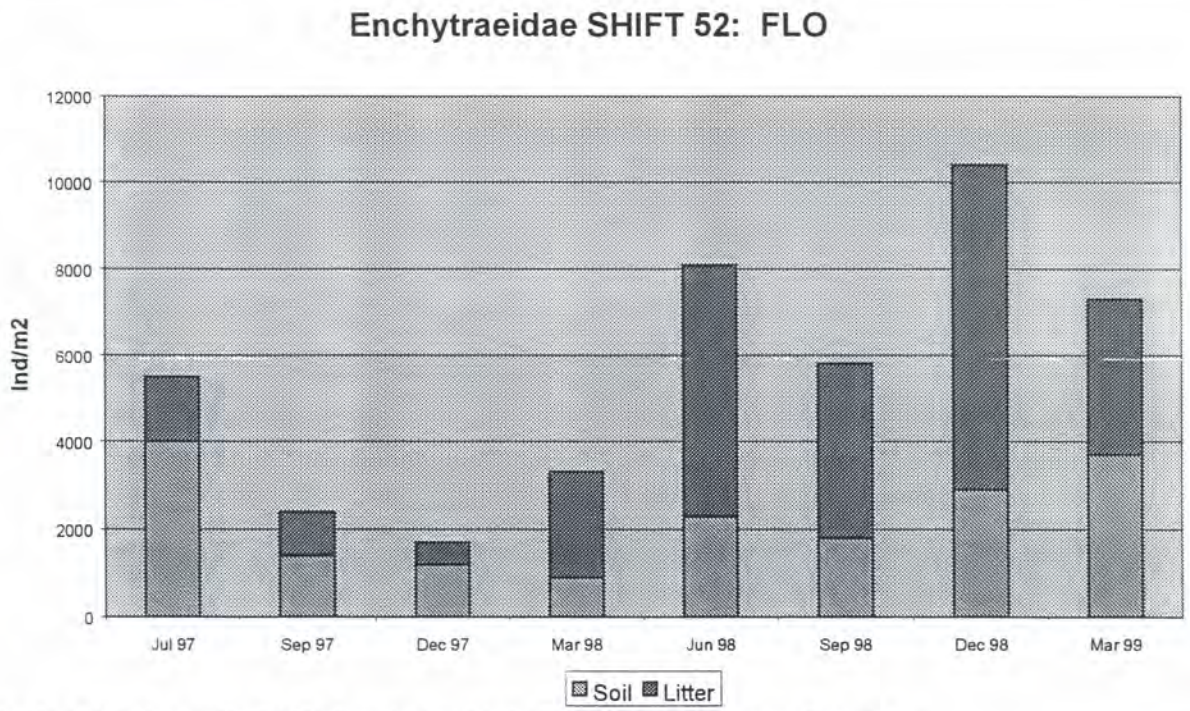

Fig. 1: Abundance [ind/m^2] of enchytraeids in FLO at the eight sampling dates

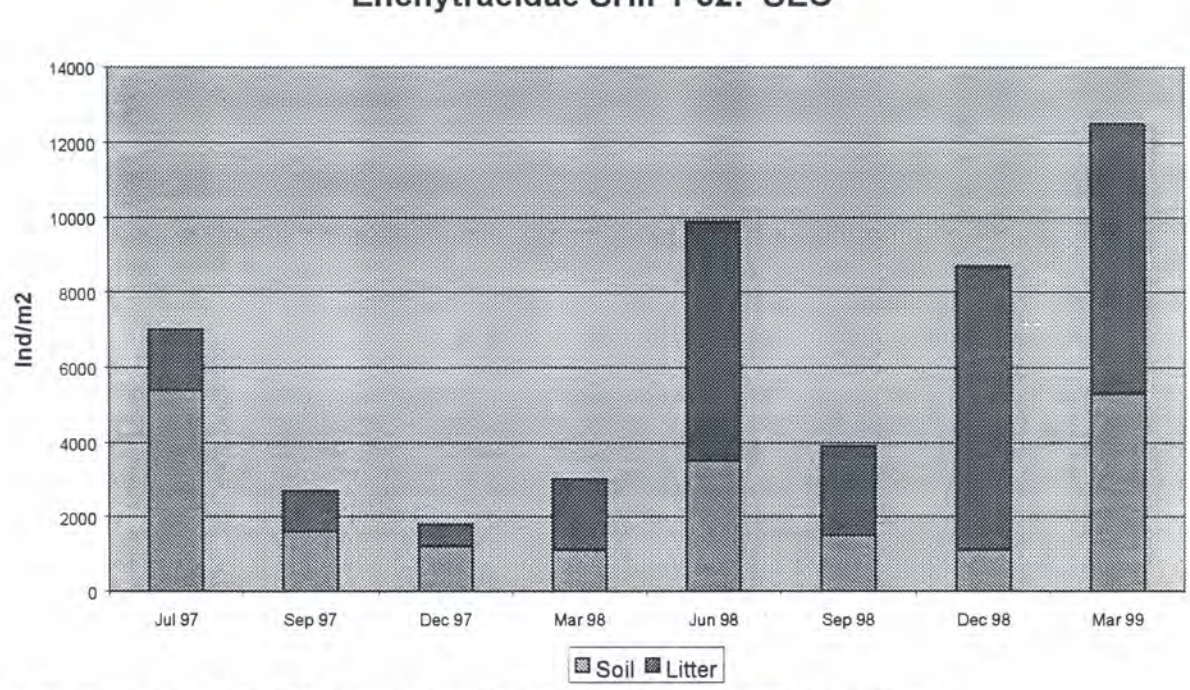

Fig. 2: Abundance [ind/m^2] of enchytraeids in SEC at the eight sampling dates

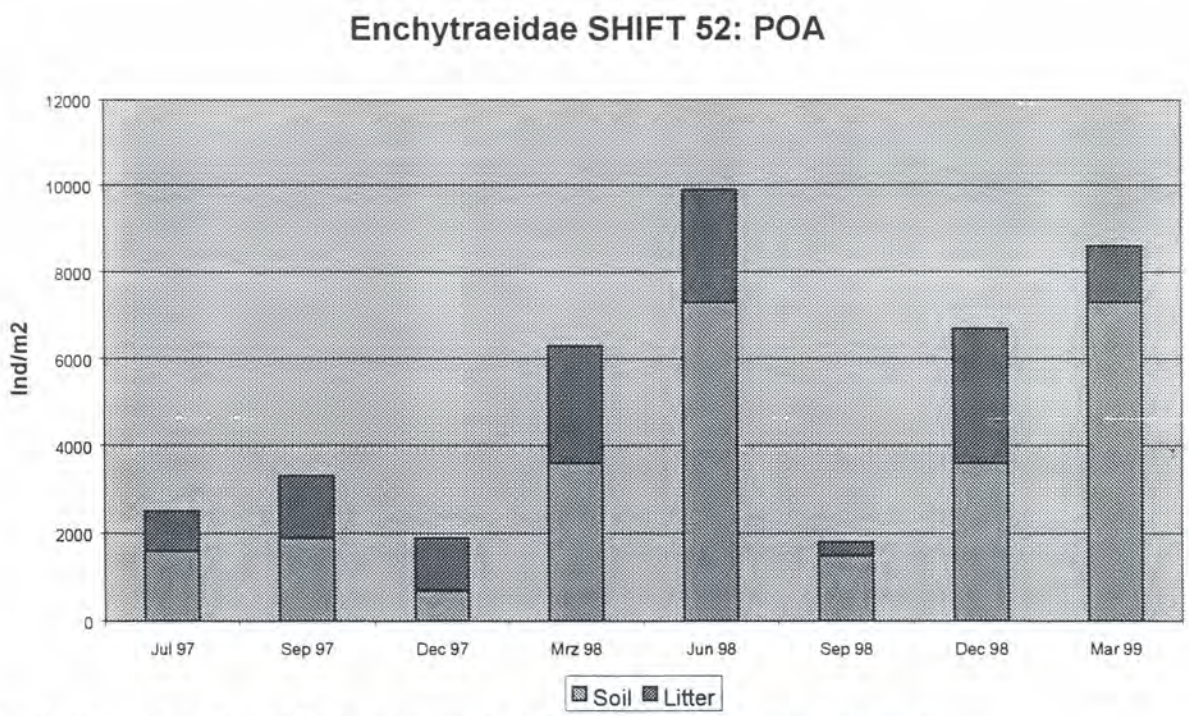

Fig. 3: Abundance [ind/m^2] of enchytraeids in POA at the eight sampling dates

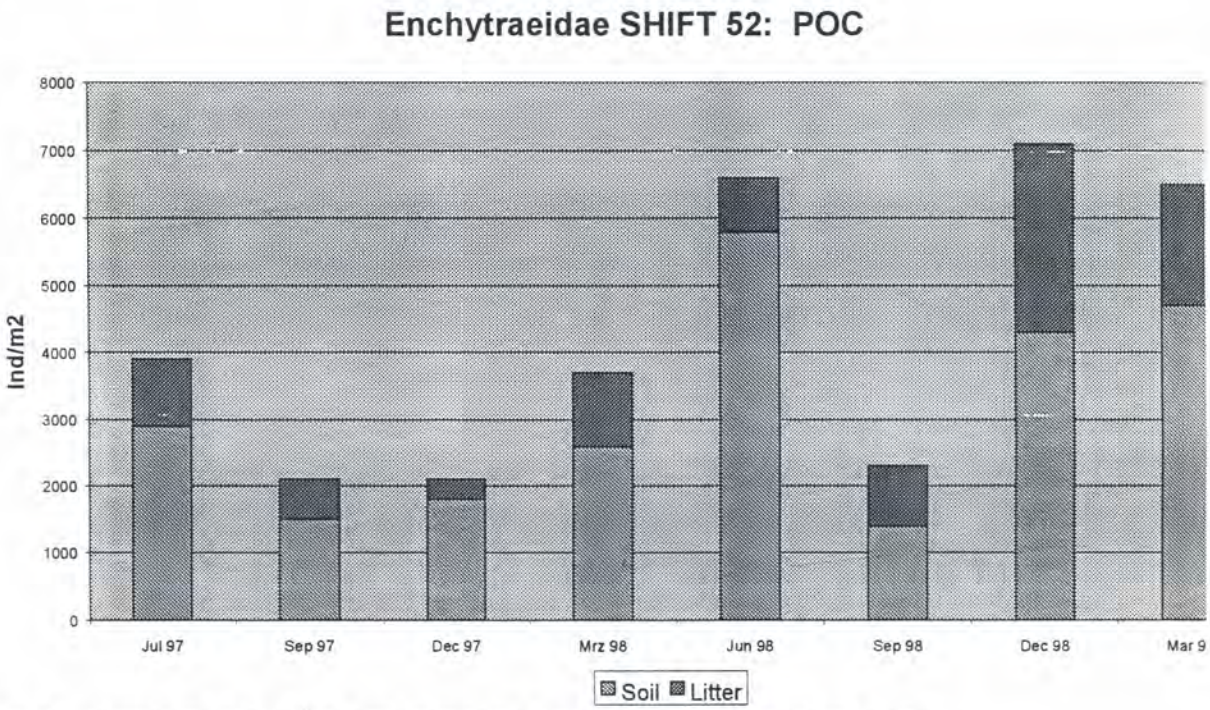

Fig. 4: Abundance [ind/m^2] of enchytraeids in POC at the eight sampling dates

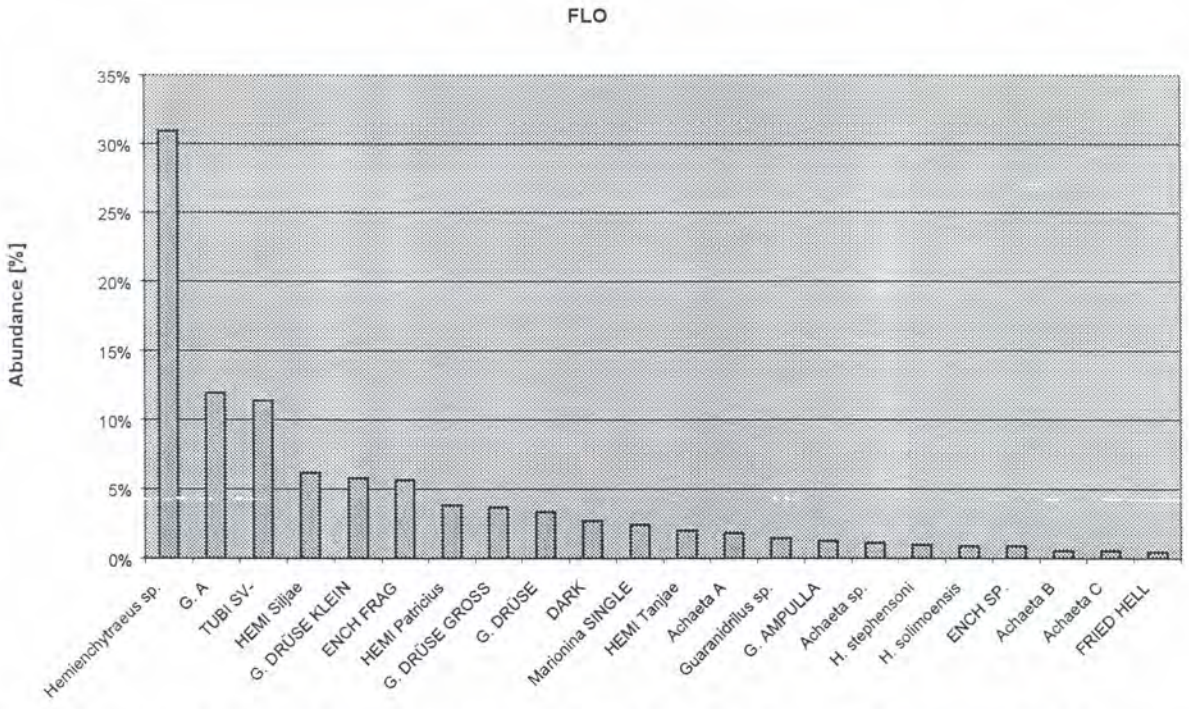

Fig. 5: Percentage of various enchytraeid species at the FLO plot based on abundance data

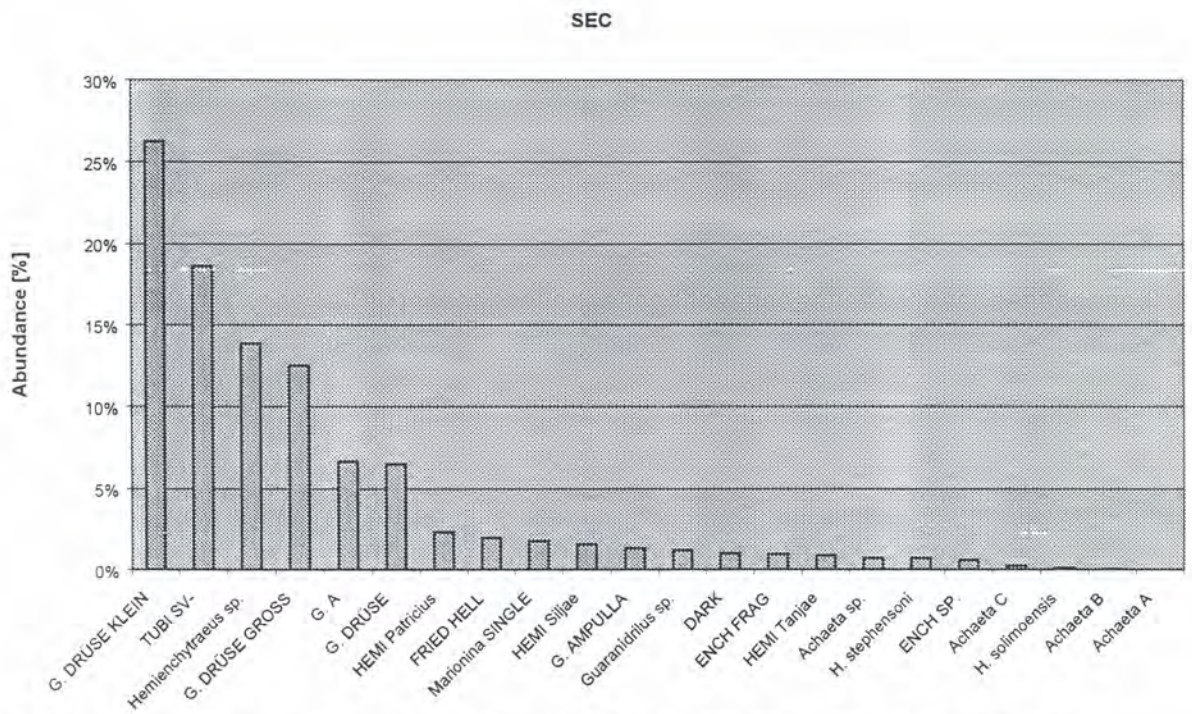

Fig. 6: Percentage of various enchytraeid species at the SEC plot based on abundance data

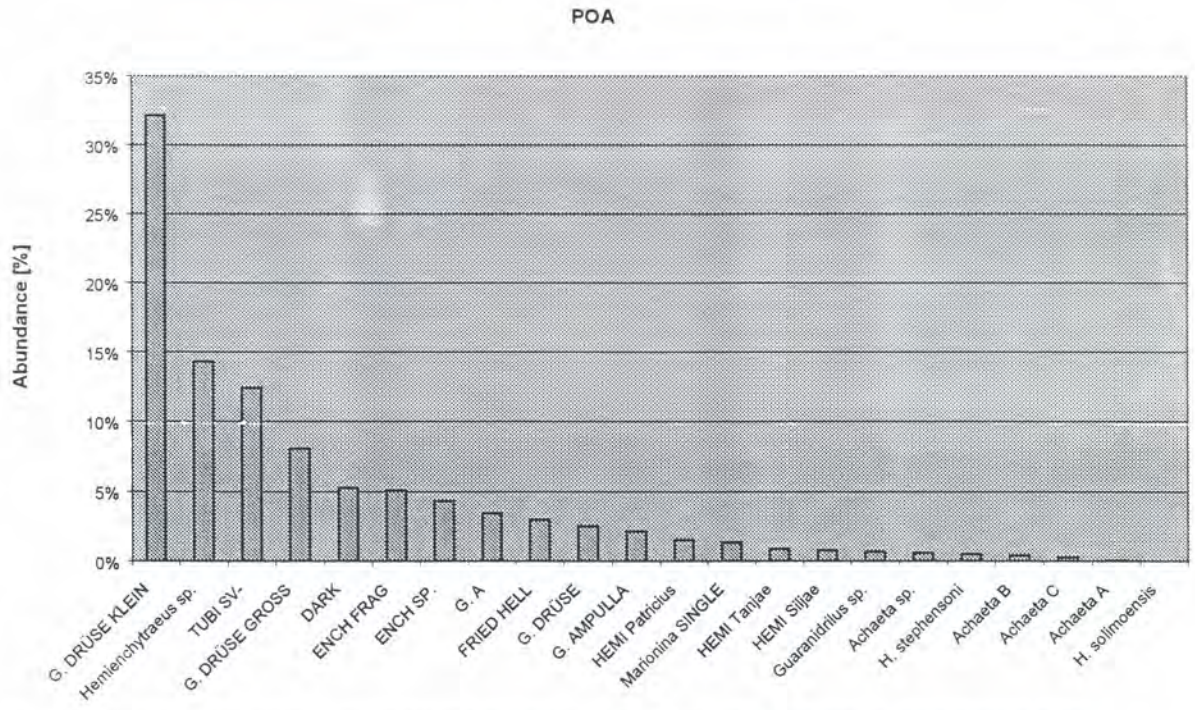

Fig. 7: Percentage of various enchytraeid species at the POA plot based on abundance data

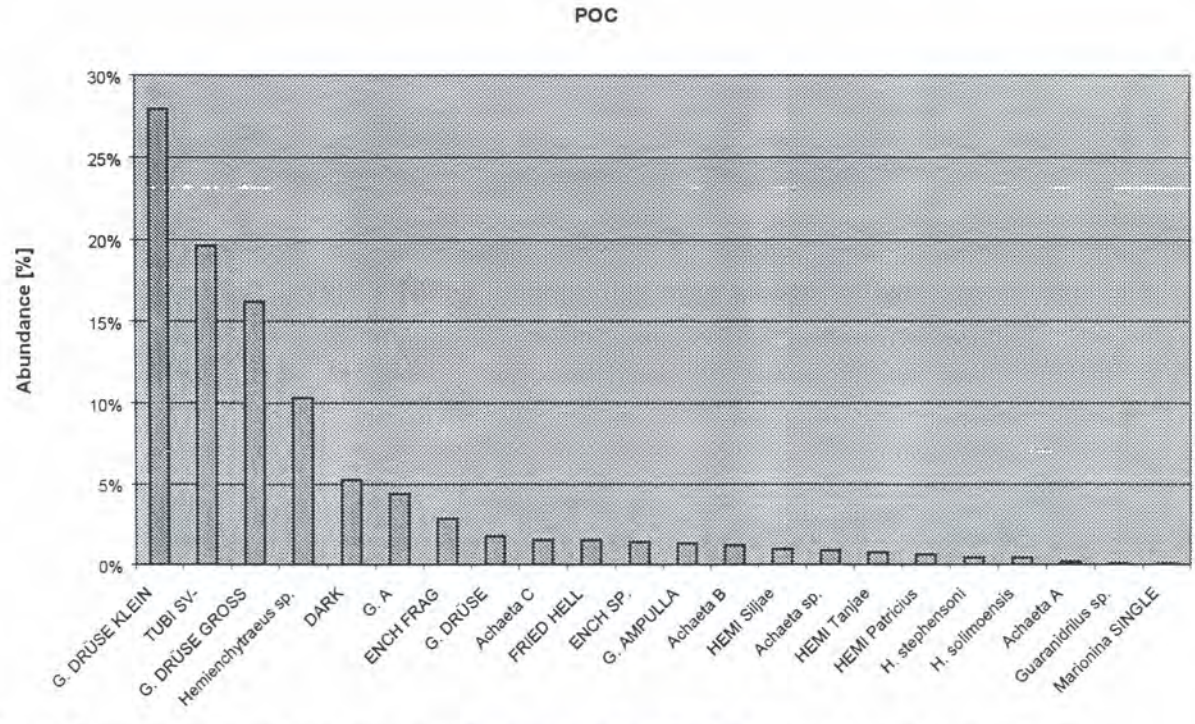

Fig. 8: Percentage of various enchytraeid species at the POC plot based on abundance data

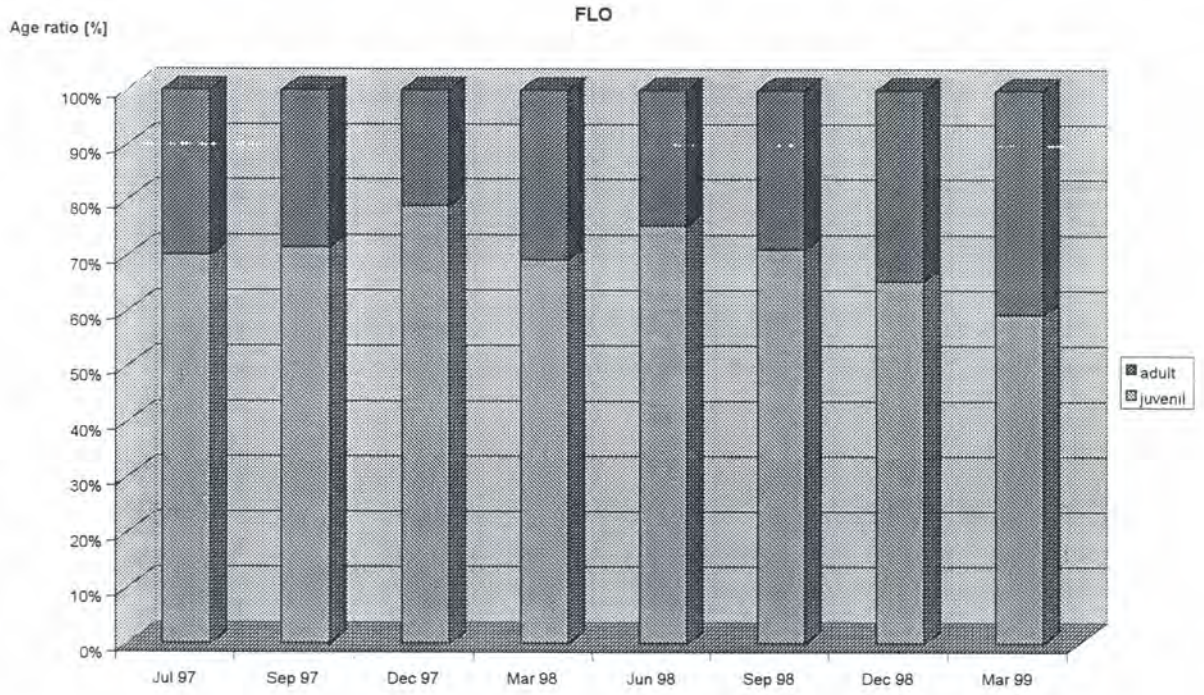

Fig. 9: Age ratio of enchytraeids in plot FLO at the eight sampling dates based on numbers

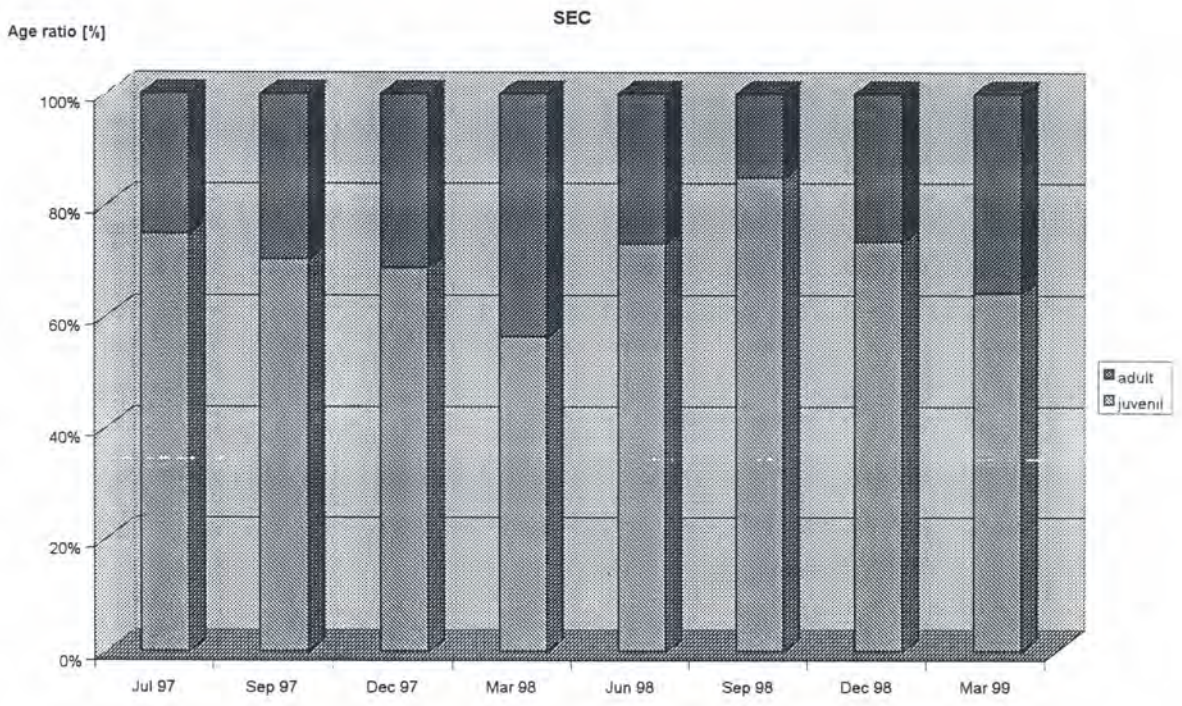

Fig. 10: Age ratio of enchytraeids in plot SEC at the eight sampling dates based on numbers

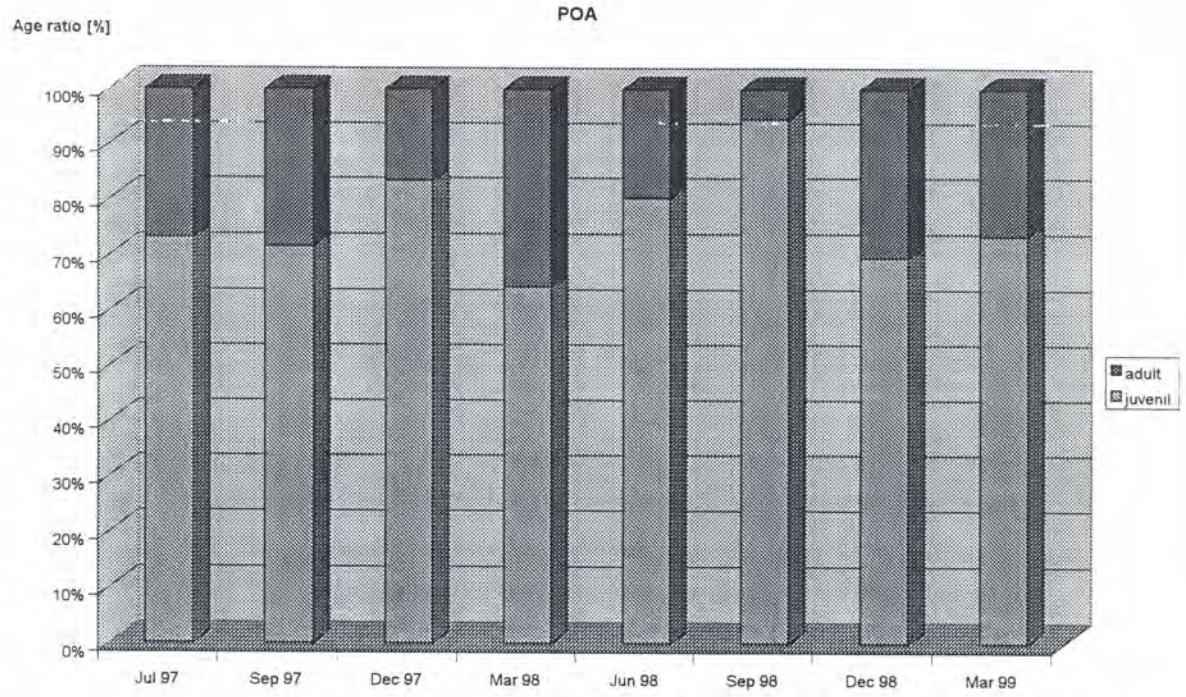

Fig. 11: Age ratio of enchytraeids in plot POA at the eight sampling dates based on numbers

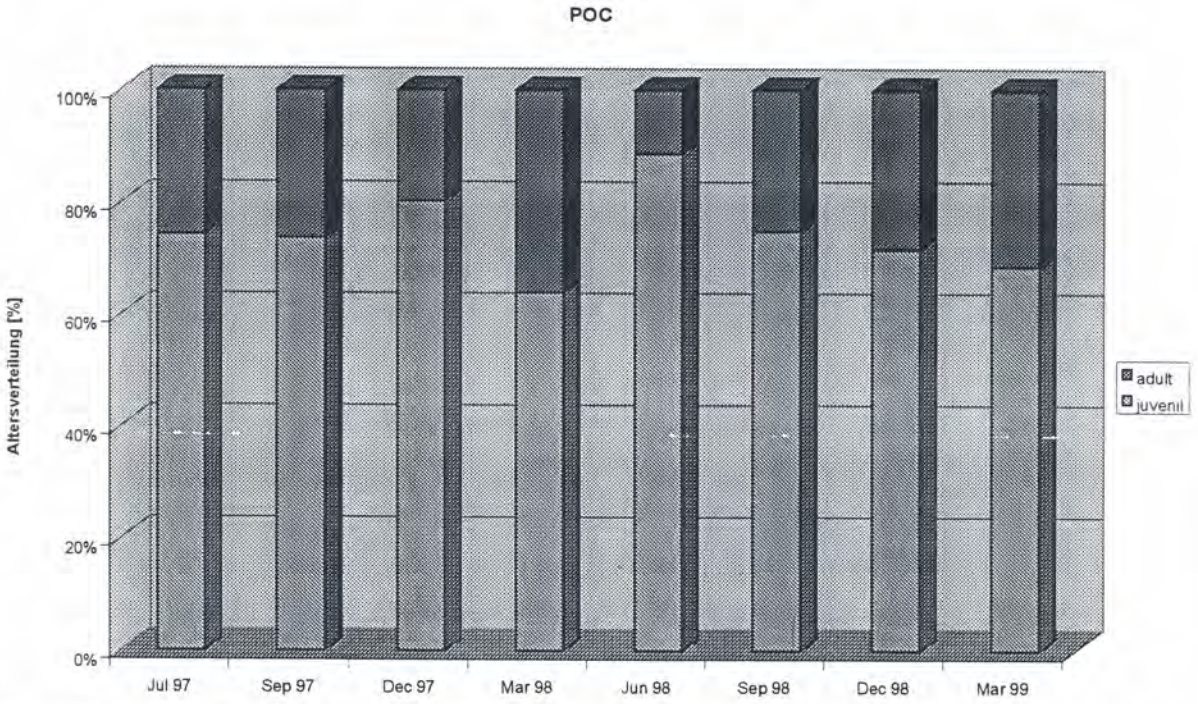

Fig. 12: Age ratio of enchytraeids in plot POC at the eight sampling dates based on numbers

Table 6: Correlation factors between various climatic parameters and earthworm biomass at the four study plots (correlation factors higher than 0.7 are given in bold)

rainfall				
correlation coefficient				
days before sampling	3	5	10	30
FLO	**0,723**	**0,708**	0,539	0,300
POA	0,532	0,598	0,562	0,621
POC	0,689	**0,738**	**0,793**	0,591
SEC	**0,755**	**0,781**	**0,728**	0,581
humidity				
correlation coefficient				
days before sampling	3	5	10	30
FLO	-0,172	-0,284	-0,274	-0,239
POA	0,638	**0,845**	**0,747**	**0,947**
POC	**0,951**	**0,951**	**0,953**	**0,840**
SEC	0,099	0,612	0,686	**0,748**
soil temperature				
correlation coefficient				
days before sampling	3	5	10	30
FLO	-0,694	-0,527	-0,506	-0,400
POA	-0,327	-0,400	-0,552	-0,228
POC	**-0,740**	**-0,802**	**-0,828**	-0,561
SEC	**-0,793**	**-0,704**	-0,699	-0,463
litter temperature				
correlation coefficient				
days before sampling	3	5	10	30
FLO	**-0,935**	**-0,752**	-0,670	-0,688
POA	-0,476	-0,643	**-0,770**	-0,695
POC	**-0,876**	**-0,965**	**-0,992**	**-0,805**
SEC	**-0,738**	**-0,747**	**-0,798**	-0,685

Soil ants

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Abstract
Between July 1997 and March 1999 ants of soil and litter were taken every three months with core samplers (21 cm Ø) in a primary rain forest, a secondary forest and two different systems of polycultures in Central Amazonia and extracted in Berlese funnels. Greatest generic diversity was found in primary forest, while in secondary forest and the two polycultures it was about 20 and 30% lower, respectively. Biomass and median density of ants were also highest in primary forest followed by secondary forest and one of the polycultures, whereas the lowest number and biomass of ants was found in the second polyculture. The predatory species of *Hypoponera* represented the biggest part of ant biomass in all areas (20-33%), whereas the very abundant mostly tiny species (< 2mm) of *Solenopsis* made up only 1,4 – 3,9% of the ant biomass. In spite of the biology of these tiny species remains poorly known, some species have been related as predators and other acting as decomposers.

1. Introduction

Ants are an important component of the natural forests and managed agricultural systems in amazon region. They contribute to soil processes and nutrient cycling in ecosystem by transposition of soil and affecting the water movement. Some species can significantly alter soil moisture and water infiltration characteristics. The soil nearby the ants nests has a very intensive turnover of nutrients. The material carried by ants to their nests is concentrated in one place and this led to a high concentration of nutrients. The microclimatic conditions in the nests can accelerate the decomposition processes of plant litter used in some species as building material (e.g. Petal, 1978; Haines, 1978 e Moutinho, 1998).
Despite the fact that many ants may not act directly on organic matter decomposition like the termites and millipedes, the ant fauna composition, e.g. high density of predatory species, might influence the fauna of decomposers.
Taking into account the relative role of ants in decomposition, a study of the abundance, biomass and genera diversity of ants in litter and soil were carried out in a primary rain forest, a secondary forest and two different systems of polycultures.

2. Material and Methods

The samples were taken 1996-1999 on four sites belonging to three different ecosystems: one primary and one secondary forest site (FLO and SEC, respectively), and a mixed culture system (areas POA and POC). Samples were taken with a soil core borer (21 cm diameter) and extracted in a Berlese funnels. The ant biomass was determined by separating all the collected individuals into size classes (by body length) according to generic level. The average fresh and dry weight was calculated for each genus. Individuals of each genera were died at freezer temperature in order to weight and measure them separately. Later, the specimens were dried at 65 °C and weighted once more. In some genera that was not possible to take the measurements, the average weight was taken from another genus with same length. The total biomass, in each genus were calculated by multiplying the number of individuals by its average weight. In the genus *Hypoponera* which has more variability in length, three size classes were created (Table 5).

3. Results and Discussion

Diversity, Density and Biomass

In all areas were recorded 49 genera including two unknown species of Ponerinae and Leptanilloidinae. In primary forest (FLO) were found the largest number of genera (42), followed by secondary forest (SEC) (35 genera) and the polycultive areas (POA and POC) (28 genera) (Table 1). Greatest generic diversity was found in primary forest, while in secondary forest and the two polycultures it was about 20 and 30% lower, respectively. Most frequent in all areas were ants of the genera *Solenopsis* (subfam. Myrmicinae) and *Hypoponera* (subfam. Ponerinae) (Tables 4a and 4b). The predatory species of *Hypoponera* represented the biggest part of ant biomass in all areas (20-

33%), whereas the very abundant mostly tiny species (< 2mm) of *Solenopsis* made up only 1,4 – 3,9% of the ant biomass (Table 3). Biomass and median density of ants were also highest in primary forest (1322 ± 611 ind/m² and 187,9 ± 93,3 mg/m²; n=160 samples) followed by secondary forest (865 ± 378 ind/m² and 87,8 ± 33,5 mg/m²; n=160) and one of the polycultures (782 ± 284 ind/m² and 91,3 ± 39,8 mg/m²; n=80), whereas the lowest number and biomass of ants was found in the second polyculture (574 ± 299 ind./m² and 45,9 ± 15,9 mg/m², n= 80) (Table 1). There is no statistically significant difference in biomass and density of ants between litter and soil samples for all study areas (Table 2).

The role of ants in organic matter decomposition

Many ant species utilize plant resources especially nectar from extrafloral nectaries or honeydew from homopterans beside their predatory activities thus acting as least partly as herbivores (see Tobin, 1994). These are often arboreal species like *Camponotus*, *Cephalotes* or *Pseudomyrmex* which are clearly underrepresented in our soil samples. Whereas the carnivory is the principal foraging strategy in some soil dwelling ants (e.g. Ponerinae and Ecitoninae), there is no clear pattern for many species. In all studied areas the genera *Solenopsis* and *Hypoponera* were most frequent. *Hypoponera* species are known by its predatory habit whereas the biology of *Solenopsis* is poorly known. They might be predominantly acting as predators including on brood of other ant species (lestobiosis) but there might be also a lot of scavenging on dead animals (decomposing activity). Among the many predatory species are a good number that as far as known are highly specialized in their type of prey, e.g. *Thaumatomyrmex* (polyxenid millipedes), *Cylindromyrmex*, *Acanthostichus*, *Centromyrmex* (termites) *Discothyrea* (arthropod eggs) or *Smithistruma* and *Strumigenys* (mainly collembolans), but indeed observations for many of these species are very scarce because of their rarity. These specialized predators are more than twice are frequent in primary and secondary forests than in polycultures. Army ants have been registered only in the forests by the method used.

Up to now no quantitative studies exist for these species that investigate the proportions of the different utilized food sources. Subterranean species of the genus *Acropyga* predominantely depend on honeydew of subterranean Coccidae, Homoptera. Other plant resources known to be exploited by ants of this study are pollen (*Cephalotes,* probably *Pseudomyrmex*), probably seeds (several genera), and leaves and leaf sap (leaf cutter ants of the genera *Atta* and *Acromyrmex*). Although leaf cutter ants do not ingest leaves directly but cultivate with them a fungus in their nests which they eat (fungivory), their ecosystematic effect is that of a herbivore, not a detritivore or decomposer. The latter role play the small species of other attine genera like *Cyphomyrmex*, *Apterostigma,* or *Trachymyrmex* which collect plants residues, arthropod corpses and insect faeces on which they cultivate their fungus. Many predatory or „omnivorous" species (utilizing plant and animal resources more or less alike) also act as detritivores by their scavenging activity on invertebrate and vertebrate carcasses. So far no studies exist for Amazonian ants that evaluate the importance of these resources for the entire diet of the species.

Relation of ant biomass and abiotic factors

Rainfall: There is not a statistically significant correlation (P ≤ 0,05) between the ant biomass and the daily rainfall averages at 3, 5, 10 e 30 days before sampling.

Relative humidity: a statistically significant and negative correlation (P ≤ 0,05) were observed in FLO (at 3, 5, 10 and 30 days before sampling) and in POA (at 5 and 10 days before sampling) between the ant biomass and the relative humidity. No statistically significant correlation were found in SEC and POA areas.

Soil and litter temperature: Only in POA were observed a statistically significant and positive correlation (P ≤ 0,05) between the ant biomass and the soil temperature (at 3 days before sampling); and the litter temperature (at 3, 5, 10 e 30 days before sampling).

4. References

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6. Annex

Table 1: Ants in the study areas: Total of individual number, density, biomass and number of genera.

Local	Nº. of samples per collection/Total Nº. of samples 1997-99	Total Nº. of individuals (Litter + Soil 0-5cm)	Average density over months ± Standard deviation (ind/m^2) (n=8)	Average biomass over months ± Standard deviation (mg/m^2) (n=8)	Nº. of Genera
FLO	20/160	7329	1322 ± 611	187,9 ± 93,3	42
SEC	20/160	4798	865 ± 378	87,8 ± 33,5	34
POA	10/80	1591	574 ± 299	45,9 ± 15,9	28
POC	10/80	2167	782 ± 284	91,3 ± 39,8	28

Table 2: Ants in the study areas: Density and biomass in soil and litter samples.

Local	Average density over months ± Standard deviation (ind/m^2) (n=8)		Average biomass over months ± Standard deviation (mg/m^2) (n=8)	
	Litter	Soil	Litter	Soil
FLO	549 ± 240	774 ± 507	71,9 ± 40,0	116,0 ± 90,7
SEC	545 ± 233	321 ± 185	43,1 ± 12,7	44,8 ± 28,2
POA	245 ± 144	330 ± 195	22,8 ± 10,5	23,1 ± 7,9
POC	339 ± 159	440 ± 218	43,8 ± 21,3	47,1 ± 29,6

Table 3: Ant biomass in study areas according to the genera.

FLO		SEC	
Genus	**Biomass average over months ± Standard deviation (mg/m²) (n=8)**	**Genus**	**Biomass average over months ± Standard deviation (mg/m²) (n=8)**
Hypoponera	37,42 ± 24,79	*Hypoponera*	21,94 ± 15,76
Pheidole	33,71 ± 49,02	*Pachycondyla*	11,01 ± 15,17
Nomamyrmex	24,11 ± 68,18	*Pheidole*	10,67 ± 16,8
Pachycondyla	18,43 ± 10,26	*Erebomyrma*	7,60 ± 21,47
Solenopsis	6,90 ± 10,48	*Labidus*	5,39 ± 15,24
Trachymyrmex	6,03 ± 12,12	*Discothyrea*	4,58 ± 1,43
Strumigenys	5,99 ± 3,07	*Anochaetus*	3,52 ± 3,44
Blepharidatta	5,33 ± 11,77	*Rogeria*	2,95 ± 1,83
Odontomachus	5,30 ± 3,73	*Solenopsis*	2,86 ± 2,23
Crematogaster	4,75 ± 7,82	*Ectatoma*	2,28 ± 3,14
Atta	4,55 ± 7,07	*Cyphomyrmex*	2,09 ± 3,36
Erebomyrma	4,50 ± 8,34	*Odontomachus*	2,08 ± 4,36
Apterostigma	4,16 ± 7,96	*Acropyga*	1,97 ± 2,49
Tapinoma	3,91 ± 5,06	*Paratrechina*	1,92 ± 2,49
Ectatoma	3,79 ± 6,44	*Tapinoma*	1,77 ± 2,08
Anochaetus	2,87 ± 4,56	More 19 genera	< 1,00 each
Acromyrmex	2,06 ± 3,82		
Megalomyrmex	1,60 ± 2,82		
Cyphomyrmex	1,59 ± 2,84		
Cylindromyrmex	1,42 ± 3,19		
Gnamptogenys	1,38 ± 3,32		
More 21 genera	< 1,00 each		
POA		**POC**	
Genus	**Biomass average over months ± Standard deviation (mg/m²) (n=8)**	**Genus**	**Biomass average over months ± Standard deviation (mg/m²) (n=8)**
Hypoponera	9,93 ± 6,43	*Hypoponera*	30,11 ± 20,63
Pheidole	7,52 ± 5,68	*Apterostigma*	11,19 ± 24,31
Ectatoma	4,55 ± 6,28	*Pachycondyla*	12,69 ± 9,27
Pachycondyla	3,40 ± 4,02	*Pheidole*	9,88 ± 15,10
Cyphomyrmex	3,36 ± 4,65	*Rogeria*	5,20 ± 4,16
Leptanilloidinae A	2,41 ± 6,81	*Anochaetus*	3,10 ± 5,75
Tapinoma	2,08 ± 2,81	*Tapinoma*	2,75 ± 3,53
Solenopsis	1,80 ± 1,76	*Paratrechina*	2,20 ± 1,65
Paratrechina	1,75 ± 1,71	*Trachymyrmex*	2,01 ± 5,38
Odontomachus	1,52 ± 4,29	*Cyphomyrmex*	1,82 ± 2,42
Rogeria	1,07 ± 1,23	*Strumigenys*	1,65 ± 1,84
More 17 genera	< 1,00 each	*Dinoponera*	1,52 ± 4,29
		Odontomachus	1,52 ± 4,29
		Azteca	1,46 ± 1,38
		Solenopsis	1,30 ± 0,81
		More 13 genera	< 1,00 each

Table 4a: Frequency of ants in FLO and SEC areas according to the genera.

FLO			SEC		
Genus	**Frequency in 160 samples**	%	**Genus**	**Frequency in 160 samples**	%
Solenopsis	115	71,9	*Solenopsis*	140	87,5
Hypoponera	114	71,3	*Hypoponera*	114	71,3
Strumigenys	104	65,0	*Rogeria*	88	55,0
Tapinoma	71	44,4	*Discothyrea*	85	53,1
Pheidole	46	28,8	*Tapinoma*	54	33,8
Crematogaster	43	26,9	*Paratrechina*	42	26,3
Pachycondyla	32	20,0	*Pheidole*	32	20,0
Rogeria	24	15,0	*Strumigenys*	28	17,5
Cyphomyrmex	21	13,1	*Anochaetus*	23	14,4
Carebara	19	11,9	*Crematogaster*	15	9,4
Acropyga	18	11,3	*Acropyga*	14	8,8
Discothyrea	18	11,3	*Pachycondyla*	11	6,9
Paratrechina	17	10,6	*Cyphomyrmex*	8	5,0
Rhopalothrix	16	10,0	*Gnamptogenys*	7	4,4
Anochaetus	15	9,4	*Carebara*	6	3,8
Hylomyrma	10	6,3	*Trachymyrmex*	5	3,1
Trachymyrmex	10	6,3	*Acromyrmex*	3	1,9
Apterostigma	8	5,0	*Azteca*	3	1,9
Erebomyrma	7	4,4	*Ectatoma*	3	1,9
Smithistruma	7	4,4	*Eurhopalothrix*	3	1,9
Wasmannia	7	4,4	*Mycocepurus*	3	1,9
Gnamptogenys	6	3,8	*Odontomachus*	3	1,9
Odontomachus	6	3,8	*Erebomyrma*	2	1,3
Ectatoma	5	3,1	*Rhopalothrix*	2	1,3
Megalomyrmex	5	3,1	*Acanthostichus*	1	0,6
Atta	4	2,5	*Camponotus*	1	0,6
Azteca	4	2,5	*Hylomyrma*	1	0,6
Acromyrmex	3	1,9	*Labidus*	1	0,6
Camponotus	3	1,9	*Nomamyrmex*	1	0,6
Cylindromyrmex	3	1,9	*Pseudomyrmex*	1	0,6
Eurhopalothrix	3	1,9	*Smithistruma*	1	0,6
Mycocepurus	3	1,9	*Thaumatomyrmex*	1	0,6
Proceratium	3	1,9	*Wasmannia*	1	0,6
Acanthostichus	2	1,3	*Zacryptocerus*	1	0,6
Blepharidatta	2	1,3			
Centromyrmex	2	1,3			
Nomamyrmex	2	1,3			
Thaumatomyrmex	2	1,3			
Oligomyrmex	1	0,6			
Ponerine n. ident.	1	0,6			
Pseudomyrmex	1	0,6			
Quadristruma	1	0,6			

Table 4b: Frequency of ants in POA and POC areas according to the genera.

POA			POC		
Genus	**Frequency in 80 samples**	**%**	**Genus**	**Frequency in 80 samples**	**%**
Solenopsis	54	67,5	*Hypoponera*	62	77,5
Hypoponera	37	46,3	*Solenopsis*	57	71,3
Tapinoma	31	38,8	*Rogeria*	48	60,0
Pheidole	30	37,5	*Tapinoma*	35	43,8
Rogeria	19	23,8	*Paratrechina*	24	30,0
Paratrechina	15	18,8	*Pheidole*	16	20,0
Strumigenys	11	13,8	*Strumigenys*	15	18,8
Wasmannia	11	13,8	*Pachycondyla*	12	15,0
Discothyrea	8	10,0	*Discothyrea*	11	13,8
Cyphomyrmex	7	8,8	*Azteca*	7	8,8
Mycocepurus	5	6,3	*Crematogaster*	7	8,8
Azteca	4	5,0	*Cyphomyrmex*	7	8,8
Pachycondyla	4	5,0	*Apterostigma*	4	5,0
Acanthostichus	3	3,8	*Anochaetus*	3	3,8
Ectatoma	3	3,8	*Mycocepurus*	3	3,8
Quadristruma	3	3,8	*Trachymyrmex*	3	3,8
Camponotus	2	2,5	*Acropyga*	2	2,5
Gnamptogenys	2	2,5	*Gnamptogenys*	2	2,5
Acropyga	1	1,3	*Quadristruma*	2	2,5
Anochaetus	1	1,3	*Wasmannia*	2	2,5
Carebara	1	1,3	*Brachymyrmex*	1	1,3
Crematogaster	1	1,3	*Cylindromyrmex*	1	1,3
Erebomyrma	1	1,3	*Dinoponera*	1	1,3
Leptanilloidinae A	1	1,3	*Eurhopalothrix*	1	1,3
Megalomyrmex	1	1,3	*Hylomyrma*	1	1,3
Odontomachus	1	1,3	*Odontomachus*	1	1,3
Talaridris	1	1,3	*Smithistruma*	1	1,3
Zacryptocerus	1	1,3	*Thaumatomyrmex*	1	1,3

Table 5. Length classes, average fresh and dry weight of ants according to the genera.

Genus	Length (mm)	Average fresh weight (mg)	Average dry weight (mg)
Acanthostichus	2,0	0,1888	0,0477
Acromyrmex	4,5	0,5283	0,2650
Acropyga	2,0	0,1888	0,0477
Anochaetus	4,0	0,9418	0,3382
Apterostigma	3,0	0,5283	0,2650
Atta	3,0	11,5684	4,2045
Azteca	4,0	0,9418	0,3382
Camponotus	5,0	5,2029	2,2372
Carebara	1,0	0,0225	0,007
Centromyrmex	4,0	0,6462	0,2550
Crematogaster	2,5	0,3626	0,1336
Cylindromyrmex	7,0	4,4961	1,5716
Cyphomyrmex	2,0	0,1888	0,0477
Discothyrea	2,0	0,3626	0,1336
Dolichoderus	8,0	14,8272	5,7093
Ectatoma	10,0	11,5684	4,2045
Erebomyrma	1,5	0,1888	0,0477
Gnamptogenys	5,0	0,6462	0,2550
Hylomyrma	2,0	0,1888	0,0477
Hypoponera	< 2,5	0,3479	0,1571
Hypoponera	3 to 5	0,6462	0,2550
Hypoponera	> 5	2,7744	1,1930
Megalomyrmex	4,0	0,9418	0,3382
Mycocepurus	2,5	0,3626	0,1336
Odontomachus	9,0	11,5684	4,2045
Pachycondyla	6,0	4,4961	1,5716
Paratrechina	2,0	0,1888	0,0477
Pheidole	3,0	0,6772	0,2558
Proceratium	2,5	0,3479	0,1571
Pseudomyrmex	3,0	0,6772	0,2558
Quadristruma	2,0	0,1888	0,0477
Rhopalotrix	2,0	0,1888	0,0477
Rogeria	2,0	0,1888	0,0477
Smithistruma	2,0	0,1888	0,0477
Solenopsis	2,0	0,0225	0,007
Strumigenys	2,0	0,1888	0,0477
Tapinoma	2,0	0,1888	0,0477
Trachymirmex	3,0	0,5283	0,2650
Wasmannia	2,0	0,1888	0,0477
Zacryptocerus	3,0	0,5283	0,2650

Soil termites in primary forest, secondary forest and an agroforestry plantation system in central Amazonia

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Abstract
Litter and soil termites were collected with soil cores (21 cm diameter) in a primary forest site, a secondary forest site and two sites of a polyculture plantation system in central Amazonia, in three-monthly intervals from 1997 to 1999. Termite genus diversity, abundance and biomass all were highest in the primary forest. The values in the secondary forest were half those of the primary forest, and they were lowest in the plantation systems, indicating that the latter sites may suffer from functional constraints concerning the process of organic residue decomposition.

1. Introduction

Termites are among the most important decomposers among the soil macrofauna in tropical ecosystems. It is therefore imperative to obtain good quantitative estimates of this particular faunal group. Here, we report on their abundance, biomass and genera diversity in litter and soil (0-5 cm) of the SHIFT project in Manaus/AM, Brasil.

2. Material and Methods

"Macrofauna" samples were taken 1996-1999 on four sites belonging to three different ecosystems: one primary forest site (named FLO) and one secondary forest site established 1984 (SEC), and a mixed culture system established 1992 (POA and POC) and consisting of 4 tree species planted in rows, among which secondary growth was allowed to develop. The macrofauna samples were taken with a soil core borer (21 cm diameter) and extracted in a Berlese extraction device (for details cf. Beck et al. 1998 a, b), in the context of studies on recultivation of former degraded areas in central Amazonia (Lieberei & Gasparotto 1998). The termite biomass was determined by separating all the collected individuals (workers and soldiers separated) into size classes (by head width; classes 0.5-1.0, 1.1-2.0, 2.1-3.0, 3.1-4.0 mm), determining the average dry weight of the size class (using freshly collected material. not the animals stored in alcohol), and multiplying the number of individuals per size class with the average weight of the class.

3. Results and Discussion

Diversity: Genus composition

Fifteen genera were recorded in total. The largest number of genera was recorded in FLO (13), followed by SEC and POA/POC in that order (Table 2, last column). These values are minima, as some genera of which only the workers were collected, could not be identified; "?" in Table 1). Of these genera, three were exclusive to FLO, and two exclusive to the plantation sites POA and POC, but due to the sampling area which is rather small for social insects with large territories, these differences should not be overemphasized. The most important genera in terms of frequency were the Apicotermitinae (soldierless humus-feeding termites) and *Heterotermes* of the Rhinotermitidae (wood-feeders and frequent pests), in FLO also *Syntermes* (large leaf-feeding termites; cf. Martius 1998) and *Cylindrotermes* (wood-feeders).
FLO was also the site which had the highest incidence ("frequency" = number of samples with termites) of all sites (Table 2). In all sites, the number of termites in the soil samples (0-5 cm depth) was higher than in the litter samples; probably due to larger substrate volume (inner surface) of the soil. Surprisingly, the genus diversity in FLO is higher than that recorded by Apolinário (1993) in a survey of 1 ha in the nearby Reserva Ducke. The reduction of genus diversity to SEC and FLO points to a possible reduction in functional diversity, with yet unknown consequences for the decomposition process.

Density and Biomass

In this study, a total of 10 275 termite individuals was collected and analyzed. The average termite density (pooled over all sample months) was 1089 individuals m^{-2} in FLO, half this value in SEC, and 1/5-1/3 this value in POA and POC (Table 2). Average biomass pooled over the months was 0.7 g m^{-2} dry mass in FLO,0.3 g m^{-2} in SEC, and 0.1-0.3 k m^{-2} in the plantations. Thus, the reduction in termite genus diversity from FLO over SEC to the plantations is more or less accompanied by a reduction in their density and biomass.

These values are very high. In a study in eastern Amazonia, Bandeira & Torres (1985) found a termite biomass of only 0.04 g m^{-2} in the soil.

The relative importance of soil inhabitants in the total sample slightly increased in the plantations (77-88% in POA and POC against 70% in FLO and SEC; Table 2). This may reflect harsher abiotic conditions in the litter layer of these more openly structured sites.

Caste and size class distribution will not be discussed here. It should be noted, however, that of the four established size classes (body length 0.5-1.0, 1.1-2.0, 2.1-3.0, 3.1-4.0), most termites belonged to the two smallest size classes, and that the ratio of individual number to biomass decreased from primary and secondary forest (FLO, SEC) to the plantations (POA, POC; Figure 1).

Seasonality

With the exception of September 1997, where POC showed the highest single termite biomass value recorded during this study (resulting from only one sample in which, apparently, one nesting site of *Cornitermes* was hit), FLO always had the highest biomass (ranging roughly between 0.5 and 0.9 g m^{-2}; Figure 2). It was followed by SEC (0.1 - 0.4 g m^{-2}), POC (wider range than SEC: 0.1 - 1.2 g m^{-2}), and POA (0.0 - 0.3 g m^{-2}). With exception of site POC, the biomass is rather stable at the different sites, the large variation between some months probably being the effect of patchy distribution rather than of seasonality. Therefore, the seasonality of soil termites can not be inferred from such studies.

4. Discussion and conclusion

Termite assemblages consist not of soil-dwelling species alone, but also of wood-inhabitants and nest-building species. The assessment of this rather complex structure requires special efforts (Eggleton & Bignell 1995). Within the project, a complete assessment of the termite fauna was attempted, of which however only the methodological part was accomplished due to technical reasons (Gomes & Martius in prep.). Therefore, the largest proportion of this important element of the tropical soil fauna remains unassessed in this study.

As discussed before (Martius 1994), the interpretation of soil termite data from soil core extraction alone is difficult because of the clumped distribution pattern of these social insects. Besides, soil fauna assessments tend to underestimate the size of the whole termite population with all its functional fractions. that On the other hand, the data allow the relative assessment of the soil termite communities in the different sites. Clearly, diversity and biomass are drastically reduced from primary forest over 13-year old secondary forest to the plantations (essentially 6-year old secondary forests; Beck et al. 1998 b).

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Tables

Table 1: List of termite genera found in Berlese samples in the study sites 1997-1999 (black cells indicate presence of genus). "-t." = "-termes"

	?	Synt.	Apicotermitinae	Cylindrot.	Diversit.	Embirat.	Heterot.	Genuot.	Planicaprit.	Cyrilliot.	Dihoplot.	Orthognathot.	Nasutit.	Crepitit.	Cornit.	Armit.
FLO	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
SEC	■	■	■	■	■	■	■	■	■	■						
POA	■		■				■						■		■	■
POC	■	■	■			■	■								■	■

Table 2: Termites in the study sites: Individual number, biomass number and frequency of genera.

	No. of Samples per Collection/Total No. of Samples 1997-99	Total No. of Individuals (Litter + Soil 0-5cm)	Average Density over months (Ind/m^2) ± Standard deviation	Average Biomass over months (mg/m^2) ± Standard deviation	Average Importance of Soil Sample Biomass in Total Sample (%)	No of Samples with Termites in Litter / in Soil*	No of Genera
FLO	20/160	6033	1089 ± 414	654,4 ± 158,6	70,4	74/177	13
SEC	20/160	2872	518 ±259	306,0 ± 135,0	70,3	39/81	9
POA**	10/80	457	165 ± 189	103,9 ± 113,2	76,6	14/36	8
POC**	10/80	913	364 ± 349	303,6 ± 405,6	88,3	9/29	

*may be higher than the number of samples (first col.) because of more than one species per sample

** 6 genera in POA, and 6 in POC; numbers of genera pooled as they depend on sample number (cf. first column)

Figures

Figure 1: The ratio of Individual Number/Biomass decreases from primary and secondary forest (FLO, SEC) to the plantations (POA, POC)

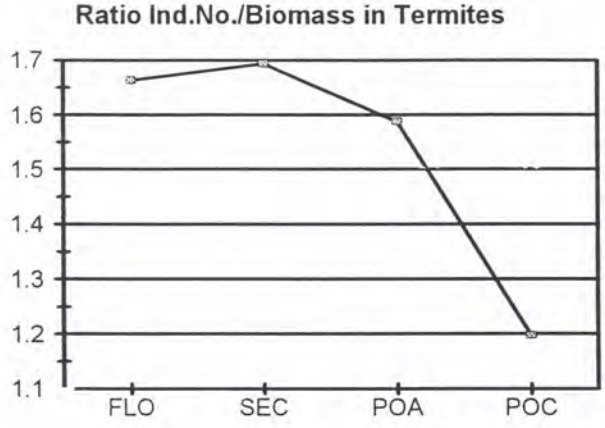
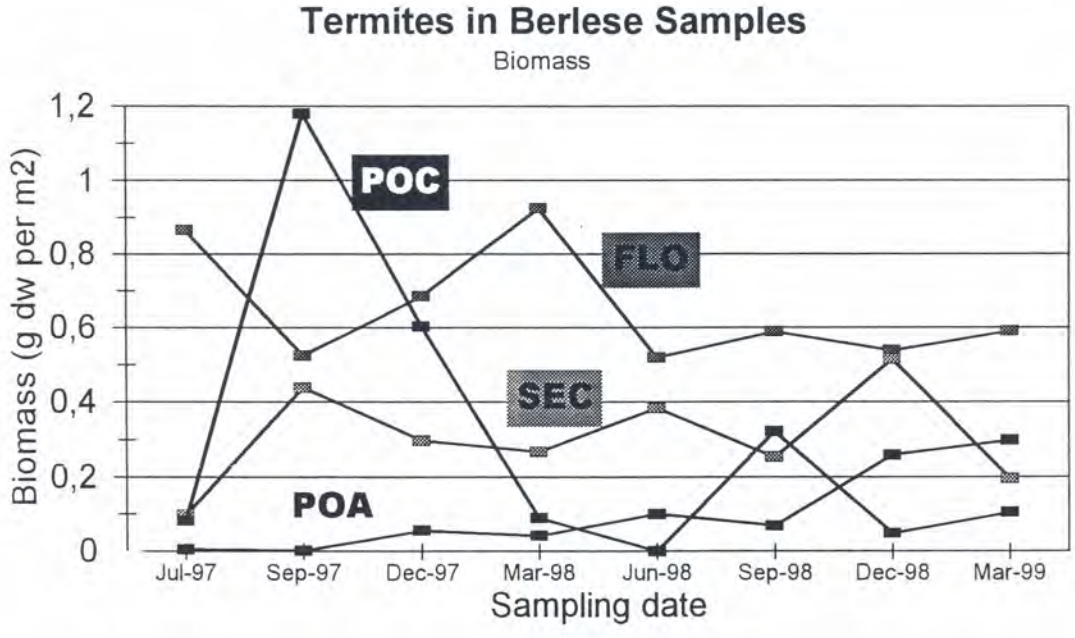


Figure 2: Biomass density of termites calculated from Berlese soil samples, from June 1997 to March 1998, in a primary forest (FLO9, secondary forest (SEC), and two mixed culture plantation sites (POA and POC), Embrapa Amazônia Ocidental, near Manaus (Amazonia), Brazil. Litter and soil (0-5 cm) samples pooled. Each point is the average of 20 (FLO, SEC) or 10 (POA, POC) samples of 21 cm diameter.



Termite ecology and respiration (in German)

Cäcilia Hanne

1.Einleitung (allgemein)

Termiten (Insecta; Isoptera) sind soziale Insekten, ihre Kolonien sind hochorganisiert, und sie leben in verschiedenen Habitaten. Dabei stellen sie einen Großteil der Bodenfauna. Die Mehrheit der über 1900 bisher beschriebenen Termitenarten finden sich in den Tropen und Subtropen. Termiten sind neben Regenwürmern wohl die wichtigsten Zersetzer von Pflanzenmaterial in tropischen Ökosystemen. Ihre Biomasse ist vergleichbar mit großen herbivoren Säugern, z.B. in einer afrikanischen Savanne liegen Antilopen bei 10 bis 80 kg pro Hektar, Termiten der gleichen Region erreichen eine Biomasse von 70 - 110 kg pro Hektar (in: Dangerfield et al., 1998). In den Neotropen errechnete Martius (1994) eine Biomasse von 25 kg pro Hektar, vermutlich liegen die Werte aber noch darüber (Sanderson 1996, Martius 1998).
Diese erstaunlich hohen Biomassewerte werden nur von Ameisen übertroffen (Hölldobler & Wilson, 1994). Auf Grund ihrer Abundanz wird angenommen, daß Termiten in tropischen Ökosystemen eine Schlüsselrolle im Umsatz toter Phytomasse spielen, da sie sich ausschließlich von organischem Material ernähren.
Verschiedene lokale Untersuchungen haben gezeigt, daß sie zwischen 16 und 100% des anfallenden toten Pflanzenmaterials umsetzen (Jones, 1990, Maldague, 1964, Edwards, 1974 und Whitford et al., 1982). Termiten sind in der Lage, Zellulose und Lignin abzubauen. Das geschieht mit Hilfe von assoziierten Darmbakterien und Protozoen. Dabei unterscheidet man niedere Termiten und höheren Termiten. Die sogenannten niederen Termiten besitzen sowohl Bakterien als auch Protozoen in ihrer Darmfauna, die höheren Termiten ausschließlich Bakterien. Von den 6 Familien und 14 Unterfamilien der Termiten finden sich 4 Familien und 7 Unterfamilien in den Neotropen (Tabelle A).

Die vorliegende Arbeit befasst sich mit zwei Teilaspekten der Ökologie von Termiten in den Neotropen:

TEIL A: CO_2 -Produktion und ihre Rolle im Kohlenstoffkreislauf.
TEIL B: Dynamik und Aktivität von Termiten in unterschiedlichen Waldsystemen

Tabelle A. Familien und Unterfamilien der Termiten (Klasse: Insecta; Ordnung Isoptera; Krishna 1970) und ihr Vorkommen in den Neotropen (Constantino 1997)

Familien/Unterfamilien weltweit	Familien/Unterfamilien der Neotropis
Kalotermitidae	Kalotermitidae
Mastotermitidae	
Hodotermitidae	
Hodotermitinae	
Termopsinae	
Porotermitinae	
Cretatermitinae (fossil)	
Stolotermitinae	
Rhinotermitidae	Rhinotermitidae
Stylotermitinae	
Termitogetoninae	
Heterotermitinitinae	Heterotermitinitinae
Coptotermitinae	Coptotermitinae
Rhinotermitinae	Rhinotermitinae
Serritermitidae	Serritermitidae
Termitidae (höhere Termiten)	Termitidae (höhere Termiten)
Apicotermitinae	Apicotermitinae
Amitermitinae	Amitermitinae
Macrotermitinae	
Nasutitermitinae	Nasutitermitinae

TEIL A

1.1 Einleitung

Unabhängig von der taxonomischen Einteilung von Termiten, die sich auf die Klassifizierung von Merkmalen stützt, werden sie von Eggleton et al. (1995) ökologisch in 4 verschiedene Nahrungsgilden eingeteilt:
Holzfresser (Xylophage), Humusfresser (Humivore), Generalisten sowie Laubfresser.

Der Ausstoß von CO_2 und Methan hängt direkt mit der assoziierten Darmfauna zusammen. Diese ist verantwortlich für den Abbau von verzehrtem organischem Material. Die Zellulose wird zuerst in Glucose-Monomere zerlegt, und anschließend zu Acetat, CO_2 und Wasserstoff vergärt (Braumann et al. 1992, Williams et al. 1994). Anschließend verwerten acetogene und methanogene Bakterien das Kohlendioxid. Die acetogenen Bakterien produzieren außerdem Acetat und die methanogenen Bakterien Methan.

Daraus ergibt sich die Frage, inwieweit der CO_2 - Ausstoß mit der Nahrung zusammenhängt. Tayasu et al (1997) stellten fest, daß die Atmungsrate abhängig vom Substrat und somit von der jeweiligen Nahrungsgilde sei. Aus den unterschiedlichen Diäten der Termiten müßten sich unterschiedliche Umsatzraten ergeben, da gilt:

$C_{(Konsumption)} = P_{(Produktion\ bzw.\ Biomasseaufbau)} + R_{(Respiration,\ d.h.\ CO2\ Ausstoß)} + FU_{(Fäzes\ und\ Urin)}$

Im Rahmen dieser Dissertation wurden folgende Fragestellungen untersucht:

- Ist die Atmungsrate der Termiten substratabhängig??
- Kann man die Termiten aufgrund ihrer Atmungsleistung in verschiedene Nahrungsgilden einteilen?

Dafür wurde für repräsentative Arten die Atmungsrate als wichtige Kenngröße ihrer Umsatzleistungen determiniert. Verschiedene Arten aus überirdischen Nestern, sogenannte Nestbauer, wurden ebenso untersucht wie unterirdisch lebende Termiten, die z.T. mit Hilfe von unterschiedlichen Ködersubstraten gesammelt wurden. Da Termiten soziale Insekten sind, wurden unterschiedliche Kasten berücksichtigt.

2 UNTERSUCHUNGEN

Die Flächen werden als terra firme-Gebiete (Festlandregenwald) eingestuft. Sie liegen auf dem Gelände der Embrapa - Amazônia Ocidental), ca 30 km nördlich von Manaus. Für die Untersuchung der Atmungsrate der Termiten wurden mehrere Primärwaldflächen beprobt.

3 Material und Methode

3.1 Entnahme der Termiten

In mehreren Primärwaldstücken wurden innerhalb einers Hektar alle zugänglichen Nester (epigäisch und arboreal) und alles auffindbare Totholz mit Termiten beprobt. Die Tiere werden mitsamt Nestmaterial ins Labor gebracht, dort aussortiert und weitmöglichst bestimmt.

3.2 Respirometrie

Es gibt verschiedene methodische Ansätze zur Respirometrie (vgl. u.a. Dunger & Fiedler, 1989). Da hier vor allem die Mineralisierung und Freisetzung von Kohlenstoff im Ökosystem interessiert, wurde die Messung der Kohlendioxidproduktion mit Hilfe der Infrarot-Gasanalyse (InfraRedGas-Analyzer / IRGA) gewählt. Bei der IRGA-Messung wird das Probengas aus einer Küvette, die die zu untersuchenden Tiere enthält, durch eine mit einer Infrarotlichtquelle und einem Detektor ausgestattete Kammer geleitet, wo die Lichtabsorption durch CO_2-Moleküle in der Luft gemessen wird. Entsprechend sensible Meßsysteme, anfänglich zur Messung der Photosyntheseleistung von Pflanzen verwendet (vgl. Piedade et al., 1991), sind inzwischen für den Einsatz zur Respirationsmessung bei Invertebraten verfügbar. Das hier verwendete Gerät ist ein Walz-HCM 1000 mit Modifizierungen. Das System erlaubt sowohl Absolut- als auch Differenzmessungen; dadurch kann eine kleine Anzahl von Tieren gemessen werden. Das Gerät mißt das ΔCO_2 (ppm CO_2 / min).

3.2.1 Messungen im Absolutmodus

- Messdauer 10 bis 20 min
- Temperatur der Küvette: 28° C
- Separate Messung der Kasten
- Biomassebestimmung

3.2.2 Durchführung der Messungen

Von jeder Gattung bzw. Art (soweit diese bestimmbar waren) wurden 40 - 80 Individuen, nach Kasten getrennt,, bis zu 16 mal für mindestens 10 min. bis zu höchstens 60 min. gemessen. Die Termiten wurden in einer perforierten Filmdose in die Messküvette des IRGAs eigesetzt. Vor und nach jeder einzelnen Messung wurde die Biomasse der eingesetzten Tiere bestimmt.

3.2.3 Berechnung der Respirationsrate

$$\Delta CO_2 * 0.169731 / (FG) = \mu g\ CO2/\ min/\ FG$$

mit

ΔCO_2 = Zunahme an ppm CO_2 pro Minute

0.169731 = Konstante (Umrechnungsfaktor)

FG= Frischgewicht

4 Ergebnisse

4.1 Atmungsmessungen

Tab. 1: Übersicht über neotropische Termiten in Brasilien (nach Constantino, 1997), unter besonderer Berücksichtigung der amazonischen Gattungen

Familie	Gattung	Arten	Amazonien	Gemessen
Kalotermitiden	7	28	14 Arten	
Rhinotermitiden	6	13	6 Gattungen	3 Gattungen
Termitiden	5			
U-Familien:				
Apicotermitinae	5	15	6 Gattungen	1 Gattung
Nasutitermitinae	31	158	29 Gattungen	7 Gattungen
Termitinae	15	59	12 Gattungen	8 Gattungen
gesamt (ohne Kalotermitiden)	57	235	53 Gattungen	**19 Gattungen**

Tab. 2: Familien und Unterfamilien sowie Nahrungsgildenzugehörigkeit der Termitenarten, für die CO_2-Produktion gemessen wurde.

Familie	Nahrungsgilde	Gattung / Art
Rhinotermitidae		
Unterfamilie:		
Heterotermitinae	xylophag	Coptotermes sp.
Rhinotermitinae	xylophag	Heterotermes sp.
	Xylophag	Heterotermes sp 1
		Rhinotermes sp.
Familie: Termitidae		
Unterfamilie		
Apicotermitinae		Anoplotermes sp.
Termitinae	unbekannt	Amitermes excellens
	Generalist	Termes fatalis
	Inquiline	Inquilitermes sp.
	Unbekannt	Cavitermes sp.
	Generalist	Genuotermes spinifer
Nasutitermitinae	Humivor	Labiotermes labralis
	Xylophag	Neocapritermes sp.1
		Neocapritermes sp .2
	Generalist	Armitermes sp.
	Humivor	Embiratermes sp.
	Laubfresser	Syntermes molestus
		Planicapritermes sp.
	Xylophag	Nasutitermes corniger
		Nasutitermes surinamensis
	Xylophag	Constrictotermes sp.
		Subulitermes sp.

Abb. 1: Zusammenstellung der Atmungsraten (Arbeiter) in Zusammenhang mit der Nahrungsgilde:

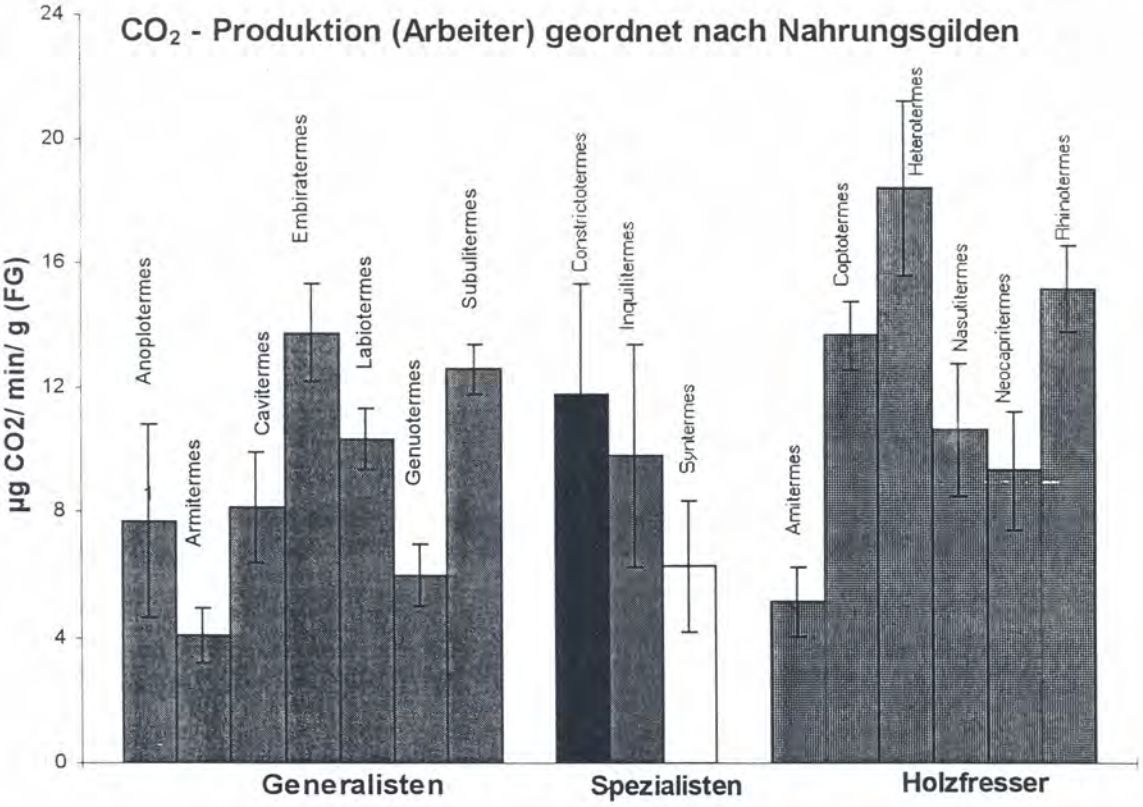


Abb. 2: Zusammenstellung der Atmungsraten (Soldaten) in Zusammenhang mit der Nahrungsgilde

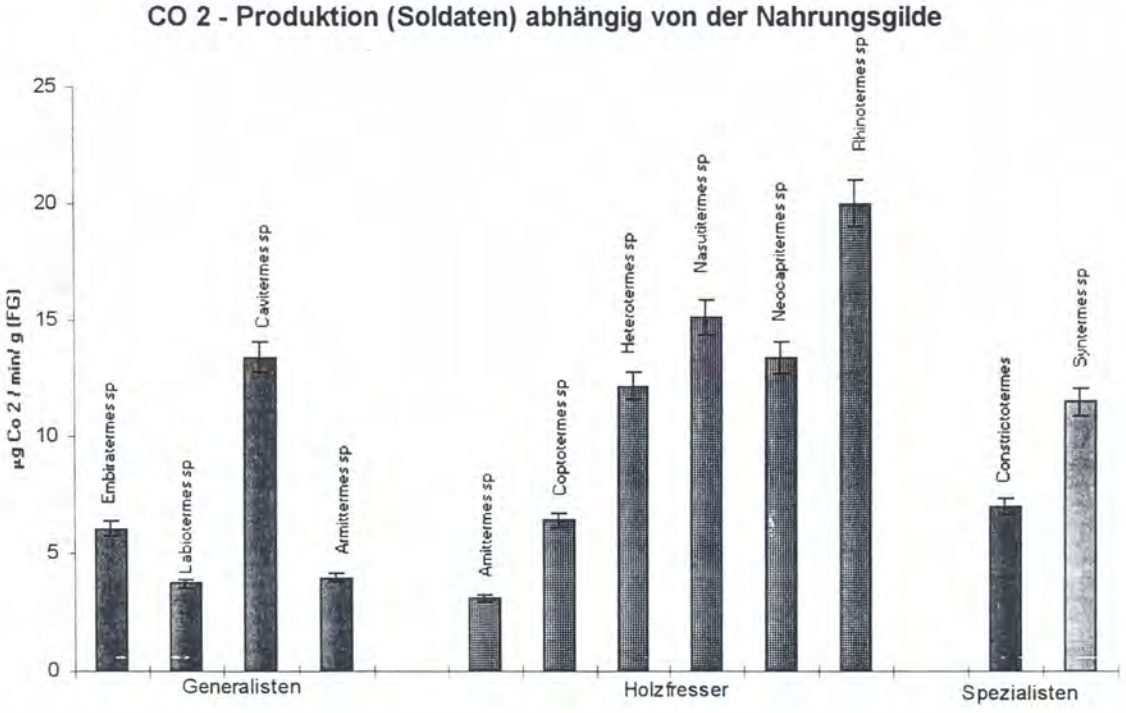


Abb. 3: Zusammenstellung der Atmungsraten (Arbeiter) im Zusammenhang mit den einzelnen Termitenfamilien (assoziierte Darmfauna)

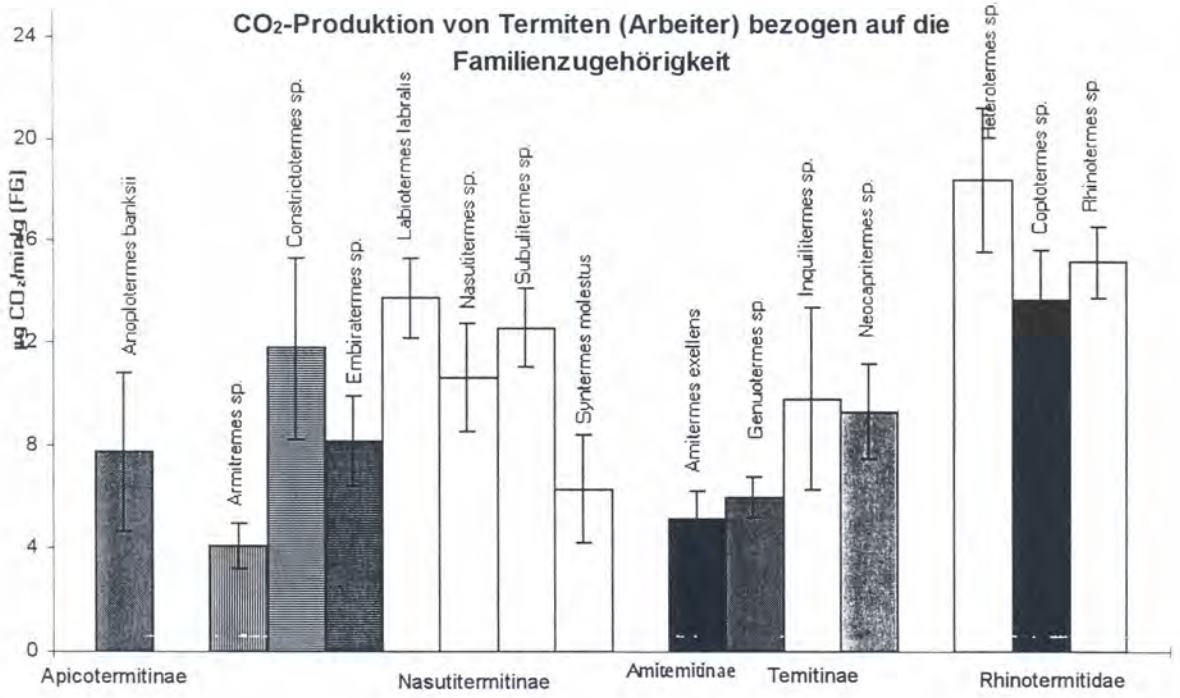
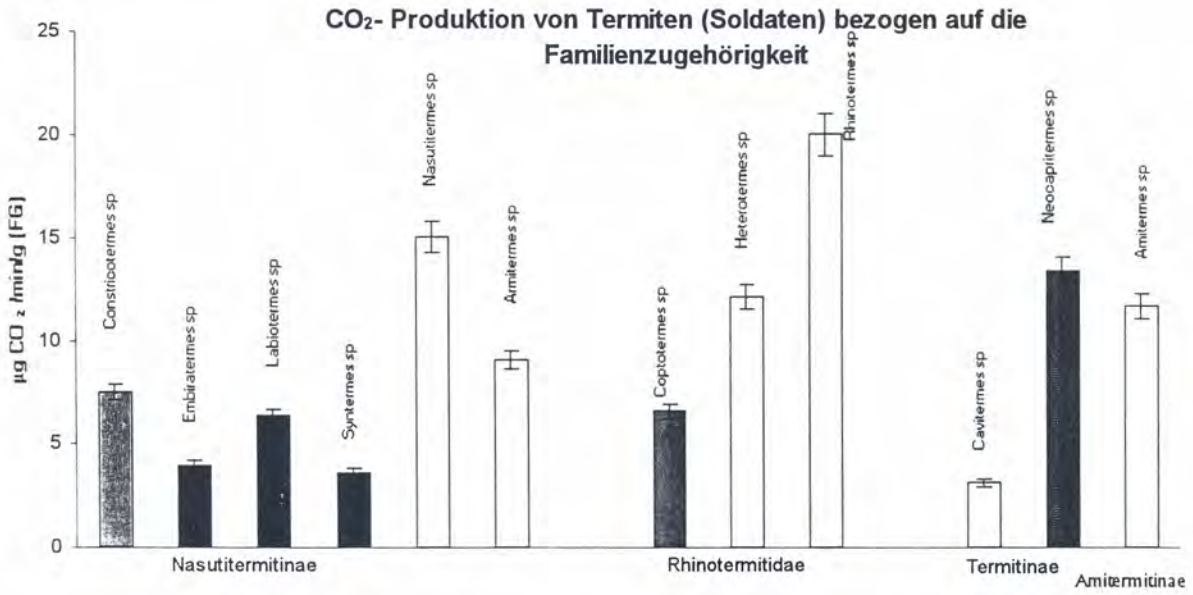


Abb. 4: Zusammenstellung der Atmungsraten (Soldaten) im Zusammenhang mit den einzelnen Termitenfamilien (assoziierte Darmfauna)



5 Diskussion

5.1 Atmungsmessungen

Die Atmungsleistungen unterscheiden sich zwischen den untersuchten Kasten (Abb. 1 - 4). Da sich bei den verschiedenen Gattungen ebenfalls Unterschiede zeigen (Abb. 1 - 4) ist davon auszugehen, ein differenziertes Model für Umsatzleistungen von Termiten erstellt werden kann.
Ein Problem ist darin zu sehen, daß eine sehr inhomogene Verteilung von Termiten respektive deren Nahrung auf den Untersuchungsflächen vorliegt (siehe Teil B). Eindeutig sind Generalisten und Holzfresser wesentlich häufiger als Spezialisten, zu denen die Laubfresser, Inquilinen und Laubfresser zählen (Abb. 1). Die Vertreter der holzfressenden Familie Kalotermitidae fehlen bisher vollständig (Tab. A). Ebenso ist zu berücksichtigen, daß es nicht möglich war, Arbeiter und Soldaten gleichmäßig zu beproben, da bei vielen Arten die Individuenzahl der Soldaten weit unter der von Arbeitern liegt (Wilson, 1994).

Eine eindeutige Einteilung nach Atmungsraten in Nahrungsgilden ist bisher nicht gelungen (Ab. 3 und 4). Bei Termiten in Afrika (Nunes *et al.* 1997 und Eggleton *et al.* 1998) wurde eine Abhängigkeit des Atmungsquotienten von der Nahrungsgilde beschrieben. Diese Autoren haben jedoch nur mit 2 Familien und 17 Arten aus 4 Gattungen gearbeitet. Entweder sind die Zusammenhänge in den Neotropen nicht so eindeutig zu zeigen, oder unsere Daten weisen auf eine stärkere Taxa-Abhängigkeit der Atmungsraten als bisher angenommen. Eine Einteilung der Atmungsleistung nach taxonomischen Gruppen (Ab. 3 und 4), für die Arbeiter läßt dagegen eine bessere Gruppenbildung erkennen (z.B. Rhniotermitidae vs. Apicotermitinae; Abb. 3). Für Soldaten, die nur indirekt von den Arbeitern gefüttert werden, ist eine solche eindeutige Klassifizierung aber nicht durchführbar (Abb. 4).
Des weiteren kann ein Umrechnung von der CO_2 - Produktion auf Atmungsquotienten die Atmungsrate der Termiten in Relation zu anderen Organismen gesetzt werden, und so eventuell eine neue Gruppierung ermöglichen.
Ein wichtiger Teilaspekt, der bisher noch nicht ausgewertet wurde, ist der Zusammenhang zwischen individuellem Körpergewicht und.

6 Ausblick

In Anbetracht der hohen Abundanz und ihrer Zersetzerrolle in Ökosystemen besitzen Termiten offensichtlich eine großen Einfluß auf die Stoffkreisläufe.
Von unterschiedlichen Seiten wurde festgestellt, daß die Ökosystem-Modelle, die sich mit globalen Kohlenstoff-Bilanzen beschäftigen und hauptsächlich mit Temperatur- und Feuchteunterschiede arbeiten (respektive Evapotranspiration), den grossen unterschiedlichen Abbauraten in vor allem tropischen Ökosystemen nicht gerecht werden (Seastedt, 1995). Deshalb wird seit längerem von verschiedenen Wissenschaftlern die Integration der Bodenfauna in Kohlenstoff und Stickstoff - Kreislauf- Modelle gefordert (Molina, 1998; Paustian, 1994). Termiten machen in den Tropen einen großen Teil der Bodenfauna aus, und somit verändern sie die Ablaufwege (pathways) im Kreislauf des organischen Materials drastisch (Lee & Wood, 1971).
Die in der voliegenden Dissertation erhobenen Daten sollen in ein Modell der Vorräte und Flüsse (stock-flow-model; nach Ackermann, 1999) integriert werden, welches es ermöglichen soll, die Rolle von Termiten im Kohlenstoffkreislauf unterschiedlicher Waldsysteme zu spezifizieren.

Frage zum Übergang zu Teil B:
Führt eine anthropogene Beeinflussung von Waldsystemen dazu, dass die Zersetzerfauna so nachhaltig beeinflusst wird, daß der Kohlenstoffzyklus verlangsamt werden könnte?

TEIL B

Die Dynamik von Termiten in agroforstwirtschaftlich genutzen Waldflächen in Zentralamazonien

6.1 Einleitung

Termiten sind keine seßhaften Organismen. Ihre Nester sind zwar zum größtenteils an einem Baumstamm fixiert (arboreal), oder befinden sich über-bzw. unterirdisch an einer Stelle (epigäisch); ihre Strategie der Nahrungssuche setzt jedoch Mobilität der Tiere voraus. Um Totholz, organisches Material oder Laub von ihrem Nest aus zu erreichen, schwärmen Arbeiter durch zahlreiche Gänge im Boden, oder überirdisch durch überdachte Galerien aus, wobei bis heute ihr Aktionsradius so gut wie unbekannt ist. Er kann sich aber über mehrer 100 m erstrecken (pers. Beobachtung; Martius, 1985; Wilson, 1994)

Im Primärwald (Terra firme) in Zentralamazonien , sind manche Termitenarten (z.B. Nasutitermes; Martius unveröff.) in hohen Dichten auf Lichtungen (in sogenannten „gaps") zu finden. Gaps sind Stellen im Wald, in denen ein oder mehrere abgestorbene, umgestürzte Bäume für ein Loch in der geschlossenen Kronendecke sorgen und so mehr Sonnenlicht bis auf den Waldboden gelangt. Daher müßten Termiten mikroklimatisch auf Trockenheit bzw. Feuchte reagieren (siehe auch de Bruyn1998).

Eine weiterer Aspekt, der die Verbreitung von Termiten beeinflußt, ist die strukturelle Biodiversitäts des Systems. Da das natürliche Habitat der Primärwald ist, stellt sich die Frage, ob diverse strukturierte Agroforstsysteme gegenüber Monokulturen nicht günstigere Bedingungen für die Bodenfauna, respektive Termiten, bieten.

Ziel dieses Teil war es, die Dynamik und Aktivität von Termiten in Ökosystemen zu dokumentieren. Zum einen wurde überprüft, ob es möglich ist, insitu die Nahrungsgilden-Zugehörigkeit von Termiten zu erfassen. Des weiteren sollte überprüft werden, ob eine geschlossene Bestandestruktur (entsprechend dem Primärwald) oder eine mehr offene (wie sie auf Lichtungen oder auf Plantagen herrscht) die Termitenverteilung beeinflussen. Dabei wurde vor allem die Bodenfeuchte als wichtiger Faktor angenommen. In einem letzten Experiment sollte deshalb untersucht werden, inwieweit die Biodiversität eines Systems Einfluß auf die Bodenfauna hat.

Die vorgestellten Überlegungen führten zur Durchführung mehrerer experimenteller Blöcke.

7 Material und Methoden

7.1 Untersuchungsflächen

Die Flächen werden als terra firme-Gebiete (Festlandregenwald) eingestuft. Sie liegen auf dem Gelände der Embrapa - Amazônia Ocidental), ca 30 km nördlich von Manaus. Dort wurden vor 15 Jahren 19 ha Primärwald abgeholzt, um eine Kautschukplantage anzulegen. Diese Plantage lag jedoch kurze Zeit später brach; daraufhin wurde sie gefällt und gebrannt. Sekundärwald wuchs nach. Im August/September 1992 wurde ein Teil des nachgewachsenen Sekundärwaldes in traditioneller Weise abgeholzt und gebrannt. Zur Rekultivierung etablierte man, im Rahmen eines SHIFT Projekts der Universität Hamburg in Kooperation mit der EMBRAPA-CPAA, 4 verschiedene Polykultursysteme , 4 Monokulturpfanzungen sowie 1 Brache. Die 4 Polykultursysteme existieren in 4 unterschiedlichen Düngervarianten. Von den Systemen gibt es 5 Wiederhohlungen (A,B, C, D, E) . Die Größe der einzelnen Polykulturflächen beträgt 32 x 48 m. Direkt an die Polykultursysteme grenzen Primärwald und Sekundärwald.

7.2 Monitorstationen

Verwendet wurden Monitorstationen modifiziert nach Su et al. (1985) Hierbei handelt sich um PVC-Röhren von 25 cm Länge und 16 cm Durchmesser, die einen Köder enthalten (Holz, Pappe etc.). An zwei Seiten befinden sich sechs 3 x 1 cm Öffnungen, die den Termiten die Zugang zum Köder erleichtern sollen. Sie wurden mit Hilfe eines Bodenbohrers vollständig eingegraben und mit einem Deckel verschlossen. So waren die Stationen vor Witterungseinflüssen geschützt. Die im Inneren der Monitorstationen plazierten Köder lassen sich problemlos entnehmen. Die Länge der Stationen begründet sich darauf, daß dieTermiten hauptsächlich in den oberen 30 cm des Bodens aktiv sind (Lavelle, 1995).

7.3 Block I

In situ Überprüfung der Nahrungsgildenzugehörigkeit sowie der Termitenaktivität

Versuchsflächen:

- Primärwald: 2 Flächen mit jeweils 40 x 40 m

- Sekundärwald: 2 Flächen mit jeweils 40 x 40 m
- System 4: 2 Polyholzkulturen (48 x 32 m), auf denen 4 Nutzholzarten (Seringueira (Kautschuk), Paricá, Mogno (Mahagoni), Andiroba) gepflanzt wurden mit spontan zugelassener Vegetation, hauptsächlich bestehend aus 2 Arten Vismia (Clusiaceae).

Verwendete Köder und ihre Zielgruppen:
- Karton bzw. Wellpappe für Laubernter, Generalisten
- Holz ("Acangaçu") für Feucht-/ Trockenholzfresser, Generalisten.
- Palmsubstrat ("Xaxim") (Humusfresser, Generalisten).

7.3.1 Versuchsaufbau Block I
In allen 3 Waldsystemen wurden jeweils 40 Fallen ausgebracht, mit alternierender Substratabfolge. Die verwendeten Köder wurden in einer Form ausgewählt, daß möglichst Vertreter aller 4 Nahrungsgilden erfasst werden konnten. Die Monitorstationen dienen zur Überwachung der Aktivität der Termiten auf den Untersuchungsflächen.

7.4 Block II
Überprüfung der Rolle der Bestandesstruktur
Versuchsflächen:
- Monokultur: Pupunha Palmen gepflanzt im Abstand von 4 m, die Versuchsfläche ist 20 x 20 m groß, keine Bodendecker.
- System 2: Polykultur aus 4 verschiedenen Nutzbaumarten mit der Fläche 48 m x 32 m: Pupunha, Urucum, Cupuacu und Castanha, mit Pueraria als Bodendecker.

7.4.1 Versuchsaufbau Block II
In der Pupunha Monokultur wurden jeweils 10 Monitorstationen (siehe 6.2) ausgebracht, da die Monokultur nur zur Hälfte mit ausgewachsenen Bäumen bepflanzt ist. Der Abstand zu jedem Baum betrug 60 cm. Die Köder waren nur aus Holz (siehe Ergebnisse zu 6.3)
Im System 2 wurden 20 Monitorstationen ausgebracht, davon jeweils 10 unter dem Bodendecker Pueraria und 10 unter den dort vorhandenen Pupunha-Palmen. Alle 1-2 Wochen wurde mit einem TDR die Bodenfeuchte in den Fallen (30 cm Tiefe) und an der Oberfläche der Falle gemessen (10 cm Tiefe). Dieses Versuchsdesign wurde in 4 Parzellen (A, B, C, D) wiederhohlt.

7.4.2 Block III
Überprüfung des Einflusses der Biodivertät eines Systems auf Termiten
- Monokulturen: 3 verschiedene Nutzbaumarten mit der Fläche 48 m x 32 m (Kautschuk, Orangen und Cupuacu) sowie Bodendecker (Pueraria)
- System 3: Eine Polykultur aus den o.g. Bäumen sowie Kokospalme und Bodendecker (Pueraria).

7.4.3 Versuchsaufbau Block III
In den Monokulturen wurden jeweils 10 Monitorstationen (siehe 6.2) ausgebracht, davon jeweils 5 unter einem Baum und 5 unter dem Bodendecker. Der Abstand zu jedem Baum betrug 60 cm. Die Köder waren nur aus Holz (siehe Ergebnisse zu 6.3)
Im System 3 wurden 40 Monitorstationen ausgebracht, davon jeweils 5 unter den Bäumen korrespondierend mit den Arten in Monokultur, 5 unter der Kokospalmen um einen möglichen Einfluss dieser Art zu dokumentieren. Bedauerlicherweise ist auf dem Versuchsfeld keine Kokspalmen-Monokultur gepflanzt worden. Falls es einen "Palmeneffekt" gibt, wird die Pupunha-Palmen Monokultur als Modell herangezogen. Die restlichen 20 Monitorstationen wurden unter dem Bodendecker Pueraria gesetzt. Alle eins bis 2 Wochen wurde mit einem TDR die Bodenfeuchte in den Fallen (30 cm Tiefe) und an der Oberfläche der Falle gemessen (10 cm Tiefe). Der Versuchsansatz wurden in den 4 Parzellen (A,B, C, D) wiederhohlt, sodaß 4 Replikate vorliegen.

8 Ergebnisse
8.1 Block I
In Tabelle 3 sind Arten aus den Monitorstationen auf den Untersuchungsflächen bis einschließlich Oktober 1998 dargestellt.

Tab. 3: Verteilung der Arten auf den Untersuchungsflächen in Abhängigkeit der Nahrungsgildenzugehörigkeit

Termitenart	Nahrungsgilde (Literatur)	Primärwald	Sekundärwald	Polyholzkultur
Constrictotermes sp.	**Xylophag**	**x**	**x**	**0**
Neocapritermes sp.	**Xylophag**	**x**	**0**	**x**
Labiotermes labralis	**humivor**	**x**	**x**	**x**
Syntermes molestus	**Laubfresser**	**x**	**x**	**0**
Amitermes sp.	**Generalist**	**x**	**0**	**0**
Coptotermes sp	**Generalist**	**x**	**x**	**0**
Nasutitermes sp.	**Generalist/ xylophag**	**x**	**x**	**0**
Termes fatalis	**Generalist**	**x**	**0**	**x**

x = vorhanden
0 = nicht vorhanden

Aus Tabelle 3 lässt sich eindeutig erkennen, daß die Artenvielfalt vom Primärwald bis zu Polyholzkultur abnimmt.

Abb. 5: Termitenaktivität im Primärwald, abhängig vom angebotenen Substrat

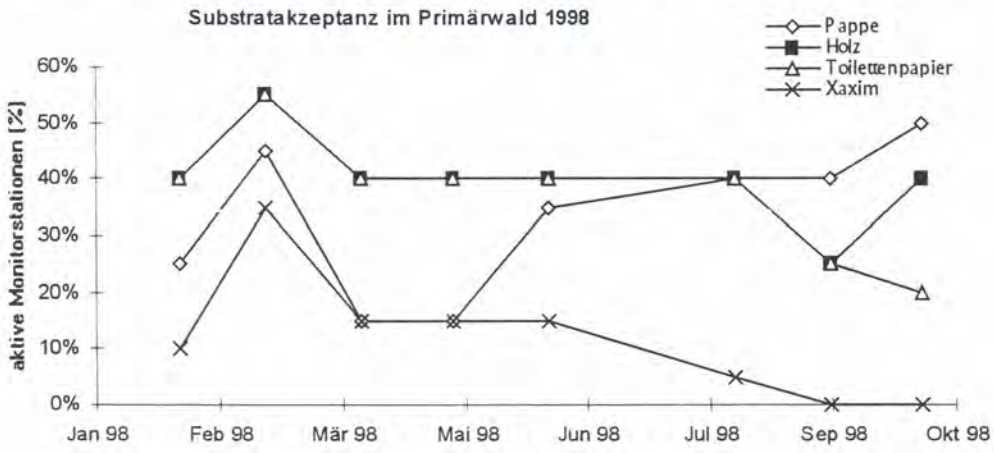


Abb. 6 : Termitenaktvität im Sekundärwald, abhängig vom angebotenen Substrat

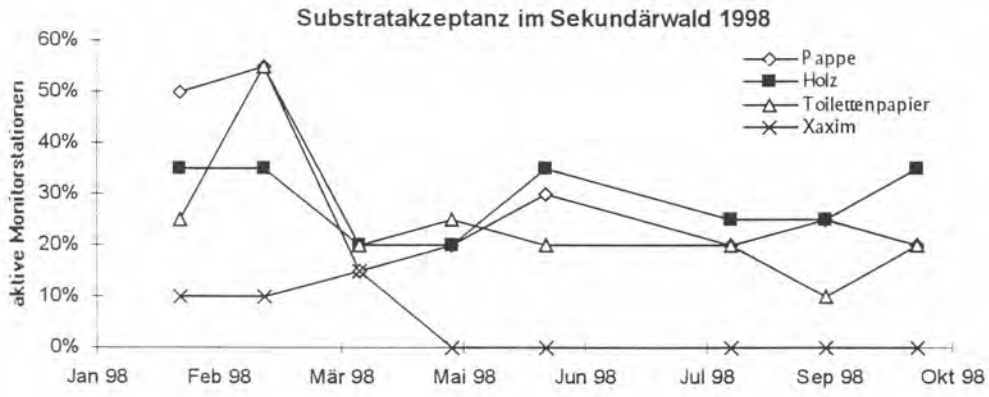
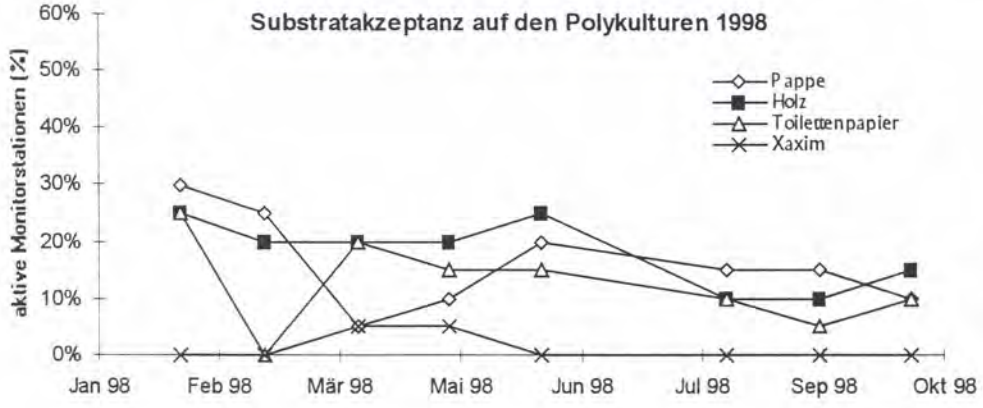


Abb.7: Termitenaktivität auf den Polykulturflächen, abhängig vom angebotenen Substrat



Die Abbildungen 5-7 zeigen einerseits die Aktivität der Termiten an den Köderfallen sowie die Akzeptanz des angebotenen Substrats.
Zu erkennen ist, daß die 3 Untersuchungsflächen unterschiedlich in der Belegung der Monitorstationen waren. Im Primärwald (Abb.5) sind am meisten Fallen akzeptiert worden, der Sekundärwald (Abb.6) liegt in der Mitte und die Polykulturen (Abb. 7) zeigt die geringste Termitenaktivität. Auffällig ist, daß die mittlere prozentuale Aktivität gleich zu Anfang erreicht wird und sich über die Zeit kaum ändert. Allerdings ist die Aktivität im Februar/März 1998 (Ende Regenzeit) besonders hoch und fällt im April/Mai 1999 (Beginn Trockenzeit) ab.

8.2 Ergebnisse Block II

Abb. 8: Termitenaktivität auf der Polykultur im Vergleich zur Monokultur

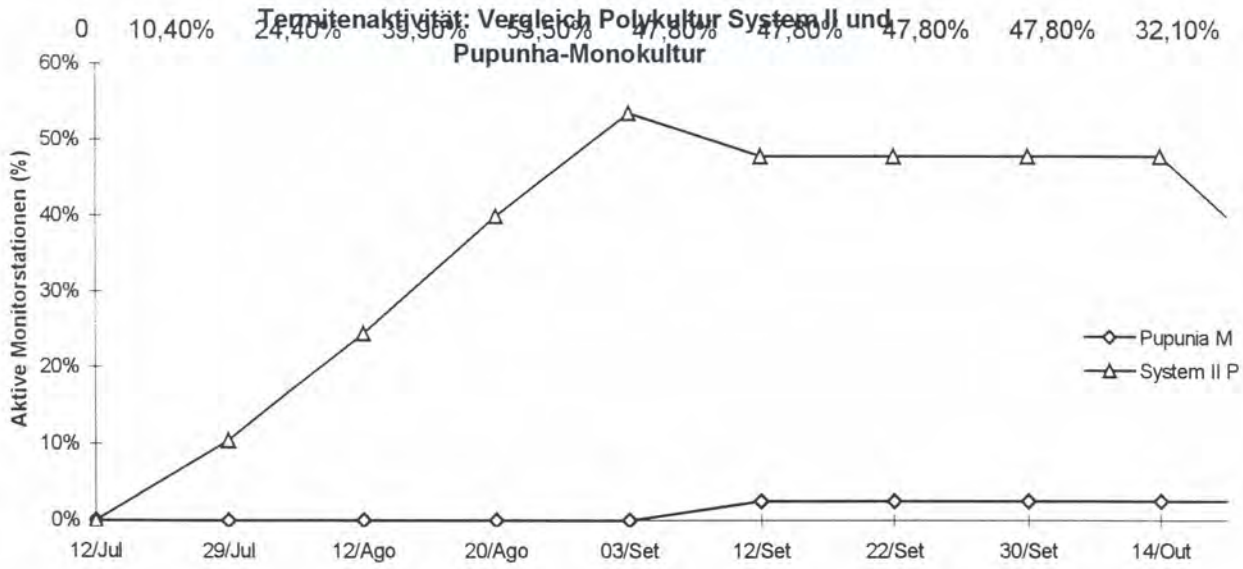


Abb. 9: Termitenaktivität unter Pueraria und Termitenaktivität unter Pupunha im System II

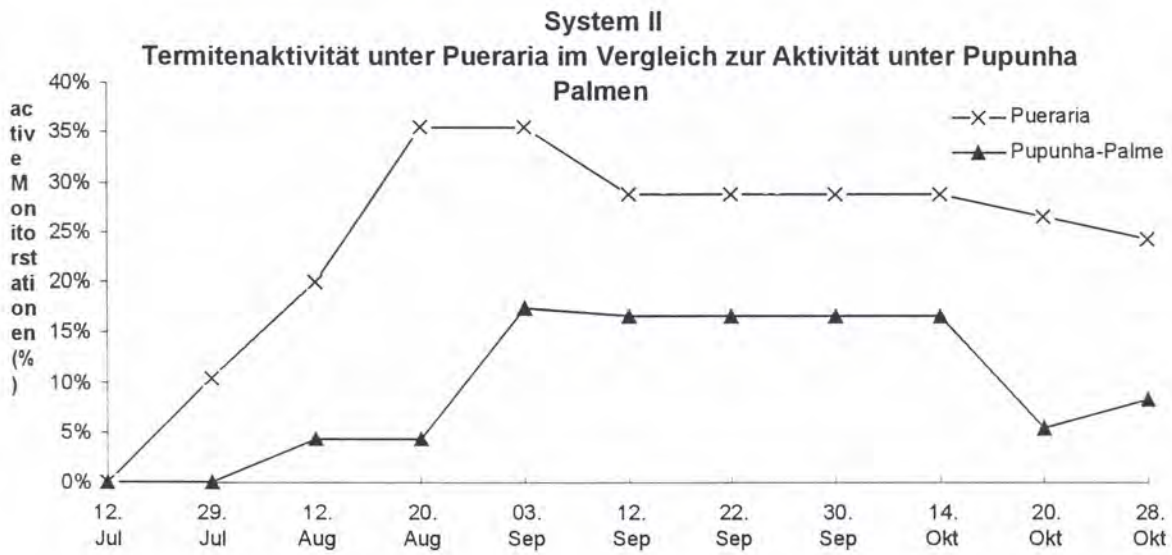
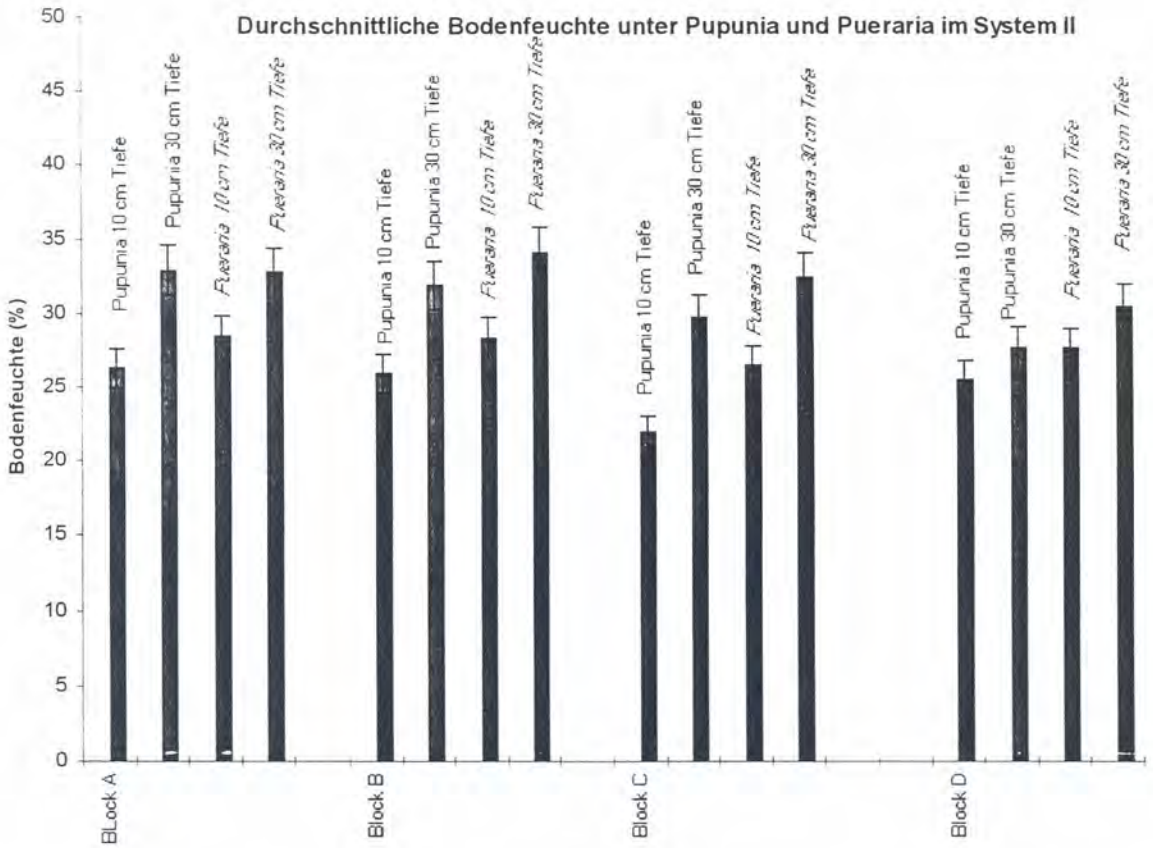


Abb. 10: Durchschnittliche Bodenfeuchte unter Pupunha und Pueraria im System II



Block II ergab folgendes: Die Pupunha Monokultur ist so gut wie nicht von Termiten frequentiert (Abb. 8). Im System II hingegen sieht man eine relativ hohe Aktivität. Innerhalb dieses System,s zeigt sich auch eine Präferenz der Termiten für die Monitorstationen unter dem Bodendecker (Pueraria; Abb. 9). Desweiteren wurde gezeigt, daß der Boden unter den Pupunha Palme trockener ist als unter der Pueraria (Abb. 10). Somit liegt eine Feuchteabhängigkeit der Termitenaktivität nahe.

8.3 Ergebnisse Block III

Dieser Versuch wurde Anfang November 1999 im Feld installiert, die Auswertung findet frühestens ab Januar 2000 statt.

9 Diskussion

9.1 Block I **"Insitu Überprüfung der Nahrungsgildenzugehörigkeit sowie der Termitenaktivität"**

Auf allen Versuchsflächen wurde in den Monaten Februar bis Oktober eine mäßige Aktivität beobachtet (siehe Abb. 5 - 7). Die Stationen wurden monatlich überprüft, Substrate, die sich in der Regenzeit als ungeeignet herausstellen, ausgetauscht. Ungeeignete Substrate sind Toilettenpapier sowie Pappe. Schon z.T. 2 Wochen nach deren Auswechslung wurde Schimmel oder Pilzbefall registriert. Dies bedeutet im Endeffekt, daß diese Substrate für ein längerfristiges Monitoring nicht geeignet sind. Das Palmsubstrat Xaxim hat sich als relativ unattraktiv herauskristallisiert (siehe Abb. 5 - 7). Im Primärwald wurde erwartungsgemäß die höchste Termitenaktivität beobachtet (vgl. Tab. 3 und Abb. 5 - 7). Die Aktivität der Termiten nimmt im Sekundärwald ab, und auf den Polyholzkulturen sind kaum Termiten zu finden.

Die Nahrungsgildendifferenzierung mit Hilfe der unterschiedlichen Substrate ließ sich nicht absichern, da es mehrere Termitenarten gab, die sowohl an Pappe, Holz und Tiolettenpapier gefunden wurden. Eine weitere Schwierigkeit dieser Differenzierung lag darin, daß häufig keine Soldaten gefunden wurden, ohne die eine taxonomische Bestimmung oft nicht möglich ist.

9.2 Ausblick zu Block I

Durch die Fraßaktivität der Termiten an den Ködersubstraten kann ihre An- bzw. Abwesenheit auf den Flächen festgestellt werden. Daraus ergibt sich ein Monitoring von Termitenpräsenz in

unterschiedlichen Waldökosystemen. Da Termiten eine wichtige Rolle im Streuabbau spielen und gleichzeitig Schädlinge für bestimmte Kulturpflanzen sind, kann diese Methode in tropischen Agroforstsystemen zum Monitoring von Termiten angewandt werden. Die hier verwendeten Monitorstationen sind zur Überprüfung der Termitenaktivität geeignet. Man kann mit Hilfe dieser Methode eine verläßliche und langerfristige Beobachtung von Termitendynamik auf unterschiedlichen Flächen durchführen. Ziel dieses Teil war es, die Dynamik und Aktivität von Termiten in Ökosystemen zu dokumentieren. Diese Ziel ist nach vorgestellter Datenlagen erreicht worden, jedoch müssen noch einige Teilaspekte einer weitergehenden Auswertung der Daten unterzogen werden; dazu gehören u.a.:

- Welchem Verteilungsmuster unterliegen die Termiten (geklumpt oder zufällig)?
- Kann eine anthropogene Systemänderung nachteilig auf die Termitenaktivität wirken, und z.B. Stoffkreislaufe verlangsamen (siehe auch Teil A)?

Die Nahrungsgildenzugehörigkeit konnte in situ nicht nachgewiesen werden. Im Laufe dieser Arbeit ergaben sich auch einige Zweifel an der Einteilung nach Eggleton (1995).
Das gab den Anreiz, die Nahrungspräferenz mit einem Laborversuch (Block IV) zu überprüfen.
Die Idee ist, 4 verschiedene Substrate (Boden, Wurzeln, Blätter und Holz) mit ^{15} N markiert 3 verschiedenen Termitenarten, deren Nahrungsgilden-zugehörigkeit in der Literatur eindeutig identifiziert ist, anzubieten. Anschließend werden die Tiere auf ^{15} N spuren analysiert.
Block IV wäre eine Basisstudie, die helfen kann, in Zukunft Nahrungsquellen von Termiten eindeutig zu identifizieren. Dieser Versuch läuft Mite Dezember 1999 an der Embrapa an.

9.3 Block II : **Überprüfung der Rolle der Bestandesstruktur**

Die Daten dieses Teils zeigen sehr interessante Aspekte der Ökologie von Termiten: Es wurde gezeigt, daß Termiten die Polykultur gegenüber der Monokultur bevorzugen (Abb. 8) sowie innerhalb des Systems II die Standorte unter dem Bodendecker bevorzugen (Abb. 9).
Da die Bodenfeuchte offensichtlich ausschlaggebend ist (Abb. 10), sind diese Informationen wertvoll, da Termiten als ein großer Teil der Bodenfauna eventuell Indikatoren für einen gesunden Boden sein könnten.
Warum die Monokultur für sie so unattraktiv ist, kann kurz angerissen werden:
Einerseits verdichten die Pupunha-Palmen sehr den Boden, was ihn sehr kompakt und "Bodenfauna"-unattraktiv macht. Andererseits trocken die Palmen über ihre hohe Evapotranspiration den Boden aus (Schroth, 1999, pers. Mitteilung).
Das Klima über dem Boden ist zwar sehr ähnlich dem im Primärwald (Martius, Schroth, pers. Mitteilung, 1999), im Boden selbst scheint dies nicht der Fall zu sein.

9.4 Ausblick zu Block II

Dieser Versuch suggeriert weitere Untersuchungen auf diesem Gebiet. Die Ergebnisse zeigen, daß es einen Zusammenhang zwischen Bodenfeuchte und Termitenpräsenz gibt. Ob Termiten generell positiv auf ein Agroforstsystem reagieren, ist nicht entschieden. Sie wirken sich auf jeden Fall positiv auf die Bodenstruktur aus und umgekehrt . Dadurch haben sie einen indirekten positiven Effekt auf Agroforstsysteme. Da sie sie eine Feuchte und Systempräferenz zeigten, kann diese Wissen in Zukunft auch auf angewandtere Fragen übertragen werden.

Die Ergebnisse dieses Versuches führten zur Durchführung von Blocks III, der zum Zeitpunkt dieses Reports in der Feldphase ist. Die Beobachtung, daß Termiten im System II wesentlich aktiver sind, ließ vermuten, daß diese Eigenschaft eventuell mit der Systembiodiversität zusammenhängt.

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Respiration Rates of Soil Fauna

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Introduction

Invertebrates are an important structural component of the soil compartment and fulfill essential functions within the ecosystem. The soil fauna is of major importance for litter decomposition and thus for the cycling of carbon (and other nutrients) in tropical forest systems as it has been demonstrated by litter bag experiments within the project SHIFT ENV 52. It could also be shown for the temperate zone in various other investigations published in the literature. Mineralization of organic matter and release of CO_2 from the soil and litter, however, is mainly attributed to the activity of the soil microflora, which in turn is thought to be enhanced by faunal feeding activity. The aim of the study reported here was to measure the amount of carbon that is directly respired by the soil fauna. Therefore an instrument to measure the respiration of small soil invertebrates was developed, based on an infra-red gas analyser (IRGA) designed to measure photosynthesis.

Methods

Respiration Measuring Device:

A portable computerised photosynthesis measuring system HCM-1000 (Heinz Walz GmbH, Effeltrich, Germany) was used. The central unit of the system consists of an infra-red gas analyser (IRGA), a peristaltic air pump, a mass flow meter and is connected to a measuring chamber (cuvette). It usually works in an open flow mode (differential mode) measuring the CO_2 -difference between the ambient air before and after passing the cuvette. The system is controlled via a computer. For soil fauna respiration measurements the flow was changed into a closed-circuit mode and the absolute CO_2 concentration was detected (Fig. 1).

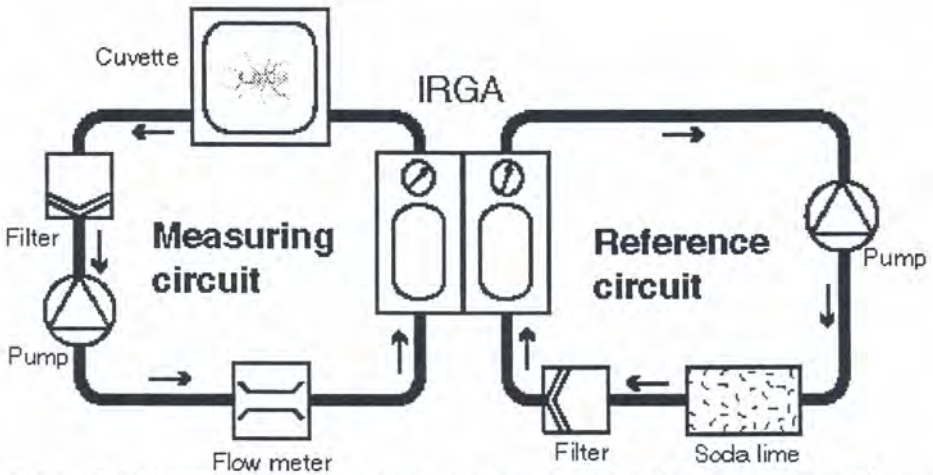

Fig.1: Respiration measuring device to measure the CO_2 –production of small soil invertebrates.

Cuvette

The cuvette, originally designed to enclose a single leave and to measure the CO_2 -uptake of the plant tissue was modified in a way that small soil invertebrates, e.g. isopods, could be placed easily in the cuvette and the cumulative increase in CO_2 over time due to animal respiration could be measured within a re-circulating air stream (closed circuit system).Therefore the original clamp of the cuvette to hold the leaf had to be replaced by a special respiration chamber. The latter consisted of a cylindrical box with a screw top made out of polyacetal (POM) and was connected via an inlet and an outlet to the closed circuit. After inserting a well perforated box (film box) containing the animal the respiration chamber was closed and flushed continuously by an air stream.. Film boxes containing animals to be measured were prepared separately beforehand so that a quick and easy exchange of the boxes was possible.

The air flow was changed in a way that CO_2 was measured in two separate closed circuits, a measuring and a reference circuit, each driven by a small peristaltic pump at a flow rate of 1000 mL min^{-1}. The measurement circuit flushed the animal containing respiration chamber while the

reference circuit was kept CO_2-free by sodalime. Only for the large glossoscolicidae the measurements were performed in the open-flow mode.
CO_2 –concentration, flow rate, temperature and relative humidity of the air inside the respiration chamber were measured permanently. A vibrating membrane in the bottom of the respiration chamber ensured that no gradients occurred.

Calibration of the system

The IRGA measured the concentration of CO_2 in an air stream as volumetric ppm. From this value the total amount of CO_2 could only be calculated if the entire volume of the closed system (V_t) was known. To calibrate the system a volume of 250 µL CO_2 was injected via a micro-syringe into the system several times. The CO_2 - concentration in the closed circuit increased by 322.6 ppm per 250 µL CO_2 added. From this increase the total volume of the circuit was calculated to be 310 mL.

Soil fauna

Different taxa of soil animals from the tropical rain forest near Manaus (Amazonia, Brazil) were chosen for respiration measurements. These were diplopods, isopods, and others (see Table 1). All animals were collected in the field by hand-sorting of the litter. They were kept in the laboratory at 26-28° C in boxes filled with soil and litter for maximal 4 days.

Respiration Measurements

On the day of measuring either one single animal or groups of animals were weighted and placed in well perforated film boxes. A film box was then put into the respiration chamber that was continuously flushed with air at 1000 mL/min in a closed circle leading to an increase in CO_2 –concentration within the circuit caused by the faunal respiration. During respiration measurements the relative humidity of the air in the closed system was in the range of 80 – 95%. The temperature inside the respiration chamber was adjusted to 28 °C. Gradients in temperature or CO_2- concentration inside the respiration chamber were avoided due to the flow rate and additional ventilation by a vibrating membrane. Each single animal or group of animals was measured on 1-4 periods, each measurement-period lasting 10 minutes. Within each period the CO_2 –concentration, temperature, relative humidity and the flow rate were measured and recorded every 30 seconds. The increase in CO_2 -concentration within each 10 minutes period was divided by ten to achieve the average increase per minute (ΔCO_2). Before putting in a new box with animals the circuit was flushed with fresh air to achieve comparable CO_2 – concentrations at starting point. Measurements with empty respiration chamber were performed before and after each measurement of animals to assess possible base-line drift of the analyser.

Calculation of faunal respiration

Respiration rate in the closed-circuit mode was calculated by the formula (1)

$$(1)\ R_{closed} = \frac{\Delta CO_2 * V_t}{FW * 60}$$

with

R_{closed}	=	Respiration rate [µL CO_2 h^{-1} g^{-1}fresh weight]
ΔCO_2	=	Increase in CO_2 –concentration [ppm/min]
V_t	=	Total volume of closed system [L]
FW	=	Biomass of the animal [g fresh weight]

Respiration rate in the open-flow mode was calculated by the formula (2):

$$(2)\ R_{open} = \frac{\Delta CO_2 * Flow}{FW * 1000}$$

with

R_{open}	=	Respiration rate [µL CO_2 h^{-1} g^{-1}fresh weight]
ΔCO_2	=	Difference in CO_2 –concentration of the air before and after passage through the respiration chamber [ppm/min]
Flow	=	Flow rate of the air stream through the cuvette [mL/min]
FW	=	Biomass of the animal [g fresh weight]

Results and discussion

All animals survived the measurements without any visible damage. Respiration rates, measured as the increase in CO_2 –concentration over a time period of 10 minutes were almost linear. The base-line drift of the system during measurements of the tropical fauna was up to 2.1 ppm/min. Therefore respiration rates were corrected for the drift. The results are given in Table 1. The values represent mixed respiration activity of animals active and at rest except for the tropical diplopod (Platyrhacidae) that was actively moving throughout the measurements.

The lowest observed CO_2 -production of the examined taxa from the tropical forest was 26.8 µL CO_2 h^{-1} g^{-1} for a beetle (Passalidae) at rest. The respiration increased to 191.2 µL when the beetle was active. Assuming a respiratory quotient of RQ = 1 the values for a Passalidae reported by Bartholomew & Casey (1977) were higher, ranging from 213 µL at rest to 551-3495 µL when active.

The highest single value was found for a true bug with 1141.8 µL CO_2 per gram biomass. It can be assumed that the CO_2 –production also depends on the quality of the food (Nunes et al. 1997). Many true bugs feed on phloem liquid which is rich in sugars that can easily be respired.

Grasshoppers (Orthopteria) always produced high amounts of CO_2 per biomass with an average of 672.3 µL.

Lower average CO_2 –production was found for isopods 291.3 µL and diplopods 240.1 µL.

Respiration rates of the tropical diplopods were in the range found for diplopods from the temperate zone (Schallnaß, 1989). The respiration of the tropical isopods was slightly higher compared to176.1 µL CO_2 h^{-1} g^{-1} for Isopods from the temperate zone (Förster unpublished data).

The respiration rate found for earthworms seemed to decrease with increasing biomass (and decreasing ratio between surface area and biomass). The same tendency was already observed by Mendes & Valente (1953) who studied the respiration rate of three species (*Pontoscolex* sp. (small size), *Pheretima hawayana* (medium size) and *Glossoscolex* sp. (large size): The respiration rate dropped from 130 – 284, 60 – 271 to 38 – 109 µL O_2 h^{-1} g^{-1}. Further work from tropical regions (e.g. Mishra & Dash 1984) is not comparable to the data presented here due to different methods and/or measurement units.

Bolton (1970) measured the respiration of the earthworm species *Dendrobaena rubida* and *Lumbricus castaneus* at 10° C and found values between 75 and 100 µL CO_2 h^{-1} g^{-1}. Larger lumbricid species like *Lumbricus terrestris* showed values between 70 – 90 µL O_2 h^{-1} g^{-1}; respiration can be higher during certain times of the day due to a diurnal rhythm (Edwards & Bohlen 1996). Uvarov (1998) could show that the respiration was (as expectable) highly temperature dependent: At 5° and at 25 ° C the respiration rate of *Dendrobaena octaedra* was 32.3 and 148.5 µL CO_2 h^{-1} g^{-1}, respectively.

In general, data on earthworm respiration reported in the literature are scarce, especially for tropical regions. Moreover the data are difficult to compare, due to the use of different methods and, even

more important, different measurement conditions. For example, often it is not known whether the conditions during measurements (temperature, moisture, light etc.) induce stress to the organisms Therefore, detailed measurements on the species level, using comparable study conditions and animals of different size and activity are required in order to determine the contribution not only of earthworms but all soil invertebrates to the function of the tropical soil ecosystem.

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Table 1: Respiration rates of some tropical soil invertebrates from Amazonia.

Taxa (No. of individual group or specimen measured)	No. of animals in the cuvette	Total Biomass fresh weight [g]	Respiration (mean) [µL CO_2 h^{-1} g^{-1} biomass]
Woodlice (Isopoda)			
(1)* Gen. sp.	10	0.306	245.2
(2)	10	0.465	308.9
(3)	10	0.650	290.8
(4)	10	0.539	273.7
(5)	5	0.293	282.7
(6)	5	0.294	303.7
(7)	10	0.584	334.4
Millipeedes (Diplopoda)			
(1) Trigoniulus lumbricinus	1	0.665	214.9
(2)	1	0.603	253.4
(3)	1	0.535	368.7
(4)	1	0.703	195.7
(5)	1	0.607	128.9
(6)	1	0.699	208.5
(7)	1	0.616	266.0
(8)	1	0.767	268.6
(9)	1	0.531	202.1
(1) Asiomorpha coarctata	5	0.251	352.7
(1) Plusioporus setiger	1	0.689	185.7
(2)	1	0.615	117.9
(1) Platyrhacidae Gen. sp. (active)	1	1.424	199.5
(1) Chelodesmidae Gen.sp.	1	0.167	258.4
(2)	1	0.258	203.3
(3)	1	0.253	306.1
(4)	1	0.256	351.7
Cockroach (Blattodea)			
(1) Gen.sp.	1	0.215	404.5
(2)	1	0.204	534.0
Beetle (Passalidae)			
(1) Gen. sp. (active)	1	1.620	191.2
(1) Gen. sp. (at rest)	1	1.620	26.8
Spiders (Opilionida)			
(1) Gen.sp.	5	0.246	363.3
Grashoppers (Orthopteria)			
(1) Gen.sp.	1	0.842	697.5
(2)	1	0.405	994.6
(3)	1	0.242	408.1
(4)	1	0.144	767.3
(5)	1	0.182	494.0
True bugs (Heteroptera)			
(1) Gen.sp.	1	0.185	1141.8
Earthworms (Glossoscolecidae)			
(1) Rhinodrilus priollii	1	1.344	172.4
(2) Rhinodrilus priollii	1	1.061	170.3
(3) ?	1	27.3	106.1
(4)?	1	71.4	48.5
(5)?	1	76.7	43.8

Decomposition in litterbags and mini-containers

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1. Introduction

Decomposition can be regarded as an ecosystem service, rendered by the faunal and microbial community living in the litter and upper soil strata. The functioning of the decomposition process, consisting of the physical and chemical breakdown of the litter, is the base for the release of nutrients from the plant residues and for the uptake by the living plants. Thus, it is vital for a sustainable use of land in agricultural or forestry systems, especially on nutrient-poor soils of the tropics.

2. Study sites and methods

Study sites were four plots of three different forest systems - one 40 x 40 m plot in a primary forest (FLO), one 40 x 40 m plot in a nearby secondary forest (growing since 1984, SEC) and two plots of 32 x 48 m large polycultures (POA, POC), where four different tree species of commercial use have been planted in rows. In the polyculture plots the tolerated secondary vegetation (dominated by *Vismia* spp., Guttiferae) constituted most of the stand and especially of the litter production (Beck et al. 1998).

We studied decomposition using the classical method of exposing weighed litter of a standard litter species enclosed in polyester gauze bags of different mesh sizes. We used about 7 g of air-dried leaves of *Vismia* sp. (Guttiferae), which were collected soon after falling from an area where these trees grow practically in monoculture. To be able to refer all later weights to dry weight of the original litter we dried subsamples in a laboratory oven at 65 °C and calculated a factor to correct weights of the air-dried leaves.

Leaves were placed in litterbags measuring 25 x 25 cm with three different mesh widths: 1 cm (10.000 µm), to allow the entrance and activity of virtually all macrofauna animals; 250 µm, to allow the entrance of mesofauna, but exclude macrofauna representatives; and 20 µm, to completely prevent faunal activity. These mesh sizes were chosen after an initial test with field exposure of bags during 1 month and extraction of the colonizing fauna (Beck et al. 1998). All bags were closed by sewing, in bags of the two smaller mesh widths seams were additionally closed by silicone glue. Two series of litterbags were exposed in the field, the first series in the late dry season at October, 27 1997 with the last of 7 retrievals at October, 27 1998; the second series started in the late wet season at April 22, 1998 with the last of 6 retrievals at April 19, 1999. The first series was thus initiated during the rainy season (November to April) and the second series during the dry season (May to November), but both were exposed over the two seasons of a whole year.

A set of three litterbags, one of each mesh width, was placed on the ground surface in each of 112 one-square-meter-quadrats randomly chosen in each plot (resp. 56 in each polyculture plot). At every retrieval date 14 sets of litterbags from each forest type were retrieved from the field, enclosed in plastic bags and transported to the laboratory, where they were opened, visually inspected for the main physical and biological actions occuring on the material (breakdown, hyphae and mycelia formation, root penetration, action of termites, accumulation of soil or other residues and presence of soil fauna) and then prepared for three different procedures: Berlese extraction of fauna (10 setsper forest type), wet extraction of

Enchytraeidae (2 sets per forest type) and respiration measures (2 sets per forest type). After Berlese extraction (7-12 days), the bags were oven dried at 45 °C and weighed; the leaves were then ground for chemical analyses and determination of ash weight. Retrieval weights were corrected by a factor resulting from the ash weight of the retrieved substrate to exclude inorganic particles (e.g. soil) and another factor to include ash weight of the original leaf material (Potthoff & Loftfield 1998). Final remaining weights were compared with the original weights for each individual litterbag and weight losses calculated and submitted to regression analyses.

As a possible alternative for studying decomposition rates we tested, for the first time in a tropical ecosystem, mini-containers, a method proposed by Eisenbeis et al. (1996), with the perspective to improve the handling of large replicate numbers and consequently the statistical analysis of decomposition data.

Mini-containers are small polyethylene containers (l=16 mm, d=11 mm) which, in our case, were filled with several leaf pieces punched out of freshly fallen, air-dried *Vismia* leaves (100 mg per container). The minicontainers were closed on either side with gauze disks. We used two of the mesh sizes of the litterbags, 20 µm and 250 µm in the minicontainers. 6 minicontainers of each mesh width were placed in alternated sequence in one PVC-bar of 38 cm length.

The mini-container bars were exposed together with the litterbag groups in two different time series. 30 mini-container-bars were randomly distributed in every plot. Bars were horizontally exposed on the litter surface, with one of the gauze sides directed to the top, and the other in contact with the litter layer.

During the first three retrieval dates of litterbags of each experiment 10 bars were always collected together with the litterbags. Thus, the first series was exposed at 27.10.97 and retrieved after 25, 56 and 84 days, while the second series was exposed at 20.4.98 and retrieved after 28, 60 and 113 days. When retrieved, every bar was enclosed in a plastic bag and transported to the laboratory, where its conditions (containers lost or gauze open or perforated) were checked and anotated. The whole bars were then put for three days in a laboratory oven at 45 °C to dry the leaf pieces. Containers were opened and their content weighed. Leaves of all containers with the same mesh width from one study area were then mixed together for further chemical analyses. Weight loss was calculated from the original and retrieval weight of each container and subjected to a regression analyses.

All statistical calculations were done with Sigmastat 2.03 and graphics and regression analyses made with Sigmaplot 4.0 (Jandel Scientific Software). To calculate the regressions we used the 10 (5 in POA and POC) single retrieval weight values, not the means of each retrieval, so that the variability was included.

3. Results

Decomposition in litterbags

The mean corrected remaining weights of the first series of litterbags from all areas are presented in Tables 1 and 3 and the course of the weight loss in different areas and mesh widths, calculated by regressions, in Figs. 1-4 and 5-8.

Table 1: Remaining weights (in % of original weight, means and standard deviations) of leaf material from each plot and mesh size after exposure in the field during the first experiment from October 97 - October 98. n = 10 for the primary (FLO) and secondary forest (SEC) and n = 5 for the polycultures (POA, POC).

plot	exposure	mesh size		
1. retrieval	25 days	fine	medium	coarse
POA		93.5 ± 1.1	94.2 ± 3.0	94.3 ± 2.0
POC		93.3 ± 1.1	95.0 ± 2.3	96.4 ± 1.3
SEC		95.9 ± 2.5	94.4 ± 2.6	94.3 ± 3.4
FLO		95.5 ± 3.0	94.1 ± 2.5	92.4 ± 4.2
2.	57 days	fine	medium	coarse
POA		94.1 ± 2.0	92.9 ± 2.0	85.9 ± 16.0
POC		94.1 ± 3.3	91.9 ± 0.5	93.0 ± 2.1
SEC		95.1 ± 1.6	94.1 ± 1.5	93.3 ± 2.2
FLO		92.6 ± 1.8	93.9 ± 8.3	78.6 ± 12.8
3.	84 days	fine	medium	coarse
POA		93.9 ± 2.8	88.7 ± 2.5	93.8 ± 4.9
POC		89.4 ± 1.4	91.0 ± 3.5	90.6 ± 1.8
SEC		94.4 ± 1.8	92.1 ± 1.1	91.5 ± 4.2
FLO		90.1 ± 1.6	90.2 ± 4.9	67.8 ± 25.8
4.	112 days	fine	medium	coarse
POA		93.1 ± 1.8	89.1 ± 1.6	90.3 ± 2.2
POC		87.1 ± 1.7	87.1 ± 0.8	48.4 ± 29.2
SEC		92.0 ± 4.8	91.4 ± 4.0	91.1 ± 2.6
FLO		81.6 ± 5.7	83.6 ± 3.5	54.1 ± 25.8
5.	168 days	fine	medium	coarse
POA		78.1 ± 7.7	81.7 ± 11.7	77.5 ± 5.6
POC		73.9 ± 3.6	78.2 ± 7.5	58.8 ± 23.1
SEC		83.6 ± 4.2	85.7 ± 2.9	76.3 ± 7.1
FLO		68.9 ± 8.6	72.0 ± 7.9	46.2 ± 22.8
6.	252 days	fine	medium	coarse
POA		78.6 ± 8.4	78.1 ± 6.6	63.3 ± 6.7
POC		65.0 ± 12.3	68.8 ± 6.4	53.8 ± 12.5
SEC		75.5 ± 9.2	82.0 ± 11.0	56.4 ± 16.2
FLO		62.9 ± 12.9	71.0 ± 7.6	38.4 ± 15.3
7.	365 days	fine	medium	coarse
POA		66.4 ± 4.4	67.6 ± 5.4	57.9 ± 8.9
POC		52.7 ± 9.1	59.3 ± 11.8	34.3 ± 15.2
SEC		67.4 ± 3.4	72.7 ± 6.6	46.8 ± 21.7
FLO		48.4 ± 10.9	54.3 ± 11.4	20.3 ± 12.7

About 80 % of the original leaf material had disappeared from litterbags exposed in both series during one year in the primary forest plot, when faunal activity was not restricted (coarse mesh). Only 46 and 50 % had disappeared from bags in the primary forest where macrofauna was excluded (medium mesh), and 52 and 48 % where mesofauna was also excluded (fine mesh)(Table 1). Differences in remaining weights between bags of coarse and medium mesh width become significant ($p<0.05$) in both series, generally from the second retrieval date. Differences between bags of medium and fine mesh width were almost never significant. The same treatment effect was significant in most of the later retrievals of the other areas, except the latest retrievals in POC.

The slow down of decomposition by exclusion of the macrofauna becomes obvious in the decomposition rates calculated from non-linear regressions (exponential decay) of the retrieval weights. Regressions by exponential decay functions were always highly significant and showed high r^2 values (Tables 2 and 4) . In both, medium and fine mesh bags decomposition rates decreased to about 50 % of the rates in coarse bags. Differences between decomposition rates of the different areas are also obvious. Especially POA and SEC showed a distinctly slower decomposition than FLO. The fact that the decomposition rates are highest in the coarse and lower in the medium and fine-meshed litterbags (Table 2) stresses again the importance of the macrofauna for the decomposition process. In all plots, except POC, decomposition was slightly faster during the second series, which was exposed in the late rainy season.

Table 2: Decomposition rates calculated from non-linear regressions (exponential decay) of retrieval weights in litterbags and mini-containers of the first series, with estimated half-life values (t_{50})(for litterbags $p < 0.0001$, minicontainers usually with $p = 0.05 - 0.07$).

mesh size	plot	k/day litterbags	r^2	k/year	t_{50} [days] litterbags	t_{50} [days] mini-container
10000 µm	**FLO**	0.0064	0.79	2.34	108	-
250 µm	**FLO**	0.0017	0.81	0.62	408	321
20 µm	**FLO**	0.0020	0.83	0.73	346	376
10000 µm	**POA**	0.0016	0.75	0.58	433	-
250 µm	**POA**	0.0011	0.81	0.40	630	409
20 µm	**POA**	0.0011	0.81	0.40	630	483
10000 µm	**POC**	0.0038	0.7	1.39	182	-
250 µm	**POC**	0.0015	0.86	0.55	462	407
20 µm	**POC**	0.0018	0.87	0.66	385	442
10000 µm	**SEC**	0.0024	0.72	0.88	289	-
250 µm	**SEC**	0.0008	0.73	0.30	845	338
20 µm	**SEC**	0.0011	0.84	0.40	630	386

Table 3: Remaining weights (in % of original weight, means and standard deviations) of leaf material from each plot and mesh size after exposure in the field during the second series (April 98- April 99). n = 10 for the primary (FLO) and secondary forest (SEC) and n = 5 for the polycultures (POA, POC).

plot	exposure	mesh size		
1.retrieval	26 days	fine	medium	coarse
POA		89.7 ± 1.7	94.8 ± 3.5	91.0 ± 7.4
POC		95.8 ± 1.9	96.8 ± 4.7	88.9 ± 13.2
SEC		96.7 ± 6.0	94.4 ± 5.5	93.5 ± 10.5
FLO		94.2 ± 4.9	98.4 ± 4.9	76.0 ± 23.5
2.	58 days	fine	medium	coarse
POA		92.2 ± 3.1	90.1 ± 5.5	89.3 ± 4.4
POC		93.3 ± 7.8	95.2 ± 1.4	92.9 ± 6.9
SEC		95.5 ± 2.6	92.2 ± 6.1	90.3 ± 6.0
FLO		88.9 ± 10.0	91.3 ± 4.3	60.8 ± 31.2
3.	111days	fine	medium	coarse
POA		92.3 ± 1.3	91.9 ± 3.9	92.9 ± 14.4
POC		84.6 ± 9.1	86.9 ± 4.2	78.3 ± 14.7
SEC		92.3 ± 4.7	89.9 ± 6.2	79.1 ± 9.6
FLO		80.4 ± 9.8	84.6 ± 4.2	42.8 ± 18.2
4.	174 days	fine	medium	coarse
POA		81.3 ± 7.0	79.7 ± 5.6	63.7 ± 12.2
POC		77.3 ± 8.1	79.3 ± 1.9	67.0 ± 9.5
SEC		83.1 ± 3.1	79.4 ± 7.0	61.7 ± 22.5
FLO		70.9 ± 8.4	69.1 ± 8.6	50.9 ± 30.7
5.	278 days	fine	medium	coarse
POA		76.5 ± 8.8	73.2 ± 6.3	56.1 ± 16.5
POC		63.1 ± 2.5	68.9 ± 5.6	44.5 ± 14.6
SEC		67.0 ± 7.0	64.0 ± 11.4	44.6 ± 8.9
FLO		53.9 ± 5.3	52.2 ± 9.8	20.8 ± 16.3
6.	350 days	fine	medium	coarse
POA		69.1 ± 4.7	64.1 ± 5.0	48.8 ± 24.4
POC		54.6 ± 8.0	60.6 ± 7.5	44.4 ± 18.4
SEC		65.8 ± 7.6	61.7 ± 6.5	42.6 ± 15.0
FLO		48.4 ± 7.6	49.8 ± 6.5	22.1 ± 14.9

Table 4: Decomposition rates calculated from non-linear regressions (exponential decay) of retrieval weights in litterbags and mini-containers of the second series, with estimated half-life values (t_{50}) (for litterbags $p < 0.0001$, for mini-containers $p < 0.05$).

mesh size	plot	k/day litterbags	r^2	k/year	t50 [days]	t50 [days] mini-container
1000 µm	**FLO**	85.00	76.00	310.00	82.00	-
250 µm	**FLO**	21.00	87.00	77.00	329.00	357.00
20 µm	**FLO**	22.00	79.00	80.00	316.00	420.00
1000 µm	**POA**	27.00	73.00	98.00	258.00	-
250 µm	**POA**	12.00	83.00	44.00	575.00	no sign. regr.
20 µm	**POA**	11.00	79.00	40.00	632.00	no sign. regr.
1000 µm	**POC**	29.00	76.00	106.00	239.00	-
250 µm	**POC**	14.00	89.00	51.00	496.00	408.00
20 µm	**POC**	17.00	85.00	62.00	408.00	433.00
1000 µm	**SEC**	30.00	70.00	109.00	232.00	-
250 µm	**SEC**	14.00	77.00	51.00	496.00	462.00
20 µm	**SEC**	12.00	85.00	44.00	575.00	481.00

Decomposition in mini-containers

Decomposition of *Vismia* leaves exposed in mini-containers was usually slightly faster than in litterbags of the same mesh size during the same periods (Figs 9 and 10). The course of the weight loss in the mini-containers over three months was not very well described neither by the usual exponential decay regression nor by linear regression. Remaining weights at the end were significantly different between the two mesh sizes (t-tests: 1. series $t_{11} = -5{,}475$, $p < 0.001$; 2. series $t_{11} = -4{,}255$, $p < 0.001$). There were highly significant differences between the remaining weights in the different plots (FLO < POA and SEC, POC < SEC) in a One-Way-ANOVA over both series.

Litterbag experiment in other vegetation types

The same litterbag experiment (three mesh sizes, using *Vismia*-leaves), realized in three other cultivated areas, a rubbertree monoculture, a peachpalm monoculture and a polyculture with cupuaçu (*Theobroma grandiflorum*), peachpalm (*Bactris gasipaes*), Brazil nut (*Bertholetia excelsa*) and urucum (*Bixa orellana*), showed the same treatment effect (decrease of decomposition by exclusion of the macrofauna)(Kurzatkowski 1999).

Factors influencing decomposition rates

As we sampled macro- and mesofauna every three months in the same areas where the litterbags were exposed, correlations between soil fauna biomass and decay rates could be made using data either from the four fauna sampling events within the period of the respective litterbag experiment or from all eight events and both experiments (Figs 11 and 12). Significant positive correlations with decay rates were calculated for decomposer biomass (including macrofauna arthropods and earthworms) for the first and over both series ($p < 0.001$); for earthworms for the second and over both series and for total macrofauna for the first series ($p < 0.007$).

Multiple regression analyses on possible factors affecting the dry weight loss of the periods between the retrievals showed significance for termite occurrence, fungi colonization and N-concentration for weight loss in FLO and SEC fine mesh litterbags during the first series and for daily rainfall, daily evaporation and/or daily deficit of soil water saturation in FLO and POA during the second series.

Nutrient content of litterbag material

C- and N-contents of the original material used for the litterbag study in the first series were N 0.74, C 48.8, C/N 65.9; for the second series N 0.86, C 51.0, C/N 59.3. Retrieved litterbags were always analysed individually. During the first series the relative N-content decreased (and C/N increased) during the first month in the polyculture plots, but not in the forest areas; during the second series N decreased only in the coarse litterbags, in all forest types. From the second retrieval (after 2 months) on the relative N-content increased in all areas, but the increase was highest in FLO, followed by POC, SEC and POA. C/N-ratios decreased consequently.

From the first series samples, of the last two retrievals (after 8.5 and 12 months) were compared statistically. Differences in N-content and C/N-ratio between areas were significant for all three mesh sizes (ANOVAs $P<0.05$). Litterbags exposed in the primary forest had higher relative N-content and lower C/N-ratio than all other plots, but in multiple comparison procedures (Tukey) differences were significant only for FLO-SEC (the extremes). Over all mesh sizes differences between all areas become significant ($P<0.01$).

Differences in N-content and C/N-ratio between mesh sizes over all forest types were highly significant ($P<0.001$) in the first series. Litter exposed in bags with coarse mesh size allowing entrance of the whole fauna had a higher relative N-content than litter in bags where macrofauna and mesofauna were excluded. In multiple comparison only differences between coarse and medium and coarse and fine mesh size were significant (both with $P<0.01$). Within the single plots, differences were only significant in POA and POC ($P<0.05$).

In the second series differences between mesh widths and differences between plots were both highly significant after one year. Litter exposed in the primary forest area again showed highest relative N-contents and lowest C/N-ratios. In multiple comparison FLO differed from SEC and from POA. In contrast to the first series, highest N-contents were found in the medium-mesh litterbags, which also had the lowest C-contents so that C/N ratios of coarse and medium mesh litterbags were both lower than of fine mesh litterbags.

The measured cation concentrations (K, Ca, Na, Mg) in the litterbag material during the first series decreased sharply from the first to the second retrieval (at the beginning of the wet season), especially in the bags of coarse mesh size, showing the leaching by rain water. In the litterbags with smaller mesh sizes leaching was obviously prevented by the mesh. In the finest mesh considerable increases of Mg, K and Na - concentrations were observed. N-concentrations increased strongly along time, leading to

a net increase of N in the decomposing leaves which is seen as a result of the biological activities (penetration of fungi mycelia, deposition of invertebrate faeces, etc.).
In both mini-container series the relative N-content also increased continuously in the primary forest in both mesh sizes and resulted in distinctly higher N-values and lower C/N-ratios than in the other plots. There were no significant differences between the two mesh sizes.

4. Conclusions

Exclusion of macrofauna by litterbags of 250 µm resulted in both series in a reduction of decomposition rates to 30 % in the primary forest area, to slightly below 50 % in the secondary forest area and in polyculture area C and below 70 % in polyculture area A.
Further exclusion of mesofauna did not lower decomposition rate very much. Decomposition rates were clearly highest in the primary forest and lowest in the secondary forest, which coincides with the low macrofauna abundance there and the observed litter accumulation (production/stock) in this area (see litter production and stocks).
As macrofauna obviously is the key group for decomposition in the studied Amazonian systems, mini-containers of medium and fine mesh width excluding macrofauna are not an adequate method to study decomposition, although they could be used to show effects of exclusion of the mesofauna, which were not shown by the litterbags.
Beside the differences in weight losses there were also differences in N-contents and consequently C/N-ratios between the areas, caused by the faunal activity as it is shown principally by the strong differences between coarse and fine mesh litterbags. The leaf litter in coarse litterbags in the primary forest is most strongly enriched in N, as a result of biological activity.
The obvious control of the decomposition process by macrofauna activity in all studied areas, including monocultures, and the dependence of macrofauna diversity and biomass from system- and site-specific variables like litter quantity and humidity points to the possibility to ameliorate microclimatic conditions in cultured areas and increase the litter (and nutrient) input in cultures by planting mulch producing plants (e.g. legumes).

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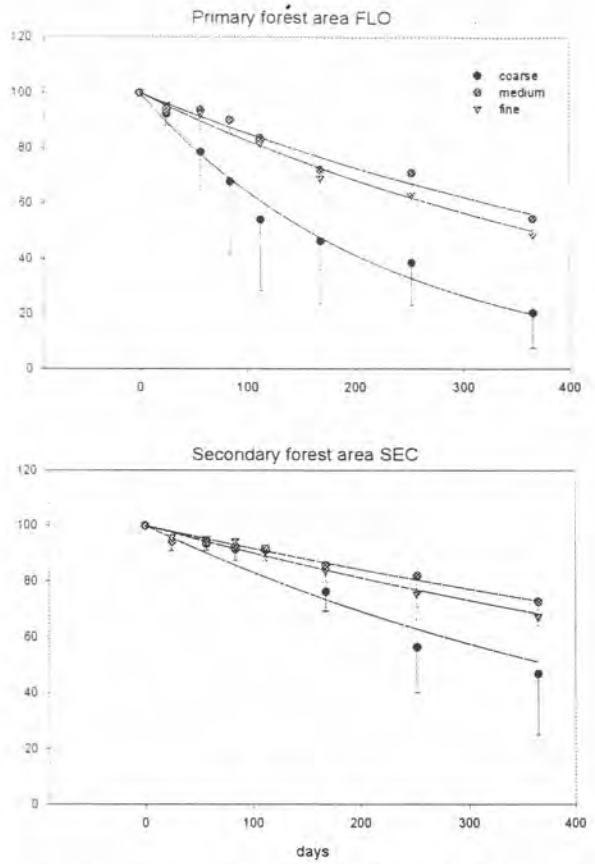
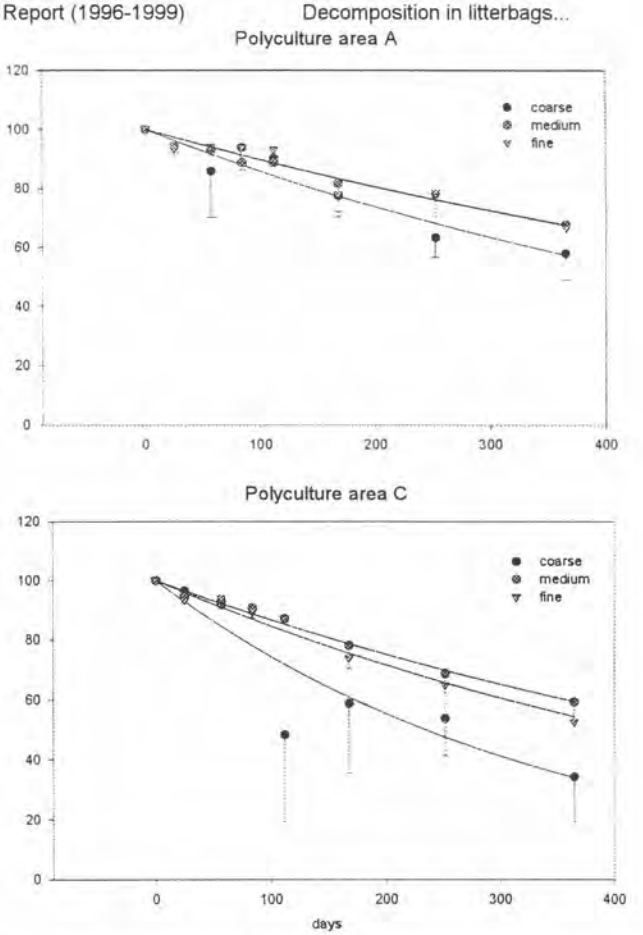
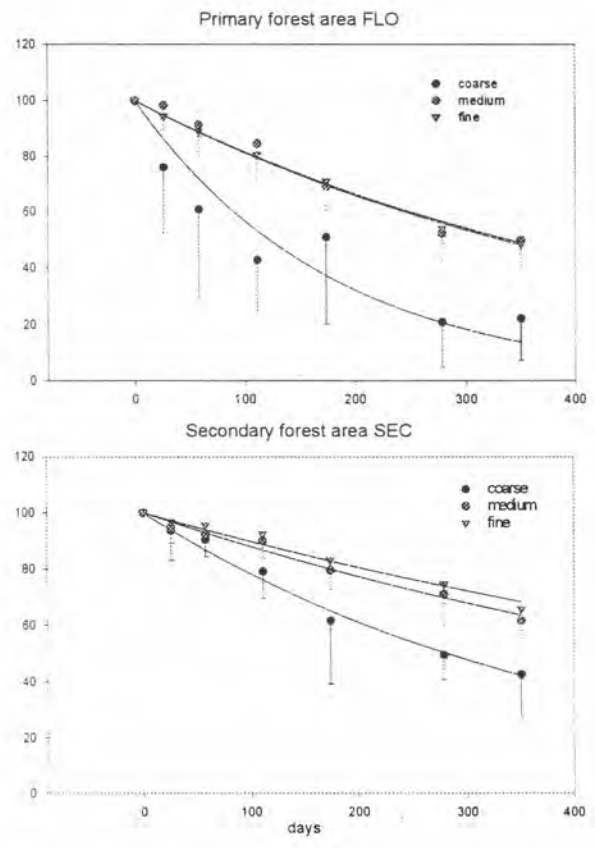


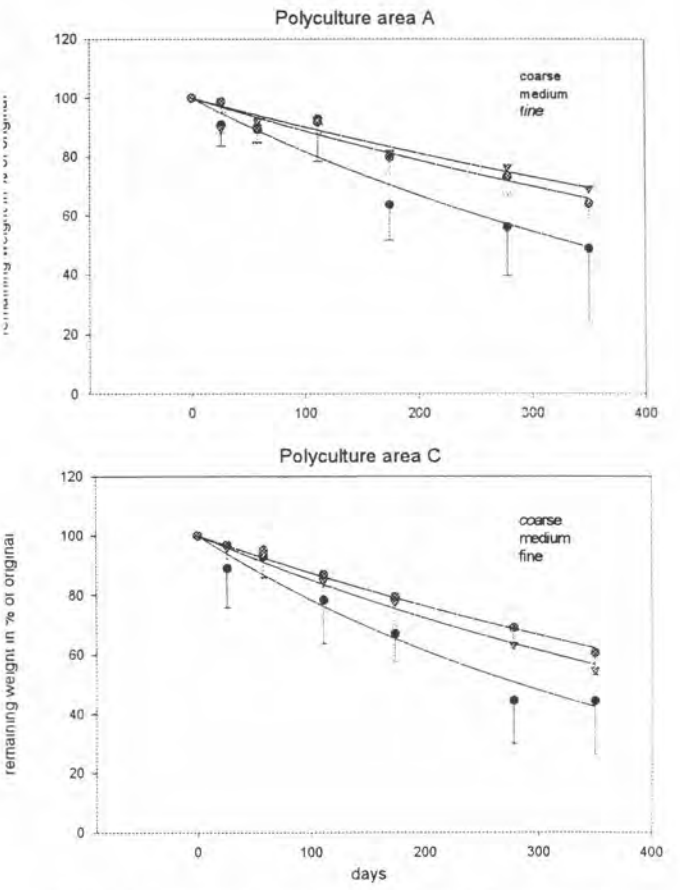
Figs 1,2: Decomposition of *Vismia* leaves in litterbags of different mesh width (regression by negative exponential decay) during the first series (October 97 - October 98)



Figs 3,4: Decomposition of *Vismia* leaves in litterbags of different mesh width during the first series (October 97 - October 98)



Figs. 5, 6: Decomposition of Vismia leaves in litterbags of different mesh width (regression by negative exponential decay) during the second series (*April* 98 -April 99)



Figs. 7, 8: Decomposition of *Vismia* leaves in litterbags of different mesh width (regression by negative exponential decay) during the second series (April 98 -April 99)

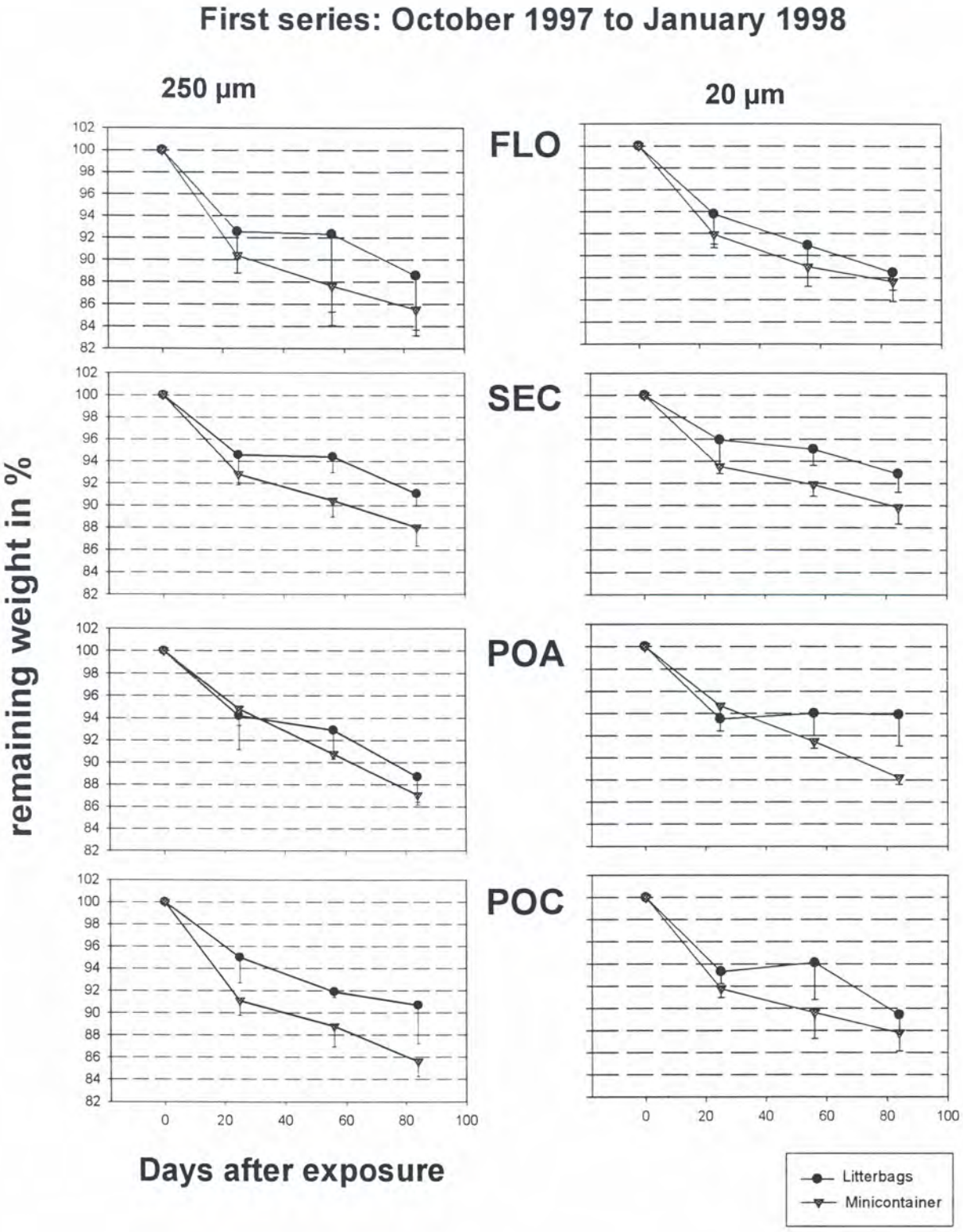


Fig. 9: Comparison of decomposition of *Vismia* leaves in litterbags and minicontainers

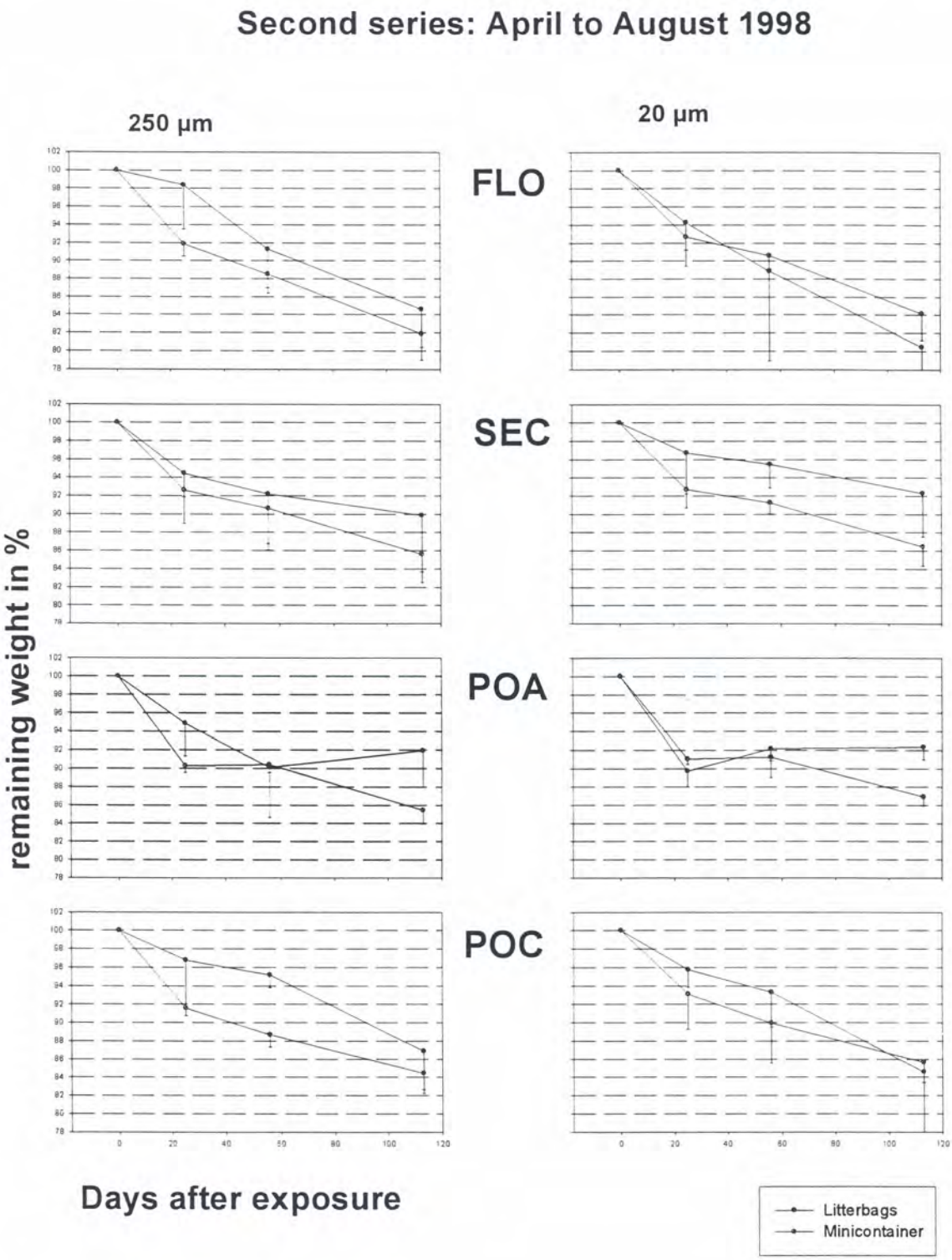
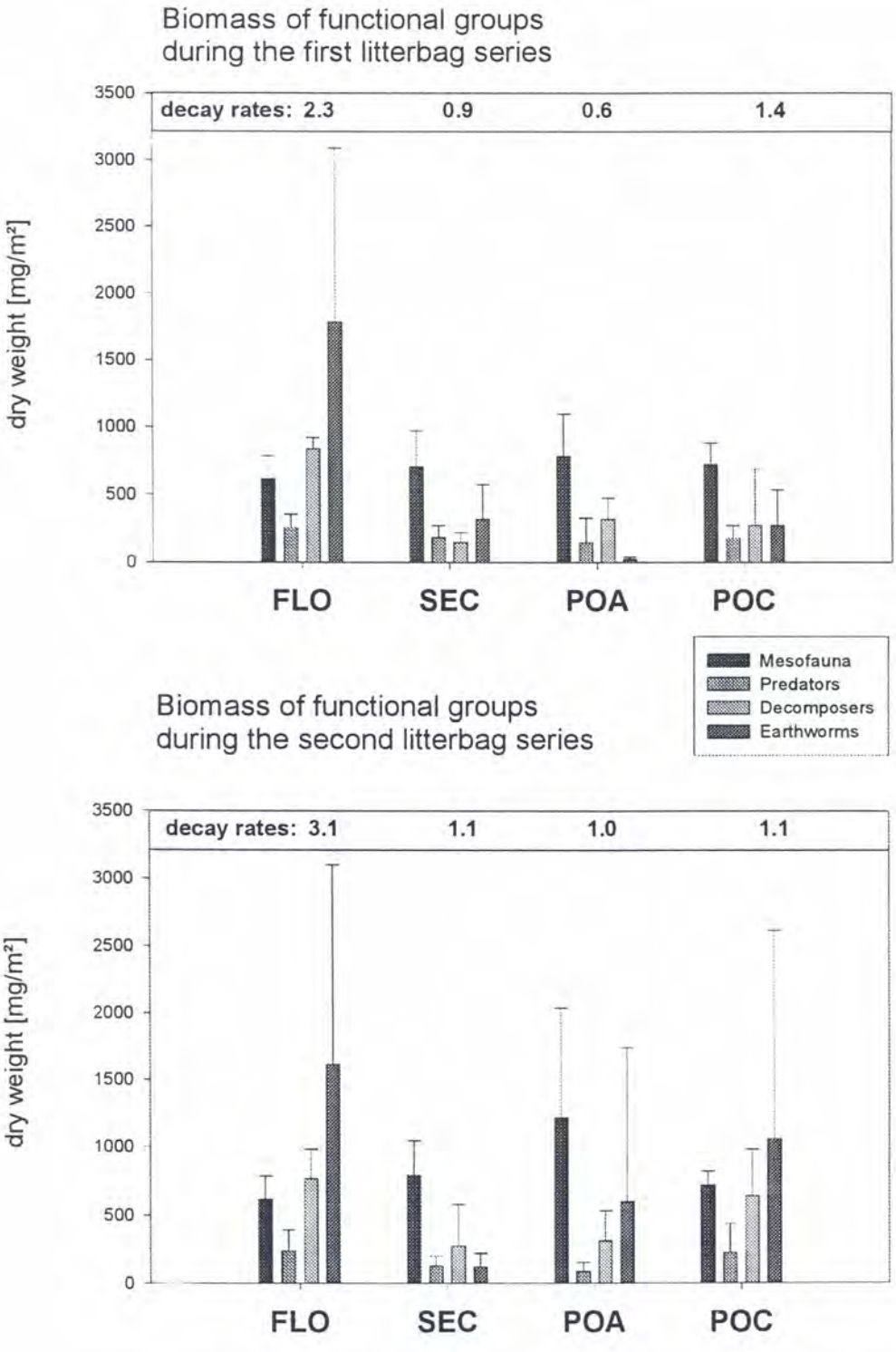


Fig. 10: Comparison of decomposition of *Vismia* leaves in litterbags and minicontainers



Figs 11, 12: Biomass of functional groups during the periods of exposition of litterbags

Invertebrados em "Litter-Bags"

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1. Introdução

Foi investigada a colonização da liteira por invertebrados de solo, em experimentos montados com folhas de *Vismia* sp., dentro de sacos de malha de náilon em diferentes parcelas: Floresta Primária (FLO); Floresta Secundária (SEC), e num Policultivo (POA e POC). A duração do experimento foi de 252 dias e as coletas distribuídas em seis períodos distintos. Foram analisados todos os grupos pertencentes a mesofauna, inclusive ácaros (Acari, Oribatida e demais subordens) e os colembolos (Collembola: Insecta). Baseado no modo principal de alimentação, os invertebrados foram separados em grupos funcionais de: Predadores, Decompositores e Herbívoros. Os insetos sociais como cupins e formigas foram analisados separadamente. Os animais não pertencentes as categorias estabelecidas acima, foram classificados em um grupo denominado "Outros".

2. Material e Métodos

2.1. Área de Estudo

O estudo foi desenvolvido em áreas localizadas na Estação Experimental do CPAA/Embrapa (Centro de Pesquisa Agroflorestal da Amazônia Ocidental/Empresa Brasileira de Pesquisa Agropecuária), situada no Km 29, AM 010 (Manaus-Itacoatiara).

Foram estudadas quatro parcelas em três diferentes sistemas florestais: Floresta Primária (FLO), parcela de 40 x 40m; Floresta Secundária (FLO), parcela de 40 x 40m e duas sub-parcelas de 32 x 48 num sistema de Policultivo (POA e POC) com quatro espécies arborícolas, cuja camada de liteira nas linhas é fortemente perturbada. No policultivo estabeleceu-se quatro espécies de árvores: Paricá (*Schizolobium amazonicum* Ducke), Andiroba (*Carapa guianensis* Aubl.) Seringueira (*Hevea brasiliensis* Muell. Arg.) e Mogno (*Swietenia macrophylla* King.). Após o plantio permitiu-se o estabelecimento de vegetação adventícia (secundária) entre as fileiras das árvores, principalmente *Vismia* spp. Esse sistema foi fortemente dominado pela vegetação secundária, de modo que pode-se considerar como uma floresta secundária jovem com 7 anos de idade (POA e POC), uma floresta secundaria de 14 anos de idade (SEC) e uma floresta primária (FLO). A área da POA está localizada ao lado de uma floresta secundaria e a POC esta situada ao lado de uma floresta primaria. Isto poderá ocasionar diferenças básicas entre os dois policultivos. Na área da POC, o sombreamento da floresta primária de copa evidentemente mais alta propicia um microclima diferente ao registrado na POA, alem de uma possível migração de invertebrados proveniente da floresta adjacente.

As áreas acima mencionadas (SEC, POA e POC) surgiram a partir da recuperação de áreas degradadas com cultivos mistos. Em agosto/setembro de 1992 foi feita a derrubada de uma capoeira de 8 anos de idade, resultante do abandono de plantação de seringueira. Após a derrubada, foi feita a queima da vegetação onde foram estabelecidas várias culturas numa área total de 189.997m^2. O solo da área é do tipo Latossolo amarelo, textura argilosa. O tipo climático da região pela classificação de Köppen é caracterizado como "Ami", com uma média anual de precipitação pluviométrica entre 1500 e 2500 mm.

2.2. Método e desenho experimental

Para o estudo proposto, foi utilizada a técnica do saco de malha ou "nylon mesh-bag technique" (Bocock & Gilbert, 1957). Foram usados sacos de náilon (30 x 30 cm) com malhas de três aberturas: **20 μm** (para excluir a ação da macro- e mesofauna permitindo assim somente entrada de microrganismos); **250 μm** (para permitir a ação da mesofauna e microrganismos) e **1000 μm** (para permitir a entrada da meso- e macrofauna). Em cada saco de malha foram colocados cerca de 7,5 g de folhas de *Vismia sp.*

As coletas dos sacos de malha foram efetuadas após transcorridos 25, 57, 84, 112, 168 e 252 dias de exposição no solo.

2.3. Preparação das amostras

Os sacos de malhas foram enchidos com aproximadamente 7,5g (peso seco ao ar) de folhas secas de *Vismia sp.*, caídas naturalmente, coletadas na camada de liteira em áreas de vegetação secundária, próximas às parcelas de estudo. Em laboratório, foram selecionadas manualmente por inspeção visual, evitando-se o uso de folhas muito quebradas, danificadas e com

desenvolvimento de hifas e micélios de fungos. O fechamento dos sacos de malha foi feito à máquina de costura, com pontos finos, sendo que os de malha fina (20 μm) foram colados nas bordas das costuras (laterais e boca) para evitar a entrada dos invertebrados. Em seguida, os sacos de malha foram numerados com marcadores permanentes, exceto os de malha grossa, cuja numeração foi feita através de plaquinhas metálicas e colocadas no interior da malha juntamente com as folhas de *Vismia* sp.

2.4. Distribuição das amostras no campo

O experimento foi instalado em outubro de 1997. Em cada área previamente demarcada, foram distribuídos em pontos aleatórios, conjuntos com três sacos de malha contendo as amostras de *Vismia sp.*, correspondendo aos três diferentes tamanhos da abertura das mechas (20 μm, 250 μm e 1000 μm). Em cada data de retirada, 10 (dez) conjuntos contendo os três sacos de malha foram coletados nas parcelas FLO e SEC e 5 (cinco) conjuntos nas parcelas POA e POC.

Ao serem retirados do campo, os sacos de malha foram acondicionados em sacos plásticos individuais e transportados para o laboratório, onde foram abertos cuidadosamente e colocados em bandejas, para as observações biológicas: umidade das folhas; quebra; descoloração e esqueletização das folhas; ação de cupins; penetração de raízes; acumulação de resíduos ou excrementos; hifas e micélios de fungos e presença de fauna de solo/liteira. Em seguida, colocou-se o material no aparelho de Berlese para extração dos invertebrados. Após retiradas dos funis de Berlese, as amostras de liteira foram limpas, removido os resíduos e materiais estranhos com pincéis. Posteriormente as amostras foram colocadas para secar em estufa a 60° C até atingirem o peso constante (geralmente três dias) para avaliação da perda de peso e posteriores análises químicas.

2.5. Descrição do aparelho de extração da fauna (BERLESE-TULLGREN)

A extração dos artrópodos do solo, foi feita através de funis de Berlese. Em laboratório, após a coleta dos sacos de malha e observação dos eventos biológicos mencionados anteriormente, as folhas foram colocadas em recipientes plásticos, com aproximadamente 25cm de altura e com tela metálica no fundo. Sobre a tela, uma malha com diâmetro de aproximadamente 0,7cm, para impedir a queda de solo e, ao mesmo tempo, possibilitar a passagem dos invertebrados. Após colocar o material, os recipientes plásticos contendo as amostras, foram cobertos com um tecido branco de algodão, preso com elástico. Estes recipientes foram conectados a funis plásticos direcionados a frascos com o líquido preservativo (uma parte de solução saturada de ácido pícrico para três partes de água). Após serem colocadas no aparelho de Berlese, as amostras permaneciam, no primeiro dia, à temperatura ambiente (aproximadamente 27° C). Nos dias subsequentes, a temperatura foi aumentada gradativamente, permanecendo de 30 a 40° C do sexto ao sétimo dia. O controle da temperatura foi feito através de lâmpadas de 25W, localizadas a uma distância de aproximadamente 14 cm acima das amostras. O material (solo e liteira) permanecia no aparelho extrator durante um período de aproximadamente 14 dias e a temperatura no final do período foi de aproximadamente 55° C. Após a extração, os invertebrados foram acondicionados em frascos com álcool 75% para posterior triagem e identificação.

2.6. Tratamento dos Dados

Baseado do hábito alimentar principal, os invertebrados foram separados em grupos funcionais de **Predadores**, **Decompositores** e **Herbívoros**. Os insetos sociais, tais como, Isoptera e Formicidae foram analisados separadamente. Animais não pertencentes as três categorias acima mencionadas foram classificados separadamente em um grupo denominado "**Outros**" .

Foram efetuados cálculos de abundância relativa e dominância dos invertebrados. Para determinação de coeficientes de correlação, foi utilizado o teste de correlação de Spearman entre o número médio de indivíduos com a perda de peso das folhas (peso seco). Foram feitos cálculos de análise de variância (One Way ANOVA) através do programa SIGMASTAT. O procedimento para análise através de comparações múltiplas foram efetuados através do teste não paramétrico de Student-Neuman Keuls (SNK).

Principais hipóteses:

a) Diferenças significativas seriam registradas entre a colonização da fauna total e dos grupos funcionais, dentro dos sacos de malha, de acordo com o seguinte gradiente de densidade e de diversidade dos grupos: malha grossa > malha média > malha fina.
b) Diferenças significativas seriam registradas entre a flutuação populacional entre os seis períodos de coleta dentro de cada parcela, com maior densidade e diversidade nos períodos intermediários

(terceiro, quarto e quinto) de coleta, segundo o processo de decomposição das folhas (tempo de exposição e perda de peso).

As datas de coletas dos sacos de malhas, assim como da implementação do experimento e estaçoes do ano referentes ao período em estudo, estão representadas na Tabela 01.

Tabela 01 – Data de implantação e períodos de retirada das unidades de amostras

Períodos	Dias de exposição no solo	Data	Estação do Ano
Implantação do experimento	**0**	27.10.1997	Seca
Primeiro	**25**	21.11.1997	Seca
Segundo	**57**	23.12.1997	Chuvosa
Terceiro	**84**	19.01.1998	Chuvosa
Quarto	**112**	16.02.1998	Chuvosa
Quinto	**168**	13.04.1998	Chuvosa
Sexto	**252**	06.07.1998	Seca

3. Resultados

3.1. Densidade da Fauna de Invertebrados

A flutuação populacional da fauna total de invertebrados nas quatro parcelas esta representada na Figura 01 e Tabela 02.

A densidade média da mesofauna (≅ 5.949 indivíduos) de invertebrados coletada nos sacos de malha foi superior na parcela da FLO, com maior abundância no período chuvoso e dominância de 40% (≅ 2.488 Indivíduos) do total coletado em todas as áreas estudadas. Foi registrado uma dominância de 20% da quantidade total capturada tanto para a SEC (≅ 1.166 indivíduos) quanto para POA (≅1.210 indivíduos): Na POC, a dominância foi de 18% (≅ 1.084 indivíduos) (Tabela 02).

Quanto aos três tamanhos de malhas, 40% da densidade média da mesofauna foi capturada na liteira da malha média (≅ 2.402 indivíduos), 33% foi capturado na malha grossa (≅ 1.959 indivíduos) e 27% foram capturados na malha fina (≅1.587 indivíduos).

Tabela 02 - Densidade média de invertebrados coletados na FLO, SEC, POA e POC em experimentos montados com liteira em sacos de malhas de diferentes tamanhos de mechas: Fina (20 micra), média (250 micra) e grossa (1000 micra), Embrapa, Manaus/AM.

Áreas	Tipos de malhas	Período de coleta (dias) 25	57	84	112	168	252	Total	Total áreas (%)
FLO	Fina	87.2	78.4	102.1	83.1	142.5	87.2	580.5	
	Média	126.7	210.2	255.9	227.9	190.8	126.7	1138.2	2488 (42%)
	Grossa	88.2	219.7	184.1	94.4	96.7	86.2	769.3	
SEC	Fina	4.1	9.9	31.1	37.1	139.5	169.7	391.4	
	Média	21	40.5	76.5	53.3	87.8	106.8	385.9	1166 (20%)
	Grossa	43.4	41.8	71.9	36.9	125	70.2	389.2	
POA	Fina	76.2	11.2	86.5	52.4	40.6	76.2	343.1	
	Média	3.2	50	100.2	121	84.8	63	422.2	1210 (20%)
	Grossa	4.2	45.4	180.8	62.2	90.2	62	444.8	
POC	Fina	65.2	12	39.6	34.8	55.6	65.2	272.4	
	Média	72	60.6	80	87	84.2	72	455.8	1084 (18%)
	Grossa	70.8	53.6	71.8	10.6	78.6	70.8	356.2	

Dominância (%) nos três tamanhos de malhas: Fina = 27%; Média = 40%; Grossa = 33%

3.2. Flutuação populacional da Fauna de Invertebrados

3.2.1. Floresta Primaria (FLO)

A maior densidade populacional registrada nos sacos de malha fina ocorreu no segundo, no terceiro, quarto e no quinto período, contudo, somente a densidade da primeira retirada foi menor em relação aos demais períodos (Tabela 03, Figura 01), coincidindo também com a estação chuvosa do ano. Nos sacos de malha media, foi confirmada a hipótese de que os períodos iniciais e finais teriam menor densidade, enquanto que a maior densidade foi registrada nos períodos intermediários. Nos sacos de malha grossa, a densidade aumentou no segundo período foi diminuindo gradativamente do terceiro para o quarto período.

Comparando-se os três tamanhos de malhas através de testes de testes estatísticos (One-way ANOVA), verificou-se que nos três tamanhos de malha, as principais diferenças foram detectadas entre malha fina, com os menores valores de densidade em relação aos demais tamanhos de malha e na malha media, com os maiores registros (Tabela 04). Desse modo, ao contrario do que era esperado, os maiores níveis de densidade populacional não foram registrados nos sacos de malha grossa.

3.2.2. Floresta Secundaria (SEC)

A flutuação populacional na SEC não seguiu o padrão observado na FLO, ou seja, maior densidade de colonização principalmente nos períodos intermediários, coincidindo assim com a época chuvosa. Foi observado enato uma tendência de aumento na densidade de acordo com o aumento de exposição da liteira no campo. Na malha fina foram registradas diferenças entre o primeiro e a segundo período em relação aos demais (Tabela 03, Figura 01). Na malha media, a densidade do primeiro período foi menor em relação ao terceiro, ao quinto e ao sexto período. Na malha grossa, a densidade do primeiro período foi menor que a do quinto e do sexto período; a densidade do quarto período de coleta foi menor que a do quinto.

Tabela 03 - Diferenças significativas(One-way ANOVA) registradas na densidade da **fauna total de invertebrados**, entre os seis períodos de coleta (25, 57, 84, 112, 168 e 252 dias de exposição sobre o solo), nas quatro parcelas.

Parcela	Tamanho da malha	Período/ (dias de exposição)	Df	q	P	Diferenças detectadas (< ou >) (Período/Tamanho da Malha)
FLO	Fina	1 (25 dias)	279.5	5.06	<0,05	<2 (57 dias) Fina
			279.5	5.06	<0,05	<3 (84 dias) Fina
			261	4.73	<0,05	<4 (112 dias) Fina
			350	6.34	<0,05	< 5 (168 dias) Fina
			294	5.32	<0,05	<6 (252 dias) Fina
	Media	1 (25 dias)	114.9	4.2	<0,05	<2 (57 dias) Média
			160.6	5.87	<0,01	<3 (84 dias) Média
			121.5	4.44	<0,05	<4 (112 dias) Média
		6 (252 dias)	129.2	4.73	<0,05	<3 (84 dias) Média
	Grossa	2 (57 dias)	291	5.27	<0,05	>1 (25 dias) Grossa
			234.5	4.25	<0,05	>2 (57 dias) Grossa
			245.5	4.44	<0,05	>5 (168 dias) Grossa
			278	5.03	<0,05	>6 (252 dias) Grossa
SEC	Fina	1 (25 dias)	283.5	5.13	<0,05	<3 (84 dias) Fina
			248.5	4.5	<0,05	<4 (112dias) Fina
			291.5	5.3	<0,05	<5 (168 dias) Fina
			429.5	7.8	<0,05	<6 (252 dias) Fina
		2(57 (dias)	323.5	5.85	<0,05	<6 (252 dias) Fina
	Media	1 (25 dias)	279.5	5.06	<0,05	<3 (84 dias) Média
			303.5	5.5	<0,05	<5 (168 dias) Média
			322	5.83	<0,05	<6 (252 dias) Média
	Grossa	1 (25 dias)	294	5.3	<0,05	<5 (168 dias) Grossa
			224.5	4.06	<0,05	<6 (252 dias) Grossa
		4(112 dias)	248	5.32	<0,05	<5 (168 dias) Grossa
POA	Fina	1 (25 dias)	93.5	4.75	<0,05	<3 (84 dias) Média
		1 (25 dias)	82	4.14	<0,05	<6 (252 dias) Fina
POC	Fina	1 (25 dias)	50.8	4.8	<0,05	<5 (168 dias) Fina

Entre os três tamanhos de malha (fina, media e grossa), as principais diferenças observadas foram com relação a menor densidade registrada na malha fina (primeiro e quarto períodos). Do mesmo modo como observado na FLO, não foi registrada maior densidade nos sacos de malha grossa em relação aos demais) (Tabela 04).

Tabela 4 - Diferenças significativas (One-way ANOVA) da densidade da **fauna total de invertebrados** entre três tamanhos de malha (fina, media e grossa), nas quatro parcelas estudadas.

Parcela	Tamanho da malha	Período/ (dias de exposição)	Df	q	P	Diferenças detectadas (< ou >) (Período/Tamanho da Malha)
FLO	Fina	1 (25 dias)	1327	8	<0,05	<2 (57 dias) Média
			1442	8.7	<0,05	< 3 (84 dias) Média
			1298	7.9	<0,05	< 4 (112 dias) Média
			1225	7.4	<0,05	< 5 (168 dias) Média
			889	5.4	<0,05	< 6 (252 dias) Média
			1369.5	8.3	<0,05	< 2(57 dias) Grossa
			1163.5	7.1	<0,05	<3 (84 dias) Grossa
	Média	3 (84 dias)	865.5	5.25	<0,05	>2 (57 dias) Fina
			865.5	5.25	<0,05	> 3 (84 dias) Fina
			859.5	5.25	<0,05	> 4 (112 dias) Fina
			826.5	5.1	<0,05	> 6 (252 dias) Fina
			893.5	5.4	<0,05	> 1 (25 dias) Grossa
			854.5	5.2	<0,05	> 2 (57 dias) Grossa
SEC	Fina	1 (25 dias)	1160.5	7	<0,05	< 3 (84 dias) Média
			953	5	<0,05	< 4 (112 dias) Média
			1221	7.4	<0,05	< 5 (168 dias) Média
			1241	7.5	<0,05	< 6 (252 dias) Média
		2 (57 dias)	1008.5	6.1	<0,05	< 3 (84 dias) Média
			1069	6.5	<0,05	< 5 (168 dias) Média
			1089	7.5	<0,05	< 6 (252 dias) Média
			950.5	5.7	<0,05	< 3 (84 dias) Grossa
			1307	7.9	<0,05	< 5 (168 dias) Grossa
	Média	1 (25 dias)	984	5.9	<0,05	< 6 (252 dias) Fina
			932.5	5.6	<0,05	< 5 (168 dias) Grossa
POA	Fina	1 (25 dias)	322	5.5	<0,05	< 4 (112 dias) Média
			322	5.5	<0,05	< 3 (84 dias) Grossa
		2(84dias)	290	4.9	<0,05	< 3 (84 dias) Grossa
POC	Fina	1 (25 dias)	297	5.1	<0,05	< 3 (84 dias) Média
			322.5	5.5	<0,05	< 5 (168 dias) Média
			337	5.8	<0,05	< 3 (84 dias) Grossa
		2 (57 dias)	301	5.1	<0,05	< 3 (84 dias) Grossa

3.2.3. Policultivo (POA)

Nos sacos de malha fina, apenas a densidade do primeiro período de coleta foi menor que o terceiro e o sexto período (Tabela 03, Figura 01). Para a densidade populacional dos sacos de malha media e grossa, nenhuma diferença foi observada entre os seis períodos de coleta.

Entre os três tamanhos de malha, as únicas diferenças detectadas foram as menores densidades registradas nos sacos de malha fina em relação aos demais (Tabela 04). Como registrado para as parcelas da FLO e da SEC, não houve diferença entre a densidade da fauna coletada nos sacos de malha media e grossa.

3.2.4. Policultivo (POC)

As densidades registradas nos sacos de malha fina dois primeiros períodos foram menores que a do quinto e a do sexto. Nas malhas media e grossa, nenhuma diferença foi detectada (Tabela 03, Figura 01).

Entre os três tamanhos de malha, do mesmo modo como registado na FLO, na SEC e na POA, as únicas diferenças detectadas foram as menores densidades registradas na população

coletada nos sacos de malha fina (Tabela 04), portanto, não houve diferença entre a densidade populacional dos animais que colonizaram os sacos de malha media e fina.

3.3. Discussão (Fauna total de invertebrados)

Para a colonização dos sacos de malha na parcela da FLO e da SEC foi possível comprovar a hipótese inicial de maior densidade nos períodos intermediários (maior densidade no terceiro, quarto e quinto períodos), coincidindo com a estação chuvosa do ano. Contudo, na POA e na POC, tal fator não foi observado, pois não houve praticamente diferença na densidade populacional entre os seis períodos de coleta na POA e na POC, o que significa que as alterações sofridas nessas áreas causou alterações acentuadas na colonização do solo.

Como pode ser observado, o tamanho da malha fina (20 micra) não excluiu a colonização dos invertebrados, embora tenha sido registrado menos densidade que a malha media e grossa. Durante o experimento foi também observado que houve penetração de raízes nos sacos, o que propiciou a entrada de grupos da mesofauna, principalmente os ácaros e os colembolos. Apesar da presença da macrofauna na malha grossa, a maior abundância ocorreu na malha média e não na malha grossa conforme se esperava. Podemos supor que tal fato ocorreu em virtude da interferência causada pela ausência de alguns grupos presentes da macrofauna, principalmente predadores como opiniões, aranhas, etc. que não conseguiam penetrar nos sacos de malha média favorecendo deste modo uma maior abundância da fauna de menor tamanho, como ácaros e colembolos, por exemplo. Também, por outro lado, o tamanho da abertura (250 micra) dos sacos de malha media, permite a entrada de imaturos de grupos da mesofauna, principalmente ácaros e colembolos. Muitos dos ácaros e colembolos que penetraram como imaturos nos sacos de malha, possivelmente não conseguiram mais sair depois de terem atingido o estagio adulto, com dimensões maiores que as da malha.

Embora a densidade da fauna de invertebrados tenha sido maior na malha média, não houve diferença entre a decomposição da liteira entre as malhas finas e médias (Figura 01). Na POC foi observado, inclusive, menor perda de peso na malha média que na malha fina. Isto significa que a mesofauna tem uma ação mais efetiva na decomposição. Seu relacionamento e maior com a microflora do solo, principalmente os fungos, pois agem como dispersores, pelo abrigo de esporos em seu trato alimentar e sobre a superfície do corpo. A função desses pequenos animais da mesofauna também pode ser maior como indicadores do estado de decomposição da liteira, já que são extremamente sensíveis as alterações ambientais, principalmente temperatura, umidade e pH.

Podemos concluir que os sacos de malha media (250 micra) não são recomendados para estudos sobre a colonização de invertebrados do solo devido aos problemas citados nos parágrafos anteriores. Do mesmo modo, os sacos de malha fina não foram suficientes para excluir a ação da mesofauna, capaz de penetrar nos menores orifícios originados por fatores biológicos como o crescimento de raízes.

No que diz respeito ao resultado das correlações entre a densidade dos invertebrados com o peso do material remanescente, apenas na SEC foi encontrado resultados significativos nos diversos períodos. Os resultados indicaram que houve aumento da população nos sacos de malha fina e media com a diminuição de peso das folhas ($r = -1,000$, $p<0,01$ e $r= -0,943$, $p<0,01$, respectivamente).

A lenta decomposição da liteira (ver Relatório Decomposição de liteira), pode ter sido um fator que influenciou também os resultados obtidos. Após 168 dias de exposição das folhas no solo, apenas cerca de 25% do material tinha sido decomposto, exceto para o material contido nos sacos de malha grossa na Floresta, onde a decomposição atingiu cerca de 50% do material (ver Relatório 'Ácaros do Solo (Acari: Oribatida), abundância e papel na decomposição de liteira em floresta primaria e numa área de policultivo de madeira').

3.4. Diversidade da fauna de invertebrados

A maior diversidade de grupos funcionais foi registrada na FLO, com redução nas demais parcelas. A taxa de redução da diversidade nas parcelas manejadas em relação a FLO, estão representadas na Tabela 05, cuja maior percentagem de redução foi encontrado nos experimentos de malha fina e média da POA com 40 e 45% respectivamente.

Tabela 05: Diversidade (media e desvio padrão; n = 6) dos grupos funcionais nas quatro parcelas. Entre colchetes a taxa de redução da diversidade nos ambientes manejados em relação a floresta primaria (FLO).

	FLO	SEC	POA	POC

FINA	16,7(±2,2)	13(±2,4) [**22%**]	10(±1,7) [**40%**]	12,7(±1) [**24%**]
MEDIA	20,2(±2,5)	15,6(±2,6) [**23%**]	11(±2,8) [**45%**]	14,5(±1,4) [**28%**]
GROSSA	22,5(±1,5)	16,5(±3) [**27%**]	17(±1,9) [**24%**]	16,7(±1) [**26%**]

3.4.1. Floresta primaria (FLO)

Nos sacos de malha fina, não foi registrada diferença entre os seis períodos. Na malha media, apenas a diversidade registrada no segundo período foi menor que as demais. Nos sacos de malha grossa, a diversidade registrada no segundo período foi menor que a do terceiro (Tabela 06).

Tabela 06 - Diferenças significativas(One-way ANOVA) registradas na diversidade de todos os grupos funcionais entre os seis períodos de coleta (25, 57, 84, 112, 168 e 252 dias de exposição sobre o solo), nas quatro parcelas.

Parcela	Tamanho da malha	Período/ (dias de exposição)	Df	q	P	Diferenças detectadas (< ou >) (Período/Tamanho da Malha)
FLO	MEDIA	2 (57 dias)	4.6	6.4	<0,01	< 1 (25 dias) Media
			4	5.58	<0,01	< 3 (84 dias) Media
			3.4	4.75	<0,05	< 4 (112 dias) Media
			3.3	4.6	<0,05	< 5 (168 dias) Media
			4.5	6.28	<0,001	< 6 (252 dias) Media
	GROSSA	2 (57 dias)	295	5.3	<0,05	< 3 (84 dias) Grossa
SEC	FINA	1 (25 dias)	4	6.4	<0,001	< 3 (84 dias) Fina
			2.7	4.33	<0,05	< 4 (112 dias) Fina
			2.7	4.33	<0,05	< 5 (168 dias) Fina
			4.2	6.75	<0,001	< 6 (252 dias) Fina
	GROSSA	3 (84 dias)	3.8	6.22	<0,001	> 1 (25 dias) Grossa
POA	GROSSA	4 (112 dias)	3.36	5	<0,05	< 1 (25 dias) Grossa
			3.76	5.67	<0,01	< 3 (84 dias) Grossa
			3.96	5.97	<0,01	< 6 (252 dias) Grossa
		2 (84 dias)	3.2	4.62	<0,05	< 6 (252 dias) Grossa

Na comparação entre os três tamanhos de malha, a diversidade registrada nos sacos de malha grossa foi geralmente maior que a registrada nos sacos de malha fina (Tabela 07, Figura 02), ao contrario do que foi observado na densidade, onde não foram registradas diferenças entre os tamanhos de malha media e grossa, a diversidade registrada nos sacos de malha grossa no terceiro, no quarto e no sexto período foi maior do que a registrada nos sacos de malha média no segundo período.

Tabela 7 - Diferenças significativas (One-way ANOVA) da diversidade da **fauna total de invertebrados** entre três tamanhos de malha (fina, media e grossa), nas quatro parcelas estudadas.

Parcela	Tamanho da malha	Período/ (dias de exposição)	DF	q	P	Diferenças detectadas (< ou >) (Período/Tamanho da Malha)
FLO	GROSSA	1 (25 dias)	92.2	3.97	<0,05	> 5(168 dias) FINA
		3 (84 dias)	86.5	3.73	<0,05	< 1(25 dias) FINA
			94.2	3.96	<0,05	> 4 (112 dias) FINA
			123.7	5.34	<0,05	> 5 (168 dias) FINA
			85.9	3.71	<0,05	> 6 (252 dias) FINA
			113.6	4.9	<0,05	> 2 (57 dias) MEDIA
		4 (112 dias)	101.7	4.39	<0,05	> 5 (168 dias) FINA
			91.6	4.95	<0,05	> 2 (57 dias) MEDIA
		6 (252 dias)	95.6	4.12	<0,05	> 5 (168 dias) FINA
			85.5	3.69	<0,05	> 2 (57 dias) MEDIA
SEC	FINA	1 (25 dias)	3.2	5.35	<0,05	< 2 (57 dias) MEDIA
			4.5	7.53	<0,001	< 3 (84 dias) MEDIA
			3.2	5.35	<0,05	< 4 (112 dias) MEDIA
			3.6	6.02	<0,01	< 5 (168 dias) MEDIA
			4.4	7.36	<0,001	< 6 (252 dias) MEDIA
			4.8	8.02	<0,001	< 2 (57 dias) GROSSA
			5.7	9.53	<0,001	< 3 (84 dias) GROSSA
			3.3	5.52	<0,01	< 4 (112 dias) GROSSA
			5.2	8.69	<0,001	< 5 (168 dias) GROSSA
			5	8.34	<0,001	< 6 (252 dias) GROSSA
	GROSSA	3 (84 dias)	3.4	5.69	<0,01	> 2 (57 dias) FINA
			3	5.02	<0,05	> 4 (112 dias) FINA
			3	5.02	<0,05	> 5 (168 dias) FINA
			3.4	5.69	<0,01	> 1 (25 dias) MEDIA
POA	MEDIA	6 (252 dias)	4.4	6.04	<0,01	> 2 (57 dias) FINA
	GROSSA	1 (25 dias)	5.4	7.41	<0,001	> 2 (57 dias) FINA
			4	5.49	<0,05	> 5 (168 dias) FINA
			3.8	5.21	<0,05	> 2 (57 dias) MEDIA
		3 (84 dias)	5.8	7.96	<0,001	> 1 (25 dias) FINA
			4.2	5.76	<0,01	> 2 (57 dias) FINA
			4.4	6.04	<0,01	> 5 (168 dias) FINA
			3.9	5.64	<0,05	> 4 (112 dias) MEDIA
			3.8	5.22	<0,05	> 5 (168 dias) MEDIA
		6 (252 dias)	6	8.24	<0,001	> 2 (25 dias) FINA
			4.6	6.31	<0,01	> 5 (57 dias) FINA
			4.4	6.04	<0,01	> 2 (57 dias) MEDIA
			4.1	5.93	<0,01	> 4 (112 dias) MEDIA
			4	5.49	<0,05	> 5 (168 dias) MEDIA
POC	FINA	2 (57 dias)	4.4	5.48	<0,05	< 3 (84 dias) MEDIA
			4.2	5.23	<0,05	< 1 (25 dias) GROSSA
			4.4	5.48	<0,05	< 3 (85 dias) GROSSA
			4.2	5.23	<0,05	< 5 (168 dias) GROSSA

3.4.2. Floresta secundaria (SEC)

Nos sacos de malha fina, a diversidade do primeiro período foi menor que a do terceiro, quarto, quinto e sexto períodos. Não houve diferença na diversidade registrada nos sacos de malha media durante os seis períodos de coleta. Nos sacos de malha grossa, apenas a diversidade do primeiro foi menor que a do terceiro período (Tabela 05, Figura 2).

Apenas a diversidade registrada no terceiro período nos sacos de malha grossa foi menor que a do primeiro período nos sacos de malha media (Tabela 07).

Tabela 08 - Densidade media dos principais grupos funcionais da fauna de invertebrados do solo nas quatro parcelas

PARCELA	Tamanho de malha	Grupo Funcional	Dias de exposição no solo 25	57	84	112	168	252	Total	%
FLO	Fina	Predadores	23.6	48.4	72.3	28	8.5	23.6	204.4	3.37
		Decompositores	55.6	25.4	20.3	50.3	120.4	55.5	327.5	5.41
		Herbívoros	3.6	0.9	0.7	0.6	0.2	4	10	0.17
		Cupins	0	0.1	0.1	0	0	0	0.2	0.00
		Formicidae	0.5	0.8	0.5	0	10.6	0.5	12.9	0.21
		Outros	3.6	2.8	8.2	4.2	2.8	3.6	25.2	0.42
	Media	Predadores	29.5	86	23.3	21.3	24.5	29.1	213.7	3.53
		Decompositores	82.6	121.6	217.1	167.9	153.3	82.6	825.1	13.62
		Herbívoros	0.3	0.7	1	1.9	3.7	0.8	8.4	0.14
		Cupins	0	0	0	0	0	0	0	0.00
		Formicidae	9	0.4	0.5	0.2	5	9	24.1	0.40
		Outros	5.2	1.5	14	14.1	4.3	5.2	44.3	0.73
	Grossa	Predadores	28.3	98.4	32.2	16.1	12.5	28.3	215.8	3.56
		Decompositores	50.4	117	134.2	68.7	69	50.4	489.7	8.08
		Herbívoros	0.6	0.8	0.9	2.1	1.6	0.6	6.6	0.11
		Cupins	0	0.1	0	0	0	0	0.1	0.00
		Formicidae	1.3	0.7	6.2	1.6	9.3	1.3	20.4	0.34
		Outros	5.6	2.7	10.6	5.9	4.3	5.6	34.7	0.57
SEC	Fina	Predadores	0.3	1.2	14.4	9.8	4.9	18	48.6	0.80
		Decompositores	2.2	3.3	0.6	23.1	129.2	144.8	303.2	5.01
		Herbívoros	0.4	1.9	0.9	0.3	0.2	0.6	4.3	0.07
		Cupins	0	0.1	0	0	0	0	0.1	0.00
		Formicidae	0.1	0.2	0.6	0	0.2	3.5	4.6	0.08
		Outros	1.1	3.2	5.6	3.9	5	2.8	21.6	0.36
	Media	Predadores	1.2	3.9	20.5	7.2	8.4	22.7	63.9	1.05
		Decompositores	17.9	32.5	50	40.8	71.3	72.8	285.3	4.71
		Herbívoros	0.4	1.5	0.6	0.9	4.5	3.5	11.4	0.19
		Cupins	0	0	0	0	0	0	0	0.00
		Formicidae	0.3	0.4	0.9	0.2	0.1	4.2	6.1	0.10
		Outros	1.2	2.2	4.5	4.2	3.5	3.6	19.2	0.32
	Grossa	Predadores	3.2	6	20.3	4.8	13.9	14.3	62.5	1.03
		Decompositores	37.3	29.9	44.5	27.4	102.9	49.7	291.7	4.82
		Herbívoros	0.1	2.4	1.2	0.3	3.2	1	8.2	0.14
		Cupins	0	0	0	0	0	0	0	0.00
		Formicidae	1.6	0.5	0.9	0	1	0.3	4.3	0.07
		Outros	1.2	2.8	4.6	4.4	4	4.9	21.9	0.36
POA	Fina	Predadores	6.2	1	62.5	3.7	6.8	6.2	86.4	1.43
		Decompositores	66.6	6.8	15.3	38.7	31	66.6	225	3.71
		Herbívoros	0.4	1.6	0	0.2	0	0.4	2.6	0.04
		Cupins	0	0	0	0	0	0	0	0.00
		Formicidae	0.2	0	1.3	0.4	0.2	0.2	2.3	0.04
		Outros	2.8	1.8	7.5	5.2	2.6	2.8	22.7	0.37
	Media	Predadores	7.6	4.9	9.6	6.7	4.8	7.6	41.2	0.68
		Decompositores	46.4	41.8	80.4	111.5	76.8	46.4	403.3	6.66
		Herbívoros	1.2	1	0.2	0.5	0.8	1.2	4.9	0.08
		Cupins	0	0	0	0	0	0	0	0.00
		Formicidae	4.6	0	1.4	0.2	0	4.6	10.8	0.18
		Outros	3.2	2.8	8.6	2.2	2.4	3.2	22.4	0.37
	Grossa	Predadores	13.6	7.4	19.8	3.7	3.4	13.6	61.5	1.02
		Decompositores	39.4	33.4	134.2	55.3	82.2	39.4	383.9	6.34
		Herbívoros	1	1.6	0.8	0.5	0.4	1	5.3	0.09
		Cupins	0	0	0	0	0	0	0	0.00
		Formicidae	3.8	0.6	9	0	0	3.8	17.2	0.28
		Outros	4.2	2.4	17	2.7	4.2	4.2	34.7	0.57

POC	Fina	Predadores	27	4.2	15.4	10.8	6.8	27	91.2	1.51
		Decompositores	32.4	4.8	17.4	21.3	36.8	32.4	145.1	2.40
		Herbívoros	0.7	1	1.2	0	4.8	0.2	7.9	0.13
		Cupins	0	0	0	0	0	0	0	0.00
		Formicidae	0.2	0	0.4	0	0	0.2	0.8	0.01
		Outros	5.4	2	5.2	2.8	7.2	5.4	28	0.46
	Media	Predadores	18.4	8.2	13.8	15.8	16.6	18.4	91.2	1.51
		Decompositores	46.6	47.4	54.8	65.5	63.2	46.6	324.1	5.35
		Herbívoros	0.8	2.6	0.6	1.8	0.8	0.8	7.4	0.12
		Cupins	0	0	0	0	0	0	0	0.00
		Formicidae	3	0	2.8	0.8	0	3	9.6	0.16
		Outros	3.2	2.4	8	3.3	3.6	3.2	23.7	0.39
	Grossa	Predadores	20.4	7	7.4	7	11.8	20.4	74	1.22
		Decompositores	43.2	40.6	40.8	18	68.6	43.2	254.4	4.20
		Herbívoros	1.4	1.8	0.4	0.3	1.4	1.4	6.7	0.11
		Cupins	0	0	0	0	0	0	0	0.00
		Formicidae	1.8	0.8	15.6	0.3	0.4	1.8	20.7	0.34
		Outros	4	3.4	7.6	3.3	6.2	4	28.5	0.47
TOTAL	N		777.9	833.6	1271	892.7	1226	1056	6057.5	100.00
	%		12.84	13.76	20.99	14.74	20.24	17.43	100.00	

[1] Acari (exceto Oribatida), Chilopoda, Dermaptera, Diplura, Opilionida, Pseudoscorpinida, Scorpionida, Ricinuleidae, Palpigradi, Uropygi

[2] Coleoptera (larva), Collembola, Oribatida (Acari), Diplopoda, Diptera (larva), Enchytraeidae, Isopoda, Lumbricidae, Nematoda, Pauropoda, Protura, Psocoptera, Symphyla, Tricoptera

[3] Homoptera (larva), Homoptera (adultos), Thysanoptera, Hemiptera (larva), Hepiptera (adultos), Orthoptera

[4] Coleoptera (adultos), Copepoda, Diptera (adultos), Embioptera, Hymenoptera (exceto Formicidae), Lepidoptera, Mollusca, Thysanura

3.6. Flutuação populacional dos grupos funcionais mais abundantes

3.6.1. Predadores

Na FLO, a densidade populacional registrada no primeiro período na malha fina foi menor em relação ao segundo, ao terceiro e ao sexto período. Na malha media, a densidade registrada no segundo período foi maior que a do primeiro, do terceiro, do quinto e do sexto período. Na malha grossa, a densidade registrada no segundo período foi maior que a do primeiro, do quarto e do quinto período (Tabela 09, Figura 03). Entre os três tamanhos de malha, as maiores diferenças foram registradas entre a malha fina em relação as demais. Com relação as malhas media e grossa, a densidade registrada no segundo período na malha media foi superior a registra no primeiro, no quarto e no quinto da malha grossa (Tabela 10).

Tabela 09 - Diferenças significativas(One-way ANOVA) registradas na densidade de **Predadores**[1], entre os seis períodos de coleta (25, 57, 84, 112, 168 e 252 dias de exposição sobre o solo), nas quatro parcelas.

Parcela	Tamanho da malha	Periodo/ (dias de exposição)	Df	q	P	Diferenças detectadas (< ou >) (Período/Tamanho da Malha)
FLO	FINA	1 (25 dias)	352.5	6.38	<0,05	<2 (57 dias) Fina
			264.5	4.78	<0,05	<3 (84 dias) Fina
			311.5	5.64	<0,05	<6 (252 dias) Fina
	Média	2 (57 dias)	325	5.9	<0,05	>1 (25dias) Média
			252.5	4.57	<0,05	>3 (84dias) Média
			223	4.03	<0,05	>5 (168 dias) Média
			228	4.12	<0,05	>6 (262 dias) Média
	Grossa	2 (57 dias)	320	5.79	<0,05	>1 (25 dias) Grossa
			309	5.59	<0,05	>4 (112dias) Grossa
			373.5	6.76	<0,05	>5 (168 dias) Grossa
SEC	Fina	1 (25 dias)	277.5	5.02	<0,05	<3 (84 dias) Fina
			278	5.03	<0,05	<4 (112 dias) Fina
			228.5	4.14	<0,05	<5 (168 dias) Fina
			333	6.03	<0,05	<6 (252 dias) Fina
		2 (57 dias)	268	4.85	<0,05	<6 (252 dias) Fina
	Média	1 (25 dias)	232.5	4.2	<0,05	<3 (84 dias) Média
			349	6.31	<0,05	<6 (252 dias) Média
		2 (57 dias)	283.5	5.13	<0,05	<6 (252 dias) Média
	Grossa	1 (25 dias)	268.5	4.86	<0,05	<5 (168 dias) Grossa
POA	Fina	1 (25 dias)	110.5	5.6	<0,05	<3 (84 dias) Fina
		2 (57 dias)	101.5	5.15	<0,05	<3 (84 dias) Fina
	Grossa	1 (25 dias)	89.5	4.5	<0,05	<3 (84 dias) Grossa
			85	4.31	<0,05	<6 (252 dias) Grossa
POC	Fina	1 (25 dias)	88	4.47	<0,05	<3 (84 dias) Fina
			118	5.99	<0,05	<6 (252 dias) Fina
		2 (57 dias)	79.5	4.03	<0,05	<6 (252 dias) Fina

[1]Acari (exceto Oribatida), Chilopoda, Dermaptera, Diplura, Opilionida, Pseudoscorpinida, Scorpionida, Ricinuleidae, Palpigradi, Uropygi

Tabela 10 - Diferenças significativas (One-way ANOVA) da densidade de **Predadores**[1] entre três tamanhos de malha (fina, media e grossa), nas quatro parcelas estudadas.

Parcela	Tamanho da malha	Período/ (dias de exposição)	Df	q	P	Diferenças detectadas (< ou >) (Período/Tamanho da Malha)
FLO	Fina	1 (25 dias)	1515	9.19	<0,05	<2 (57 dias) Grossa
			1450	8.8	<0,05	<2 (57 dias) Média
			1014	6.1	<0,05	<6 (252 dias) Grossa
			957	5.8	<0,05	<4 (112 dias) Média
			927	5.6	<0,05	<5 (168 dias) Média
			904.5	5.5	<0,05	<6 (252 dias) Média
			891.5	5.4	<0,05	<3 (84 dias) Grossa
			860	5.2	<0,05	<3 (84 dias) Média
		5 (168 dias)	1225	7.4	<0,05	<2 (57 dias) Grossa
			1160	7	<0,05	<2 (57 dias) Média
		4 (112 dias)	958	5.8	<0,05	<2 (57 dias) Grossa
			893.5	5.4	<0,05	<2 (57 dias) Média
	Media	1 (25 dias)	847	5.1	<0,05	<2 (57 dias) Grossa
		2 (57 dias)	824	5	<0,05	>1 (25 dias) Grossa
			835.5	5	<0,05	>4 (112 dias) Grossa
			987	5.9	<0,05	>5 (168 dias) Grossa
SEC	Fina	1 (25 dias)	910	5.5	<0,05	< 3 (84 dias) Media
			825	5	<0,05	< 5 (168 dias) Media
			1268	7.7	<0,05	< 6 (252 dias) Media
			994	6	<0,05	< 3 (84 dias) Grossa
			1121	6.8	<0,05	< 5 (168 dias) Grossa
			1121	6.8	<0,05	< 6 (252 dias) Grossa
		2 (57 dias)	1108	6.7	<0,05	< 6 (252 dias) Media
			834	5.1	<0,05	< 3 (84 dias) Grossa
			961.5	5.8	<0,05	< 5 (168 dias) Grossa
			961.5	5.8	<0,05	< 6 (252 dias) Grossa
	Media	1 (25 dias)	831	5	<0,05	< 6 (252 dias) Fina
			814.5	4.9	<0,05	< 3 (84 dias) Grossa
			942	5.7	<0,05	< 5 (168 dias) Grossa
			942	5.7	<0,05	< 6 (252 dias) Grossa
POA	Fina	1 (25 dias)	294.5	5	<0,05	< 3 (84 dias) Grossa
			311	5.3	<0,05	< 6 (252 dias) Grossa
		2 (57 dias)	295	5	<0,05	< 6 (252 dias) Grossa
	GROSSA	1 (25 dias)	336	5.7	<0,05	< 3 (84 dias) Fina
POC	Fina	1 (25 dias)	337	5.5	<0,05	< 6 (252 dias) Media
			309.5	5	<0,05	< 6 (252 dias) Grossa
	Media		372	6	<0,05	< 6 (252 dias) Fina
	Grossa	1 (25 dias)	376	6.1	<0,05	< 6 (252 dias) Fina
			319	5.2	<0,05	< 6 (252 dias) Media

[1]Acari (exceto Oribatida), Chilopoda, Dermaptera, Diplura, Opilionida, Pseudoscorpinida, Scorpionida, Ricinuleidae, Palpigradi, Uropygi

Na parcela da SEC, a densidade populacional nas malhas fina e media foi menor nos dois períodos iniciais. Na malha grossa, apenas o primeiro período foi menor que o quinto (Tabela 09, Figura 03). Entre malhas, as maiores diferenças foram registradas na menor densidade da malha fina em relação as demais. Não houve diferença acentuadas que demonstrassem a maior densidade da fauna coletada nos sacos de malha grossa em relação aos de malha fina (Tabela 10).

Na POA, a densidade da terceira coleta registrada na malha fina foi maior que a da primeira e a da Segunda. Não foram detectadas diferenças na densidade populacional de predadores nos sacos de malha media. A primeira coleta da malha grossa foi menor que a terceira e a sexta (Tabela 09, Figura 03). Na comparação entre os três tamanhos de malha, não foram detectadas diferenças entre as malhas medias e grossa (Tabela 10).

Na POC, nos sacos de malha fina as diferenças foram registradas apenas no primeiro e no segundo período com relação a maior diversidade do terceiro e do sexto. Não foram registradas diferenças entre os seis períodos nos sacos de malha media e grossa (Tabela 09, Figura 03). Entre os três tamanhos de malha, mais uma vez as diferenças registradas foram apenas entre a menor densidade nos períodos iniciais dos sacos de malha fina em relação a densidade dos sacos de malha media e grossa. Não foram registradas diferenças entre os sacos de malha media e grossa (Tabela 10).

3.6.1.1. Grupos taxonomicos mais abundantes entre os predadores

Acari (exceto Oribatida) e Pseudoscorpioes foram os predadores mais importantes. Os registros de dominância de Acari foram superiores a 70% em todas as parcelas. Os Peudoscorpionida, tiveram dominância variando entre 0,1 e 22% (Tabela 11). Esses grupos também foram dominantes nas coletas trimestrais efetuadas nas quatro parcelas através do método de extração de Kempson.

Tabela 11 - Dominância (%) dos grupos mais abundantes de predadores[1] e decompositores[2] capturados nas quatro parcelas em estudo, localizadas na Embrapa, Manaus/AM.

Parcela	Tamanho de malha	Grupo Funcional	Dias de exposição no solo					
			25	57	84	112	168	252
FLO	FINA	**PREDADORES**						
		Acari (exceto Oribatida)	99	99	99.7	100	94	99
		Pseudoscorpinida	1	0	0.1	0	4.7	0.8
		DECOMPOSITORES						
		Acari Oribatida	58	76	54	17	28	59
		Collembola	39	8.6	33	78	70	39
		Diplopoda	1	0	0	0.4	0.9	1
		Isopoda	0.2	0	0	0	<0,1	0.2
		Psocoptera	1.8	12	12	3	0.6	1.8
		Diptera (larva)	0	3.1	0	0.2	0	0
	MEDIA	**PREDADORES**						
		Acari (exceto Oribatida)	97	99.6	98	98	97.5	81
		Pseudoscorpinida	0.7	0.3	0.8	1.6	1.6	0.7
		DECOMPOSITORES						
		Acari Oribatida	81	96.3	50	74	68	81
		Collembola	15	3.4	49	20	31	15
		Diplopoda	1.8	0	<0,1	0	0.1	1.8
		Isopoda	0	0	0.6	0	0	0
		Psocoptera	0.8	0.2	0	0.7	0.4	0.8
		Diptera (larva)	0.6	<0,1	<0,1	4	0.2	0.6
	GROSSA	**PREDADORES**						
		Acari (exceto Oribatida)	95	99.3	90	86	72	95
		Pseudoscorpinida	3.5	0.5	5.9	8	20	3.5
		DECOMPOSITORES						
		Acari Oribatida	77	89.5	83	81	81	77
		Collembola	13	8.3	9.2	12	13	13
		Diplopoda	2.6	0.2	1.2	1.3	3.6	2.6
		Isopoda	2.6	0	0.6	7	1	2.6
		Psocoptera	1	1	1	2.6	8	1
		Diptera (larva)	2	1	0.2	1.6	0.3	2
SEC	FINA	**PREDADORES**						
		Acari (exceto Oribatida)	100	92	92	99	100	98
		Pseudoscorpinida	0	0	7	1	0	1.7
		DECOMPOSITORES						
		Acari Oribatida	77	61	28	62	5	97
		Collembola	0	12	44	19.5	94	2
		Diplopoda	0	0	0	0.4	0.1	0.3
		Isopoda	0	0	0	0	0	0
		Psocoptera	23	27	28	16	0.5	1.1
		Diptera (larva)	0	0	0	0	0	<0,1
	MEDIA	**PREDADORES**						

		Acari (exceto Oribatida)	83	100	100	99	99	98
		Pseudoscorpinida	16	0	0	1	1	0
		DECOMPOSITORES						
		Acari Oribatida	87	81	74	56	80	85
		Collembola	4.4	1	17.2	9.8	17	13
		Diplopoda	0.5	0.6	0	0	1	<0,1
		Isopoda	0	0	0	4	0	0
		Psocoptera	6.1	7.4	8	4	0.4	1.4
		Diptera (larva)	1.1	0	0.8	0.2	0.3	0.4
	GROSSA	**PREDADORES**						
		Acari (exceto Oribatida)	72	97	98	94	89.2	96
		Pseudoscorpinida	22	1.6	0.7	3	3.5	0
		DECOMPOSITORES						
		Acari Oribatida	93	81	66	85	88.5	84
		Collembola	5	16	26	8	7	8.6
		Diplopoda	0.2	0.3	2.2	0.4	3.2	2
		Isopoda	0	0	0	0	<0,1	0
		Psocoptera	1.6	1.7	5	7	0.7	3
		Diptera (larva)	0	0.7	0.2	0.4	0.2	1.2

Parcela	Tamanho de malha	Grupo Funcional	Dias de exposição no solo 25	57	84	112	168	252
POA	FINA	**PREDADORES**						
		Acari (exceto Oribatida)	87	100	100	100	97	87
		Pseudoscorpinida	0	0	0	0	0	0
		DECOMPOSITORES						
		Acari Oribatida	88	88	87	89	94	88
		Collembola	11	8.8	8.2	5.6	5.8	11
		Diplopoda	0.3	0	1.6	2.6	0	0.3
		Isopoda	0	0	0	0	0	0
		Psocoptera	0.9	0	3.2	2.6	0	0.9
		Diptera (larva)	0	0	0	0	0	0
	MEDIA	**PREDADORES**						
		Acari (exceto Oribatida)	100	100	98	100	96	100
		Pseudoscorpinida	0	0	0	0	0	0
		DECOMPOSITORES						
		Acari Oribatida	72	89	89	94	93	72
		Collembola	19	7.2	5.5	1.8	4	20
		Diplopoda	3.4	2.4	0.5	0.2	0.8	0
		Isopoda	0	0	0	0	0	0
		Psocoptera	1.3	0.9	3.5	2.9	0.5	0
		Diptera (larva)	3	0	0.5	0	1.3	1.3
	GROSSA	**PREDADORES**						
		Acari (exceto Oribatida)	94	92	94	91	76	94
		Pseudoscorpinida	0	2.7	3	0	6	0
		DECOMPOSITORES						
		Acari Oribatida	79.6	87	90	94	94	80
		Collembola	12	8.4	3.4	1.8	1	12
		Diplopoda	3	4.2	3	0.6	2.4	3
		Isopoda	1	0	0	0	0	1
		Psocoptera	0	0	1.3	2.4	0.5	1.5
		Diptera (larva)	2.5	0	0.3	0.6	2.4	2.5
POC	FINA	**PREDADORES**						
		Acari (exceto Oribatida)	99	95	100	100	100	99
		Pseudoscorpinida	0.7	4.6	0	0	0	0
		DECOMPOSITORES						
		Acari Oribatida	79	71	59	83	67	79
		Collembola	17	16	24	8.2	28	17
		Diplopoda	0.6	4.2	2.3	3.5	1.6	0.6
		Isopoda	0	4.2	0	0	0	0
		Psocoptera	2.5	4.2	13	3.5	2	2.5
		Diptera (larva)	0	0	0	0	0	0
	MEDIA	**PREDADORES**						

	Acari (exceto Oribatida)	92	100	98	98	100	92
	Pseudoscorpinida	2.2	0	0	0	0	2
	DECOMPOSITORES						
	Acari Oribatida	87	63	70	82	78	87
	Collembola	9	32	23	7.2	17	9
	Diplopoda	1.3	0.4	2.5	5.7	2.2	1.3
	Isopoda	0	0.4	0	0	0	0
	Psocoptera	0.4	2.9	3	4.1	0.3	0.4
	Diptera (larva)	1.3	0.4	0	0	0.3	1.3
GROSSA	**PREDADORES**						
	Acari (exceto Oribatida)	96	8.2	97	100	100	96
	Pseudoscorpinida	2.9	17	0	0	0	3.9
	DECOMPOSITORES						
	Acari Oribatida	79	56	57	74	83	79
	Collembola	11	31	29	9.7	7.3	11
	Diplopoda	2.8	9	6.4	8.3	6.4	2.8
	Isopoda	0	3.4	2.5	0	2.3	2.8
	Psocoptera	1.9	0	3.9	7	0.5	1.8
	Diptera (larva)	2.3	0	0	0	0.6	2.3

[1]Acari (exceto Oribatida), Chilopoda, Dermaptera, Diplura, Opilionida, Pseudoscorpinida, Scorpionida, Ricinuleidae, Palpigradi, Uropygi

[2] Coleoptera (larva), Collembola, Oribatida (Acari), Diplopoda, Diptera (larva), Enchytraeidae, Isopoda, Lumbricidae, Nematoda, Pauropoda, Protura, Psocoptera, Symphyla, Tricoptera

3.6.2. Decompositores

Na FLO, os resultados estatísticos analisados na malha fina entre os períodos de coletas indicaram que no primeiro período a abundância foi menor que a encontrada no quarto, quinto e sexto períodos. Na malha média e grossa a densidade media do terceiro período foi maior que a do primeiro e sexto, ficando de acordo assim com a hipótese de que a densidade maior seria nos períodos intermediários de coleta (Tabela 12, Figura 04). A análise estatística da densidade média entre os tipos de malha indicaram que a malha média (terceiro período) e grossa apresentaram uma maior densidade que a malha fina (Tabela 13).

Na SEC (Tabela 12, Figura 04), os valores densidade média encontrados na malha fina durante o primeiros períodos foram menores que aqueles encontradas nos últimos períodos de coleta (quinto e sexto). Na malha média os resultados foram semelhantes com a densidade média do primeiro período menor que as encontradas no terceiro, quinto e sexto períodos. Entretanto na malha grossa, a densidade média encontrada para o quinto período foi estatisticamente maior que a do primeiro e do quarto período. Os resultados encontrados entre os diferentes tipos de malhas indicaram que as principais diferenças foram com uma menor densidade média nos sacos de malha fina principalmente com relação a densidade média nos sacos de malha média (Tabela 13).

Tabela 12 - Diferenças significativas(One-way ANOVA) registradas na densidade de **Decompositores**[1] entre os seis períodos de coleta (25, 57, 84, 112, 168 e 252 dias de exposição sobre o solo), nas quatro parcelas.

Parcela	Tamanho da malha	Período/ (dias de exposição)	Df	q	P	Diferenças detectadas (< ou >) (Período/Tamanho da Malha)
FLO	Fina	1 (25 dias)	249	4.5	< 0,05	<4 (112 dias) Fina
			373	6.76	< 0,05	<5 (168 dias) Fina
			319	5.78	< 0,05	<6 (252 dias) Fina
	Media	3 (84 dias)	288	5.22	< 0,05	>1 (25 dias) Média
			271	4.91	< 0,05	>6 (252 dias) Média
	Grossa	3 (84 dias)	236	4.78	< 0,05	>1 (25 dias) Grossa
			264	4.28	< 0,05	>6 (252 dias) Grossa
SEC	Fina	1 (25 dias)	272	4.92	< 0,05	<5 (168 dias) Fina
			372.5	6.74	< 0,05	<6 (252 dias) Fina
		2 (57 dias)	240.5	4.35	< 0,05	<5 (168 dias) Fina
			372.7	6.7	< 0,05	<6 (252 dias) Fina
	Media	1 (25 dias)	239	4.32	< 0,05	<3 (84 dias) Média
			274.5	4.97	< 0,05	<5 (168 dias) Média
			270	4.89	< 0,05	<6 (252 dias) Média
	Grossa	5 (168 dias)	298.5	5.4	< 0,05	>1 (25 dias) Grossa
			264	4.78	< 0,05	>4 (112 dias) Grossa
POA	Fina	1 (25 dias)	83	4.21	< 0,05	<4 (112 dias) Fina
			82.5	4.19	< 0,05	<6 (252 dias) Fina
	Media	3 (84 dias)	99.5	5.05	< 0,05	<4 (112 dias) Média
POC	Fina	1 (25 dias)	91.5	4.65	< 0,05	<5 (168 dias) Fina

[1] Coleoptera (larva), Collembola, Oribatida (Acari), Diplopoda, Diptera (larva), Enchytraeidae, Isopoda, Lumbricidae, Nematoda, Pauropoda, Protura, Psocoptera, Symphyla, Tricoptera

No Policultivo A (POA), a densidade populacional média dos invertebrados na malha fina foi maior no quarto e no sexto período que no primeiro, enquanto que na malha média a densidade populacional apenas do terceiro período foi menor que a do quarto período. Entretanto, na malha grossa não houve nenhuma diferença estatisticamente significativa entre os períodos (Tabela 12, Figura 04). Entre três tamanhos de malhas, houve diferença estatisticamente significativa entre a densidade média dos sacos de malha média e grossa com os sacos de malha fina (Tabela 13).

No Policultivo C (POC), a maior densidade na malha fina foi registrada no quinto período. Na malha média e grossa não houve nenhuma diferença estatisticamente significativa na densidade populacional (Tabela 12, Figura 04). Na diferença entre malhas, a densidade média foi menor no primeiro período que a do segundo e quinto da malha média e ao quinto período da malha grossa (Tabela 13).

Tabela 13 - Diferenças significativas (One-way ANOVA) na **Densidade de Decompositores**[1] entre três tamanhos de malha (fina, media e grossa), nas quatro parcelas estudadas.

Parcela	Tamanho da malha	Período/ (dias de exposição)	Df	q	P	Diferenças detectadas (< ou >) (Período/Tamanho da Malha)
FLO	Media	1 (25 dias)	932	5.3	<0,05	>1 (25 dias) Fina
		2 (57 dias)	1271	7.3	<0,05	>1 (25 dias) Fina
			964	5.5	<0,05	>2 (57 dias) Fina
			1020.5	5.9	<0,05	>3 (84 dias) Fina
		3 (84 dias)	1581.5	9.1	<0,05	>1 (25 dias) Fina
			1274.5	7.3	<0,05	>2 (57 dias) Fina
			1331	7.6	<0,05	>3 (84 dias) Fina
			1051	6	<0,05	>4 (112 dias) Fina
			934.5	5.4	<0,05	>6 (252 dias) Fina
			969.5	5.6	<0,05	>6 (252 dias) Grossa
		4 (112 dias)	1355	7.8	<0,05	>1 (25 dias) Fina
			1048	6	<0,05	>2 (57 dias) Fina
			104.5	6.4	<0,05	>3 (84 dias) Fina
		5 (168 dias)	1326	7.6	<0,05	>1 (25 dias) Fina
			1019	5.8	<0,05	>2 (57 dias) Fina
			107.5	6.2	<0,05	>3 (84 dias) Fina
		6 (252 dias)	949	5.4	<0,05	>1 (25 dias) Fina
		3 (84 dias)	934.5	5.4	<0,05	>1 (25 dias) Fina
			969.6	5.6	<0,05	>6 (252 dias) Grossa
	Grossa	2 (57 dias)	1157	6.6	<0,05	>1 (25 dias) Fina
			906.5	5.2	<0,05	>2 (57 dias) Fina
		3 (84 dias)	1281.5	7.4	<0,05	>1 (25 dias) Fina
SEC	Media	2 (57 dias)	866	5.2	<0,05	>1 (25 dias) Fina
			817	4.9	<0,05	>2 (57 dias) Fina
		3 (84 dias)	1122	6.8	<0,05	>1 (25 dias) Fina
			1073	6.5	<0,05	>2 (57 dias) Fina
			814	5	<0,05	>3 (84 dias) Fina
		4 (112 dias)	953	5.8	<0,05	>1 (25 dias) Fina
			953	5.5	<0,05	>2 (57 dias) Fina
		5 (168 dias)	1192	7.2	<0,05	>1 (25 dias) Fina
			1142.5	6.9	<0,05	>2 (57 dias) Fina
			883.5	5.3	<0,05	>3 (84 dias) Fina
		6 (252 dias)	1167	7.1	<0,05	>1 (25 dias) Fina
			1117.5	6.7	<0,05	>2 (57 dias) Fina
			885.5	5.2	<0,05	>3 (84 dias) Fina
	Grossa	2 (57 dias)	835	5	<0,05	>1 (25 dias) Fina
		3 (84 dias)	1046	6.4	<0,05	>1 (25 dias) Fina
			997	6	<0,05	>2 (57 dias) Fina
		5 (168 dias)	1297.5	7.9	<0,05	>1 (25 dias) Fina
			1248	7.5	<0,05	>2 (57 dias) Fina
			989	6	<0,05	>3 (84 dias) Fina
			828.5	5	<0,05	>4 (112 dias) Fina
			821	4.9	<0,05	>1 (25 dias) Média
		6 (252 dias)	1054	6.4	<0,05	>1 (25 dias) Fina
			1004.5	6.1	<0,05	>2 (57 dias) Fina
POA	Media	4 (112 dias)	339.5	5.8	<0,05	>1 (25 dias) Fina
			300	5.1	<0,005	>2 (57 dias) Fina
POC	Fina	1 (25 dias)	295	5	<0,05	>2 (57 dias) Média
			299.5	5.1	<0,05	<5(168 dias) Média
			296.5	5	<0,05	<5 (168 dias) Grossa

[1] Coleoptera (larva), Collembola, Oribatida (Acari), Diplopoda, Diptera (larva), Enchytraeidae, Isopoda, Lumbricidae, Nematoda, Pauropoda, Protura, Psocoptera, Symphyla, Tricoptera

3.6.2.1. Grupos mais abundantes entre os Decompositores

Os Decompositores mais importantes foram Acari Oribatida e Collembola, com dominância de mais de 85% do total de invertebrados registrado (Tabela 10). Somente houve uma baixa na densidade populacional de Oribatida na FLO, registrada nos sacos de malha fina durante o quarto período (17%), no terceiro e quinto períodos da SEC (28 e 5% respectivamente). Estes valores de densidade inferior ao normalmente encontrado deve-se ao aumento na densidade populacional de Collembola nestes mesmos períodos.

Outros grupos abundantes foram Diplopoda, Isopoda, Psocoptera e larva de Diptera (Tabela 11). Psocoptera teve uma densidade populacional relativamente alta, quando comparada com outros

grupos e foi muito superior a registrada no solo e na liteira. Esta maior abundância de Psocoptera nos experimentos com "litterbags", provavelmente é em função da maior quantidade de fungos na liteira do interior dos sacos de malha em conseqüência de uma maior umidade neste ambiente, que a encontrada no solo e liteira.

3.6.3 Outros Grupos

Os testes estatísticos (ANOVA) revelaram que na FLO, a densidade populacional no terceiro período foi superior aos demais períodos nos sacos de malha fina. Na malha média e grossa a maior densidade ocorreu nos períodos intermediários de coleta (Tabela 14, Figura 05). Entre os três tamanhos de malha a maior densidade populacional foi registrada na malha média no terceiro período (Tabela 15).

Tabela 14 - Diferenças significativas(One-way ANOVA) registradas na densidade de **Outros Grupos** entre os seis períodos de coleta (25, 57, 84, 112, 168 e 252 dias de exposição sobre o solo), nas quatro parcelas.

Parcela	Tamanho da malha	Período/ (dias de exposição)	Df	q	P	Diferenças detectadas (< ou >) (Período/Tamanho da Malha)
FLO	Fina	3 (84 dias)	7.2	8.1	< 0,001	>1 (25 dias) Fina
			5.4	6.1	< 0,001	>2 (57 dias) Fina
			3.98	4.48	< 0,05	>4 (112 dias) Fina
			5.4	6.08	< 0,001	>5 (156 dias) Fina
			4.6	5.18	<0,01	>6 (252 dias) fina
	Media	3 (84 dias)	277.5	5.03	< 0,05	>1 (25 dias) Média
			290	5.25	< 0,05	>2 (57 dias) Média
			227	4.1	< 0,05	>5 (156 dias) Média
		4 (112dias)	374	6.77	< 0,01	>1 (25 dias) Média
			386.5	6.99	< 0,05	>2 (57 dias) Média
	Grossa	3 (84 dias)	8.1	7.15	< 0,001	>1 (25 dias) Grossa
			9.7	6.97	< 0,001	>2 (57 dias) Grossa
			6.3	6.56	< 0,01	>5 (156 dias) Grossa
			5	4.42	< 0,05	>6 (252 dias) Grossa
SEC	Fina	1 (25 dias)	279	5.05	< 0,05	<3 (84 dias) Fina
	Media		231	4.18	< 0,05	<3 (84 dias) Média
	Grossa		236	4.27	< 0,05	<3 (84 dias) Grossa
POA	Fina	3 (84 dias)	6	6.21	< 0,01	>1 (25 dias) Fina
			5.2	5.38	< 0,01	>2 (57 dias) Fina
			4.4	4.55	< 0,05	>5 (156 dias) Fina
		4 (112 dias)	4.6	4.76	< 0,05	>1 (25 dias) Fina
	Grossa	3 (84 dias)	110	5.59	< 0,05	>1 (25 dias) Grossa
			80	4.06	< 0,05	>2 (57 dias) Grossa
			79.5	4.04	< 0,05	>4 (112 dias) Grossa
POC	Media	3 (84 dias)	96	4.88	< 0,05	>1 (25 dias) Média
	Grossa	3 (84 dias)	6	5.55	< 0,05	>1 (25 dias) Grossa

Tabela 15 - Diferenças significativas (One-way ANOVA) da densidade de **Outros Grupos** entre três tamanhos de malha (fina, media e grossa), nas quatro parcelas estudadas.

Parcela	Tamanho da malha	Período/ (dias de exposição)	Df	q	P	Diferenças detectadas (< ou >) (Período/Tamanho da Malha)
FLO	Media	1 (25 dias)	879	5.3	< 0,05	<3 (84 dias) Fina
		2 (57 dias)	918	5.6	< 0,05	>3 (84 dias) Fina
		3 (84 dias)	1265.5	7.68	< 0,05	>1 (25 dias) Fina
			980	5.95	< 0,05	>2 (57 dias) Fina
			957.5	5.8	< 0,05	>5 (168 dias) Fina
			902	5.5	< 0,05	>6 (252 dias) Fina
		4(112 dias)	1009.5	6.13	< 0,05	>1 (25 dias) Grossa
			1129.5	6.8	< 0,05	>2 (57 dias) Grossa
			975	5.9	< 0,05	>1 (25 dias) Fina
			832	5.1	< 0,05	>2 (57 dias) Grossa
	Grossa	2 (57 dias)	832	5	< 0,05	<3 (84 dias) Fina
		3 (84 dias)	1103	6.6	< 0,05	>1 (25 dias) Fina
			817	4.9	< 0,05	>2 (57 dias) Fina
			1013	6.1	< 0,05	>1 (25 dias) Média
			1052	6.4	< 0,05	>2 (57 dias) Média
SEC	Media	1 (25 dias)	841	5.1	< 0,05	<3 (84 dias) Fina
	Grossa	1 (25 dias)	820	4.9	< 0,05	<3 (84 dias) Fina
POA	Fina	1 (25 dias)	299.5	5.1	< 0,05	>1 (25 dias) Grossa
			325	5.6	< 0,05	<3 (84 dias) Grossa
POC	Media	1 (25 dias)	313.5	5.4	< 0,05	<3 (84 dias) Grossa

Na SEC, ao contrário da tendência anteriormente observada com densidade superior nos períodos intermediários, os testes estatísticos revelaram uma densidade populacional média do primeiro período inferior a do terceiro (Tabela 14, Figura 05). As únicas diferenças detectadas para os três tamanhos de malha foi para a menor densidade da malha fina (Tabela 15)

Na POA, foi registrada maior densidade nas malhas finas e grossa durante os períodos intermediários (Tabela 15, Figura 05). Foi detectada diferença apenas para a menor densidade populacional na malha fina em relação a malha grossa no terceiro período (Tabela 15).

Na POC, os testes estatísticos indicaram resultados significativos de maior densidade populacional na malha média durante o terceiro período (Tabela 14, Figura 05). Foi detectada menor densidade do primeiro período da malha media em relação ao terceiro período da malha grossa (Figura 15).

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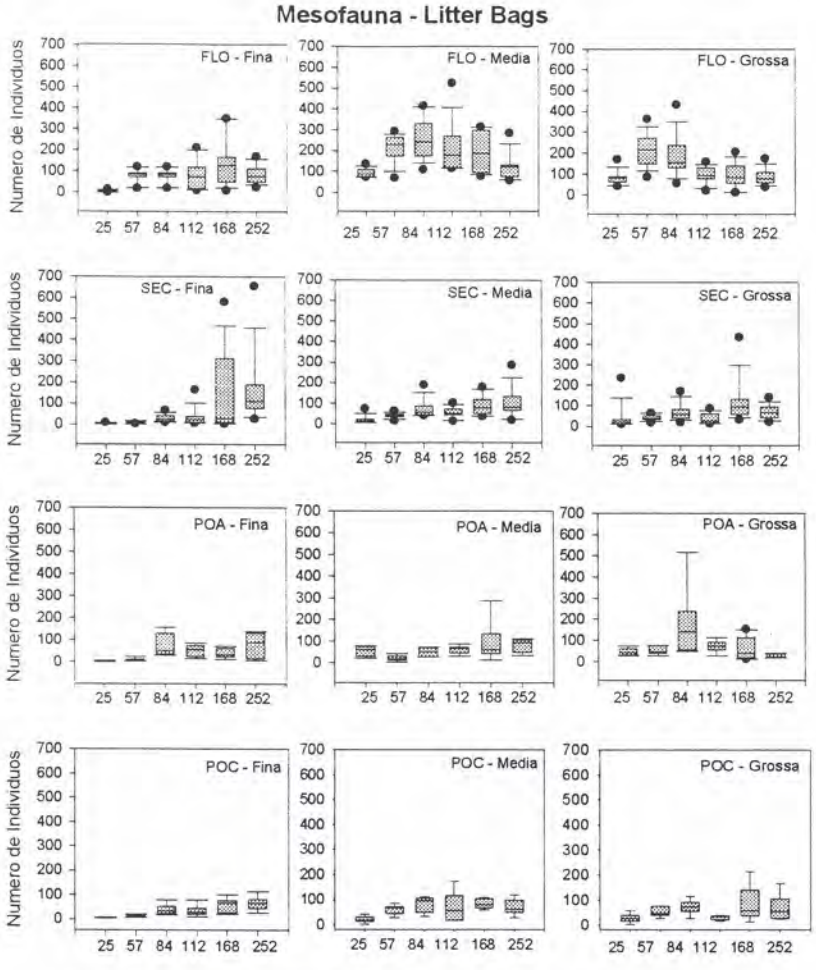

Figura 01 - Colonizacao dos sacos de malha de náilon pela fauna de invetebrados do solo, após 25, 57, 84, 112, 168 e 252 dias de exposicao sobre o solo nas quatro parcelas.

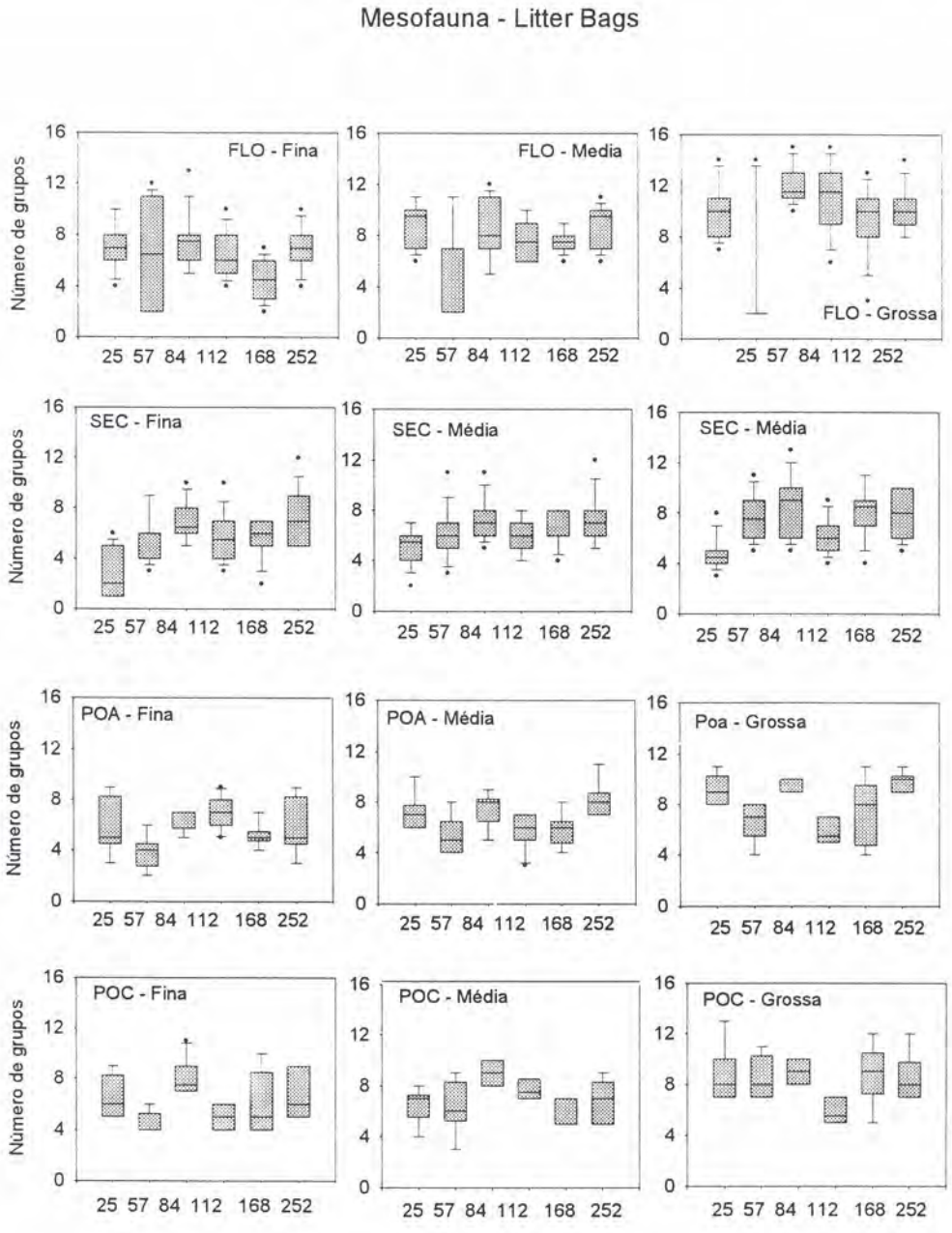

Figura 02 - Flutuacao da diversidade de invertebrados do solo nas quatro parcelas

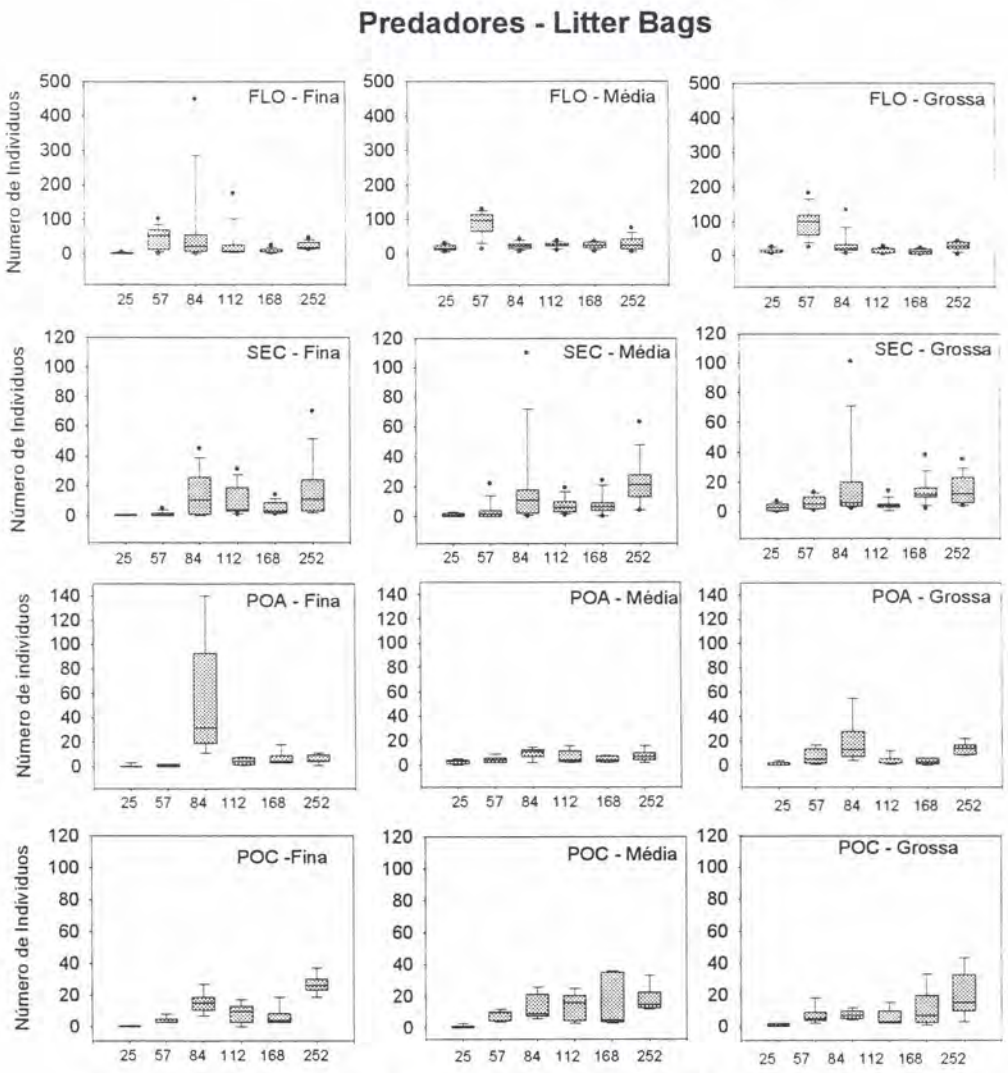

Figura 03 - Colonizacao dos sacos de malha de náilon pela fauna de predadores, após 25, 57, 84, 112, 168 e 252 dias de exposicao sobre o solo nas quatro parcelas

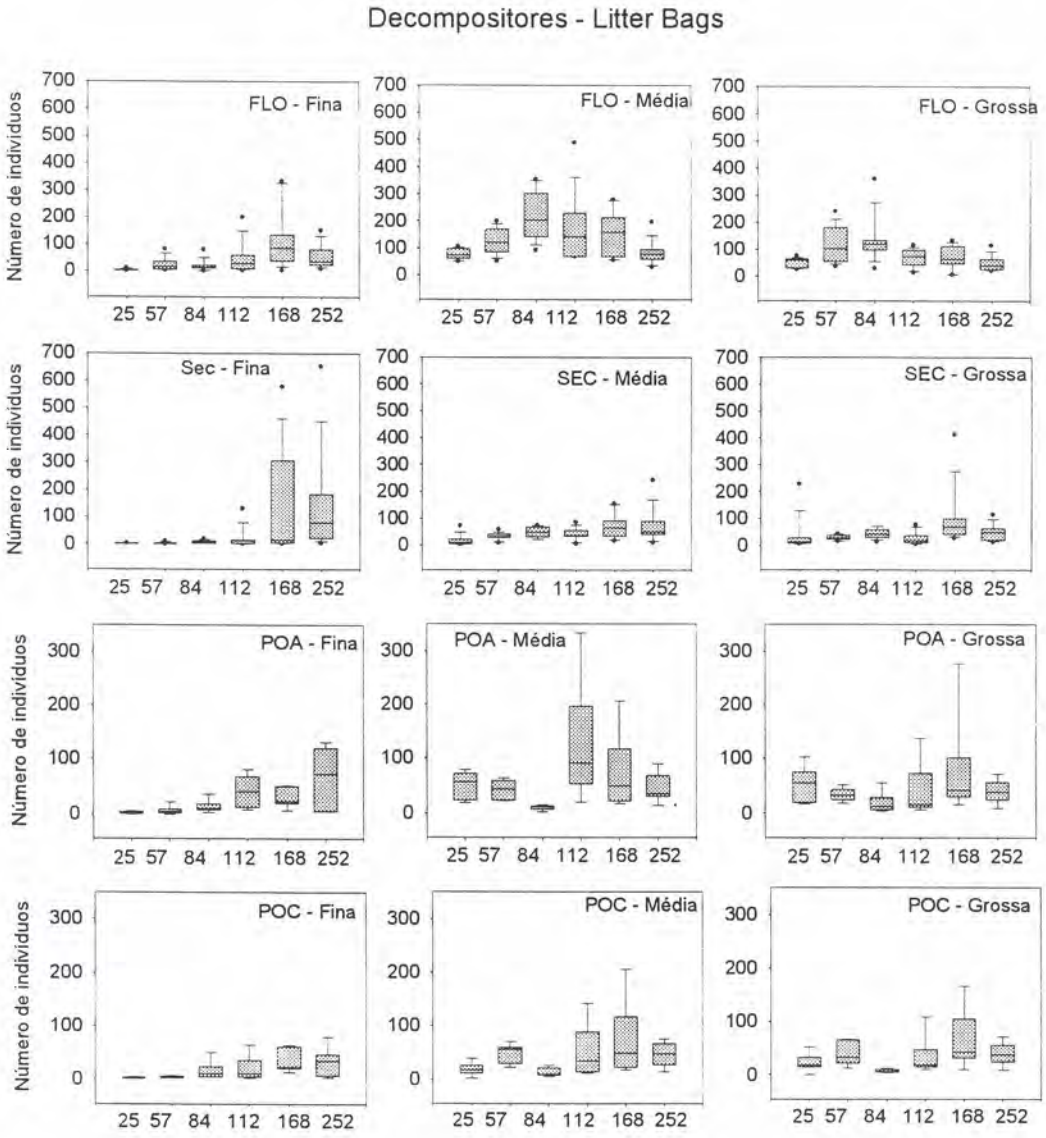

Figura 04 - Colonizacao dos sacos de malha de nailon pela fauna de decompositores apos 25, 57, 84, 112, 168 e 252 diaas de exposicao sobre o solo das quatro parcelas.

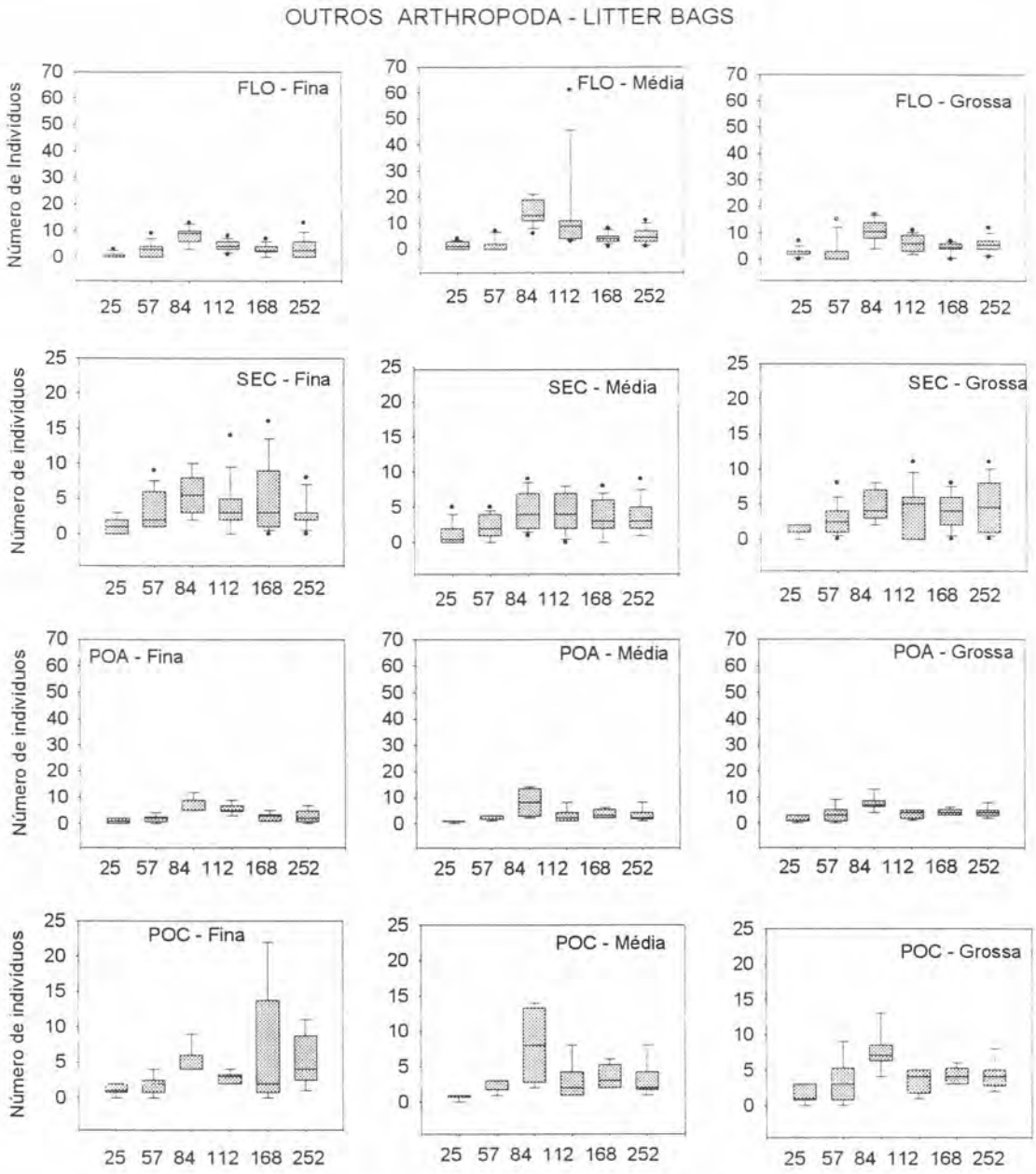

Figura 05 - Colonizacao dos sacos de malha de nailon pela de Outros Invertebrados apos 25, 57, 84, 112, 168 e 252 dias de exposicao sobre o solo das quatro parcelas.

Bait-lamina

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1. Introduction

The study of the soil ecosystem should include structural and functional endpoints. The latest approach for testing functional endpoints is the bait-lamina-test. Assessment endpoint is the feeding activity of a variety of soil animals (e.g. earthworms, Collembola, Enchytraeidae) whereas the activity of micro-organisms is not detectable (Pfeif et al. 1996). The absolute amount of fed material as well as the vertical distribution of the feeding activity are recorded and statistically evaluated. Since environmental conditions like climate or soil moisture can influence strongly the results, the method should only be applied for comparing the biological activity between closely related plots measured simultaneously. The principle can be summarised as follows (Von Törne 1990a,b; Kratz 1998): The loss of artificial or natural material exposed in small plastic strips to soil animals (no specification of certain organisms is possible) is measured for several days up to a few weeks.
The important advantages of the method are simplicity and short exposure periods (5 - 20 days). Additionally, nearly no training, special skills or equipment is necessary. In comparison to the measurement of other functional endpoints like litter decomposition the bait-lamina method does practically do not disturb the soil substrate. The results are expressed as percentage of "fed" holes versus the absolute number of holes. Additionally, the vertical distribution of the feeding activity is assessed graphically. In any case, expert judgement will be required to evaluate the impact of environmental conditions.

In parallel to the basic sampling program of SHIFT ENV 52, bait-lamina tests have been performed since July 1997. This functional method, measuring indiscriminately the feeding activity of soil organisms, has never been performed in the tropics so far.

2. Study sites and methods

Study sites

Study sites were four plots of three different forest systems - one plot of 40 x 40 m in a primary forest (FLO), one plot of 40 x 40 m in a nearby secondary forest (growing since 1984, SEC) and two plots of 32 x 48 m large polycultures (POA, POC), where 4 different tree species of commercial use have been planted in rows. In the polyculture plots the tolerated secondary vegetation (mainly *Vismia* spp., Guttiferae) still dominated the stand and especially the litter production (Beck et al. 1998; Höfer et al. 1999).

Performance of the tests

Bait lamina consist of plastic strips 120 mm*6 mm* 1 mm, which have a sharpened tip at the lower end. In the lower part (85 mm) of each lamina 16 holes of 1.5 mm diameter are drilled, which are 5 mm apart from each other. They are filled with bait material (consisting of powder of cellulose and bran 70:30 m/ms, together with a small amount of activated carbon). The sticks are exposed in a way that the uppermost hole is just beneath the soil surface. Measurement endpoints are the total amount of fed holes (determined visually in a yes/no manner) and the vertical distribution of the feeding activity. At the end of the exposure period, bait-lamina sticks are retrieved from their burrow and visually assessed (sticks held against the light):

- Visual distinction of „fed" (perforated) versus „not-fed" holes.
- Feeding rate is measured as absolute number of „fed" holes.

The results are evaluated statistically, e.g. by using the Wilcoxon-Test.
Two different approaches were used: In parallel to the quarterly basic sampling program, five blocks of bait-lamina sticks (each consisting of 16 individual sticks) were exposed on each plot (FLO, SEC, POA and POC) for four days. In addition, four "paired" experiments (one on each plot) were performed to determine the impact of the litter layer on the feeding activity in periods between the quarterly samplings (June (POA), July (SEC) and September (POC, FLO) 1998). Ten blocks of bait-lamina sticks (each consisting of 16 individual sticks) were exposed on subplots where the litter layer was removed by hand. Ten additional blocks, exposed on subplots immediately besides the other

ones but without any litter removal served as controls. The exposure time (about four days) has been determined in a pre-test in June 1997, when bait-lamina sticks were exposed on all plots for 14 days.

3. Results and Discussion

Comparison of the four plots

In general, the measurement of the functional endpoint "feeding activity" using bait-lamina sticks at the EMBRAPA site was possible without problems. No adaptation to tropical conditions except a shortage in exposure time was necessary.

In Table 1, average values for the total feeding rate at the four study plots are given for all four sampling dates. Despite the fact that the absolute amount is different it seems that the feeding activity on the two plantation plots is twice as high as on the two forest plots (SEC and FLO). This difference seems to be caused mainly by a decrease of feeding activity in the uppermost soil layer. The standard deviation is more than twice as high on POA and POC in comparison to FLO and SEC. Due to the high variability within the individual blocks, no statistical significant differences between the four plots could be identified.

Table 1: Average amount of the feeding rate at the four study plots in percent of the total number of bait lamina holes

Date:	FLO	SEC	POA	POC
12/97	9	7	14	24
06/98	17	20	36	35
09/98	19	16	43	43
12/98	11	11	27	05
Mean	14	14	30	27
Std.-Dev.	± 4.8	± 5.7	± 12.5	± 16.5

Comparison between control and treatments (litter removal study)

In the case of the litter removal study, all data gained so far are presented in Table 2. They seem to support the impression that the feeding activity is higher at POA and POC. On all investigation plots, the number of fed holes is higher for the controls than for the treated blocks. However, this difference is only small in the case of FLO and not very high in the case of POA and POC. Only at SEC the results are statistically different. Again, the standard deviation is much higher on the polyculture plots in comparison to the forest sites. It seems that the vertical distribution has changed accordingly (i.e. at the top layer more holes are fed; Fig. 5 and 6).

Table 2: Average amount of the feeding rate of control and litter removal plots at the four study plots in percent of the total number of bait lamina holes

Manipulation	FLO	SEC	POA	POC
Control	12.5	22.8	46.3	38.5
Std.-Dev.	10.9	14.8	18.3	26.6
Treatment	10.1	7.5	37.5	23.6
Std.-Dev.	9.4	4.2	21.9	21.3

Note: Only in SEC the difference is statistically significant.

Often the data evaluation was hindered by the fact that individual blocks were influenced by factors which could not be controlled: e.g. ants build their nest between the sticks of one block, eating nearly all holes. If things like this happened on some blocks which by chance belonged to the treated group, this could influence the overall assessment considerably.

Discussion

The bait-lamina test is a simple test with a „yes" or „no" answer. Despite the fact that not all data are evaluated it seems that this method can give important information on the function of the soil biocoenosis. This is especially true when closely related plots (e.g. with and without anthropogenic influence) are compared at the same point of time (e.g. Paulus et al. 1999).

In a short pre-test, it was checked whether peregrine earthworms from the polyculture sites (*Pontoscolex corethrurus*) and from a compost heap near the EMBRAPA site (*Eisenia fetida*) would feed on bait-lamina sticks. After 4 days in culture boxes, *P. corethrurus* had eaten 44 % in comparison to 100 % fed by *E. fetida*. These results indicate that tropical earthworms (like those in temperate regions) are among the organisms feeding on bait-lamina.

4. Conclusions and outlook

The most important results gained so far when using bait-lamina sticks on the four EMBRAPA plots can be summarised as follows:

- The feeding activity is always lower on FLO and SEC than on POA and POC, but these differences are statistically not significant.
- The removal of litter (= treatment) leads to a decrease of the feeding activity but with the exception of SEC these differences are statistically not significant.
- In both cases, the variability of the results is much higher on the polyculture plots compared to the forest plots, indicating mainly the different abiotic conditions at the various plots.

Finally, it seems that the bait-lamina-test is an easy to perform screening method to assess the activity of soil organisms. However, data evaluation has to be improved.

In the future the following issues will be checked whether

- there is a correlation between number (or better: biomass) of certain, mainly saprophagous animal groups like earthworms
- the vertical distribution can be assessed in detail (especially statistically)
- the study design should be changed, taking the recommendations of Imler (1998) into consideration.

Additionally, laboratory studies should be performed in order to determine which species and in which time tropical soil organisms feed on bait-lamina.

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6. Annex

See following pages

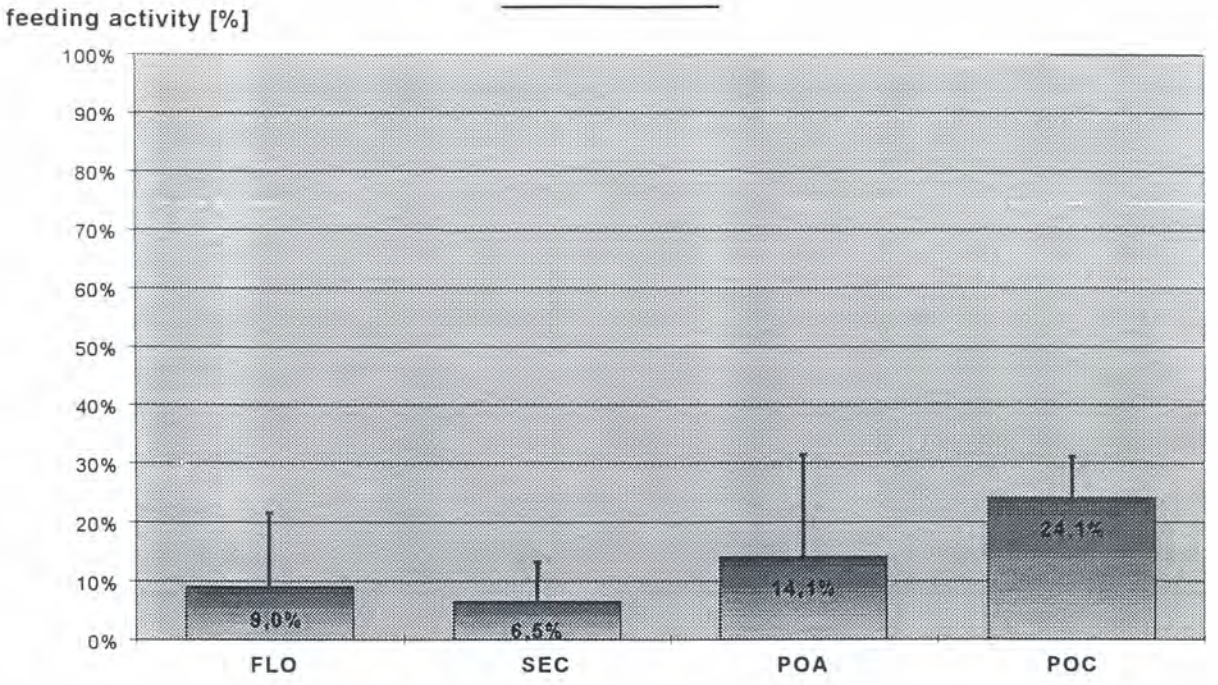


Fig. 1: Comparison of the feeding activity at the four plots (December 1997)

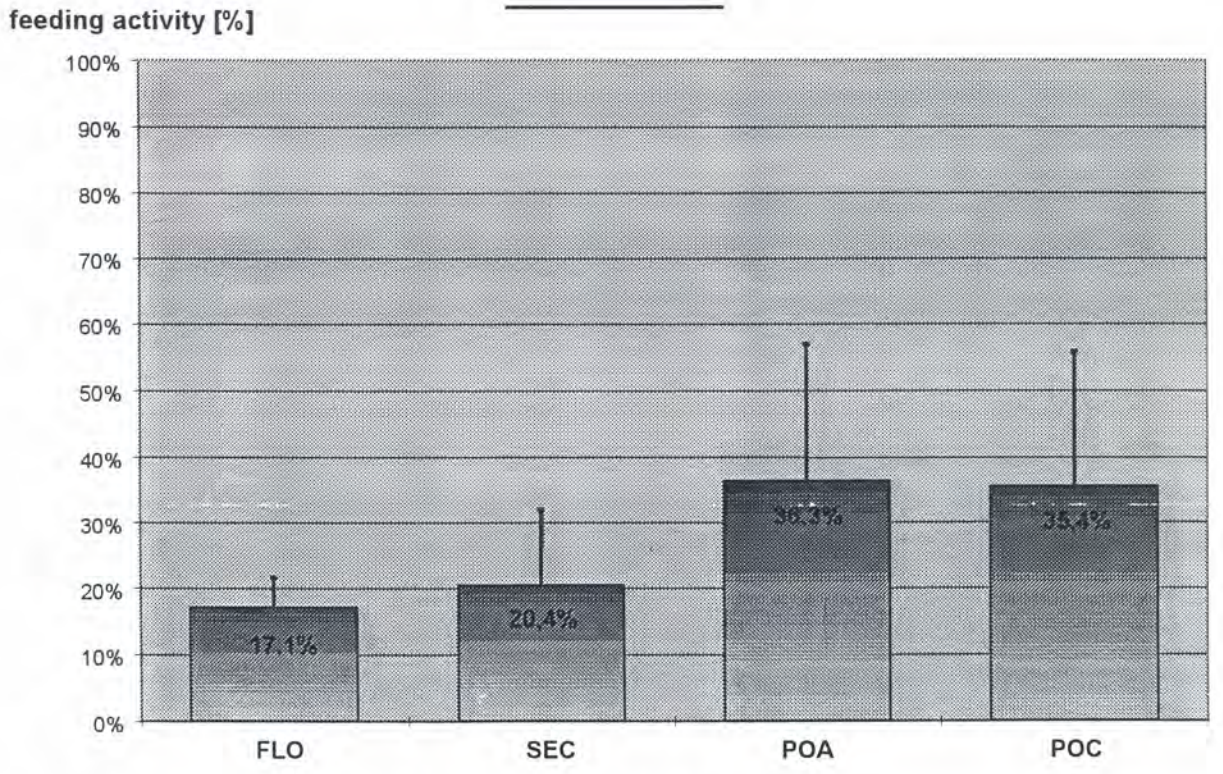


Fig. 2: Comparison of the feeding activity at the four plots (June 1998)

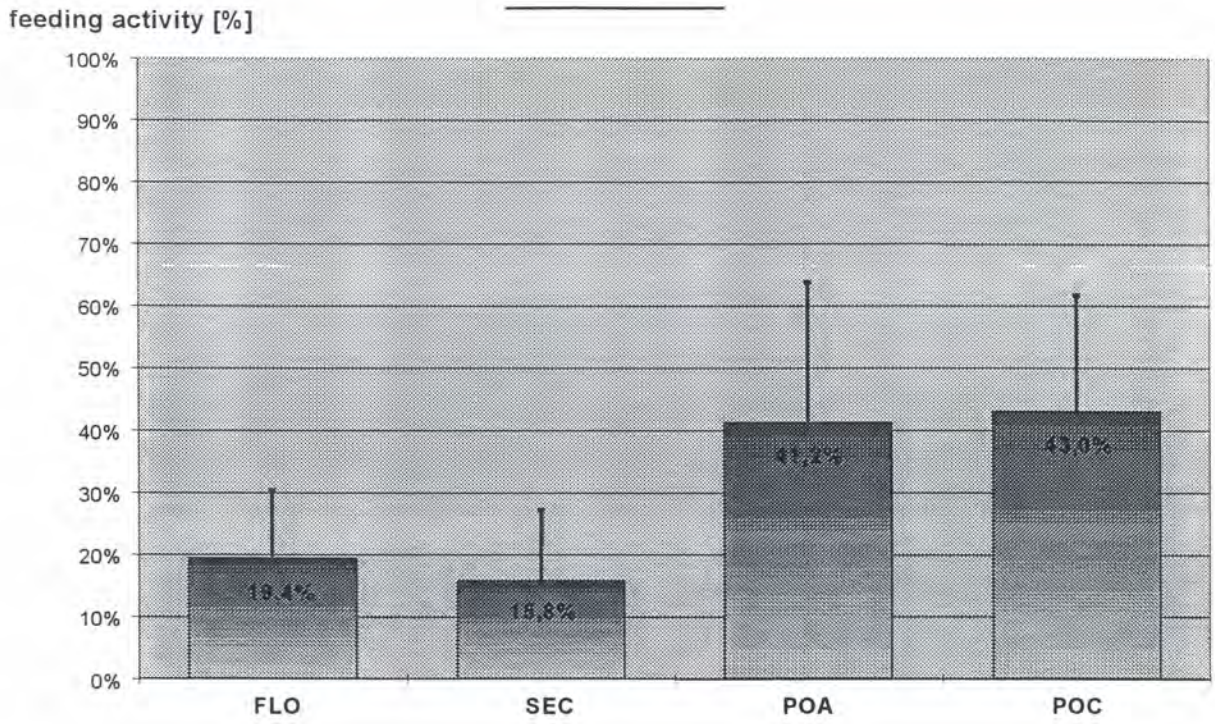


Fig. 3: Comparison of the feeding activity at the four plots (September 1998)

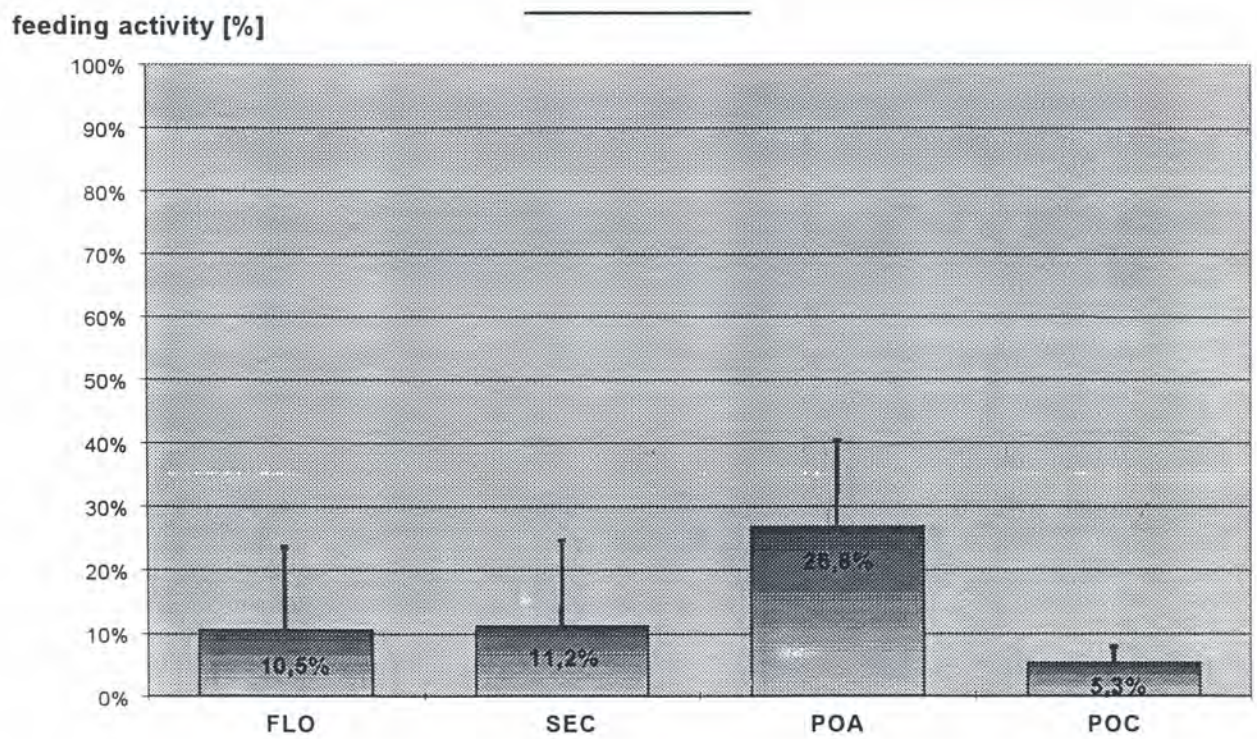


Fig. 4: Comparison of the feeding activity at the four plots (December 1998)

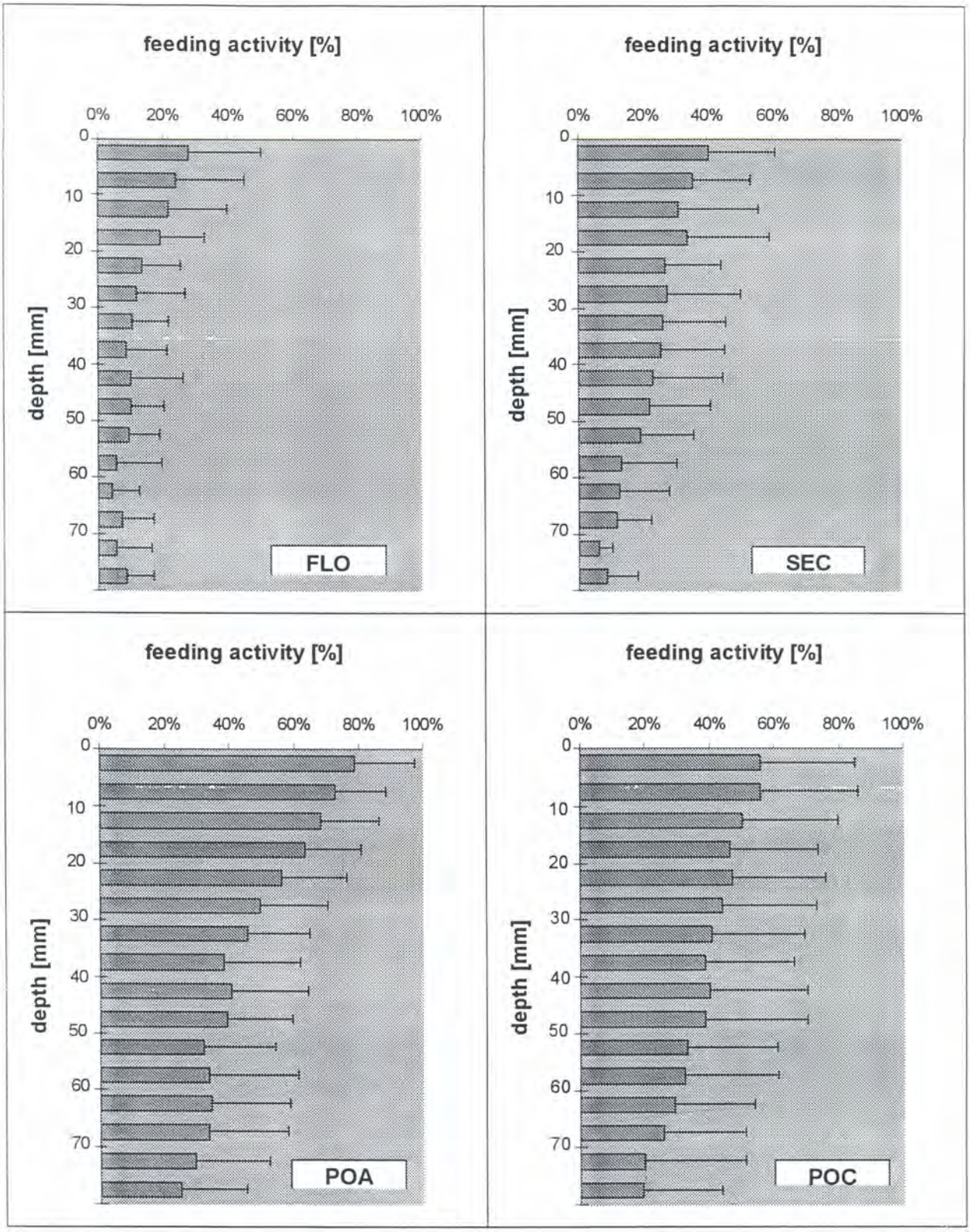


Fig. 5: Vertical distribution of the feeding activity in the litter removal test: Control sites

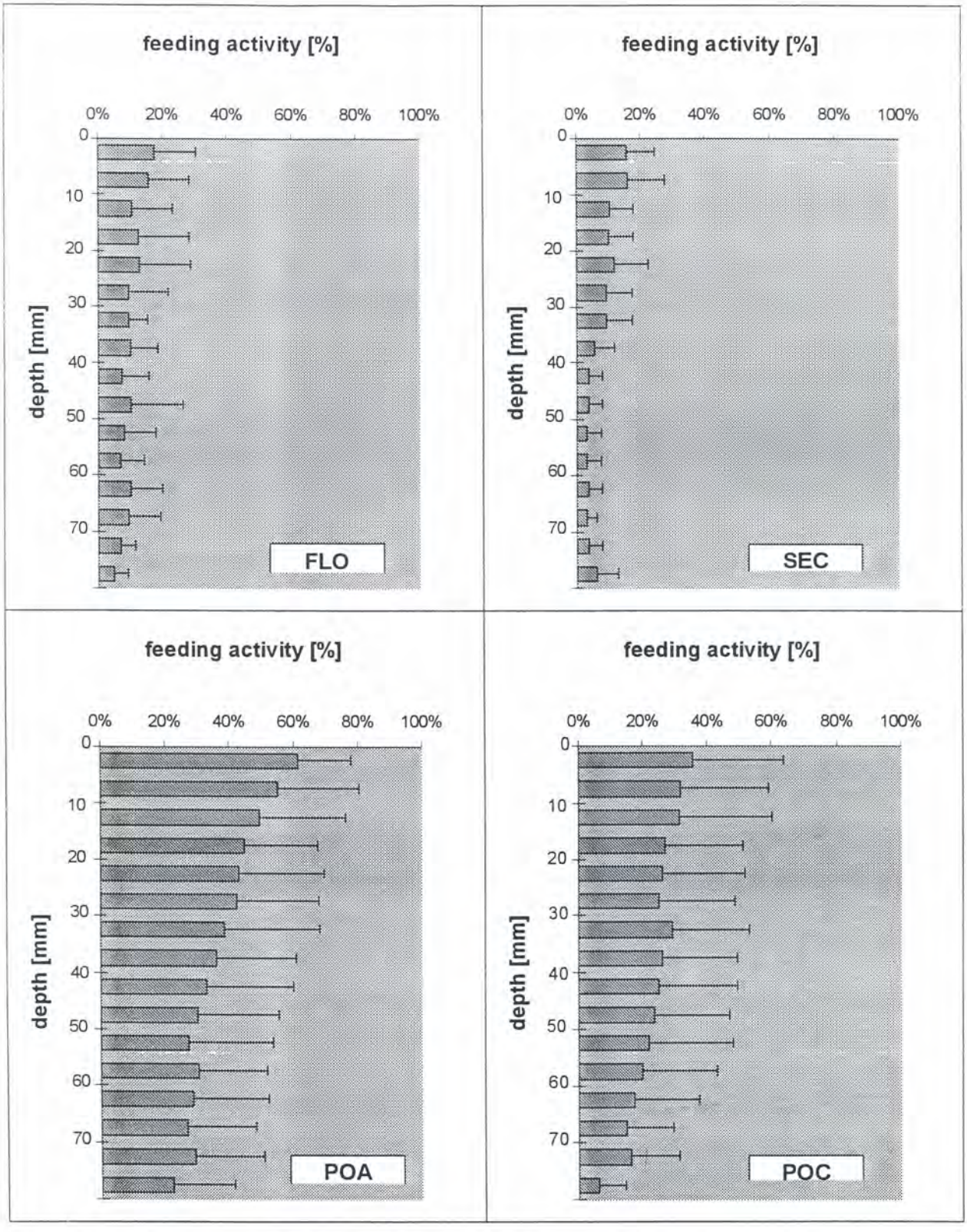


Fig. 6: Vertical distribution of the feeding activity in the litter removal test: Treatment sites

Table 1: Realized analyses

Substrate	Total no. of analyses	Specification
Litterstock	**72**	Aug 97 - Dec 98 (6 fauna sample dates,mixed samples)
Soil 0-5 cm	**192**	Aug 97 - Mar 99 (8 fauna sample dates, mixed samples of first and second day)
Litter production	**228**	from 19 months (except the first) always one weekly mixed sample
Litterbags, 1. Serie	**1620**	single samples from 6 retrieval dates
Litterbags, 2. Serie	**1080**	single samples from 4 retrieval dates
Minicontainer	**144**	mixed samples of 2 mesh widths, 3 retrieval dates
other substrates	**20**	leaves of other tree species
fauna	**20**	soil arthropods
Sum	**3448**	

2. Methods

2.1 Calibration

Elementary analysis by the VARIO EL analyzer is a relative method, which means that the measuring device must be calibrated before running. Standard substance used for the calibration was Acetanilid (C_8H_9NO; N 10.4 %, C 71.1 %, H 6.7 %, C/N 6.8365). Input weights ranged from 0.1 mg to 30 mg. The calibration was done by partitioning the measured values in a part of the curve analysed by linear regression (below) and a part of the curve analysed by a polynomial regression (above). Regression coefficients were:

element	linear calculation	polynomial calculation
N	**999978**	**47200**
C	**999999**	**12235**
H	**999949**	**58492**

Regression coefficients should be close to 1 in linear regression and close to 0 in polynomial regression. More important to judge the quality of the calibration is the difference between the theoretical absolute content and the absolute content calculated from the curve (theoretical/actual). Acceptabel differences are for all elements **0.002 - 0.003 mg** for input weights until 5 mg and **0.004 - 0.008 mg** for input weights up to 15 mg.In our calibration series the following minimum and maximum differences occured in the curves:

regression type	linear		polynomial	
element	**min**	**max**	**min**	**max**
N	**0**	**23**	**0**	**-4**
C	**1**	**-0.0032/+0.0047**	**1**	**-15**
H	**-1**	**-22**	**1**	**-7**

The two red values for C are from the samples Nr. 11 and 17. Although the differences theoretical/actual for these two samples are larger than defined as acceptabel they were not eliminated, because they equalize each other and the curve shows a very high regression coefficient in this range. Furthermore most of our samples are in the range of C-content falling into the polynomial part of the curve.

2.2 Daily factors

By calculating daily factors using three (or more) analyses of 5 mg-Acetanilid-samples at the beginning of a daily series we correct small deviations from the calibration due to daily conditions (like athmospheric pressure), but also control the validity of the calibration. Table 2 shows a quality controle by repeated analyses of the standard substance Acetanilid. Standard deviations of less than 1 % of the mean are possible and serve as orientation for desired standard deviations for analyses of real samples (see below).

Table 2

input weight	substance	N in %	C in %	H in %	C/N
5,392	Acetanilid	9,2208	62,1270	5,9929	*6,7377*
5,307	Acetanilid	9,0957	62,1880	6,0430	*6,8371*
4,961	Acetanilid	9,1136	62,2230	6,0475	*6,8275*
4,973	Acetanilid	9,0424	62,1690	6,0294	*6,8753*
5,071	Acetanilid	9,0366	62,1740	6,0160	*6,8802*
4,974	Acetanilid	9,0114	62,1860	6,0190	*6,9008*
5,049	Acetanilid	9,0340	62,1550	6,0079	*6,8801*
5,064	Acetanilid	8,9947	62,2520	6,0079	*6,9210*
mean		9,06865	62,18425	6,02045	6,857461
std.-deviation		0,068525	0,036365	0,017379	0,053524
in % of mean		**0,75562**	**0,05848**	**0,288665**	**0,780516**
variance		0,004696	0,001322	0,000302	0,002865

Nitrogen in litterfall samples (1 mixed sample of 1 week from e												
	N-content [%]				litter weight [g/collector*week]				N-content [g/m²*week]			
	POA	POC	SEC	FLO	POA	POC	SEC	FLO	POA	POC	SEC	FLO
lowest	0,96	1,09	1,12	1,20	1,60	1,60	1,80	2,40	0,08	0,09	0,09	0,14
highest	1,52	1,53	1,53	1,67	6,30	8,40	9,50	10,90	0,38	0,44	0,58	0,64
mean	1,31	1,34	1,28	1,42	3,35	4,03	3,80	4,83	0,17	0,22	0,20	0,28
							N g/20 weeks*m		3,50	4,31	3,96	5,52
							N g/year*m²		9,1	11,2	10,3	14,4
							N [kg/year*ha]		90,88	112,13	103,05	143,55

2.3 Input weights

Ideal input weight of leaf material was checked using repeated measures of the litter production sample POA W-26 from 11.8.1997, starting with weights of 2 mg up to 17 mg, always weighing three replicates. Objective was to come to a stable mean with standard deviations of the three replicate measures of below 2 % of the mean (fig. 1). Based on the graphical analyses we decided to use input weights between 10 and 12 mg for leaf material.

Ideal input weight of soil material was checked using repeated measures of the sample POA I-02 from 2.12.1997 (5-15 cm depth), starting with weights of 6 mg up to 35 mg, always weighing three replicates. Objective was to come to a stable mean with standard deviations of the three replicate measures of 2 % of the mean (fig. 2). We decided to use input weights between 25 and 30 mg for soil material.

2.4 Variance of analyses of single samples and exclusion of outliers

To see which precision we could reach in the analyses of our substrates we started with numerous repeated analyses with input weights between 10 and 12 mg of the same sample (litterfall sample from POA W26, 11.8.97) and calculated the mean and standard deviation in % of the mean (N: 1.582/0.8 %; C: 49.6467/0.13 %; C/N: 31,3739/0.78 %; graphically for N in fig. 3). Based on these measures we decided to set a general limit for outliers to a standard deviation of 2 % of the mean. When single

samples exceeded this limit we checked the three repeated measures of this sample for an outlier caused by an error in the analyses. Two characteristics make an error obvious: 1. a distinctly higher N-value between equal C- and H-values is most probably caused by entrance of air (high N-content); 2. if all three (N, C and H) values deviate distinctly in the same direction a weighing error is probable. Such a recognized outlier was excluded from the calculation of the mean and standard deviation. If no outlier was recognized, e.g. the three single values all differed more or less equally the analyses of the sample was repeated.

3. Results

3.1 Litter production

Litter production was measured by quadratic litter collectors (0.25 m² each). 10 collectors are installed in the polyculture areas POA and POC, 20 in the primary and secondary forest areas. Fallen litter is sampled from the collectors every week since July, 28 1997. One weekly sample of every month was chosen to be chemically analysed. Resulting data are available from August 97 to March 99. From the collection of 11.8.97 we analysed C and N contents of litter of every single collector to get an idea of variance within the areas (fig. 4). N-content (in % of total weight) of the fallen litter in single collectors ranged from 0.84 to 2.4; the mean was highest (1.42 %) and consequently the C/N-ratio lowest in FLO (35.1). Lowest mean N-content was found in samples from POC (1.25 % N, C/N 40.6). Differences of N-content and C/N between areas are not significant.

From all other dates the litter of all collectors of the same area were joined and mixed. Mean N content over 20 weekly samples (August 97 to March 99) was highest in FLO (1.42 %, C/N 34), intermediate in POC (1.34 %, C/N 36) and POA (1.31 %, C/N 38) and lowest in SEC (1.28 %, C/N 40, table 3). Differences of C/N ratios between areas are statistically significant (RM ANOVA, P=0.01). Multiple comparison (Tukey) showed that POA and SEC differ significantly from FLO (P=0.01). Using the absolute N-content from these mixed samples from each area we calculate an average input of 9.1 g N/year*m² in POA, 11.2 in POC, 10.3 in SEC and 14.4 g N/year*m² in FLO. The relatively weak differences between the different areas in single weekly samples sum up to considerably different Nitrogen conditions (fig. 5).

As we use exclusively freshly fallen leaves from *Vismia* spp. in our litterbag experiment we analysed fresh leaves from the trees and freshly fallen leaves of this species and compared it with the other tree species planted in mono- and polycultures (*Hevea brasiliensis*, *Schizolobium amazonicum*, *Swietenia macrophylla* and *Carapa guianensis*) and the cover crop *Pueraria phaseoloides*. Table 4 shows N- and C-contents and C/N-ratios for these substrates.

Table 4: N- and C-contents of leaves from different tree species

substrate	condition	origin	N in %	C in %	C/N
Vismia	alive from tree	area for litterbag material	1,600	51,155	31,985
Vismia	freshly fallen	dito	1,231	51,907	42,182
Vismia	dry on ground	dito	0,813	51,618	63,507
Vismia	decomposed by Isopoda	laboratory	1,405	48,133	34,260
Vismia	orig. material of litterbag series 1	area for litterbag material	0,72-0,74	48,7-48,9	65,9-68,1
Vismia	orig. material of litterbag series 2	area for litterbag material	0,860	51,000	59,300
Andiroba	alive from tree	monoculture	1,129	45,290	40,131
Andiroba	freshly fallen	monoculture	1,418	45,817	32,303
Andiroba	dry on ground	monoculture	1,006	45,187	44,941
Andiroba	already decomposed	monoculture	1,269	43,324	34,211
Mogno	alive from tree	monoculture	1,489	47,757	32,067
Mogno	dry on ground	monoculture	1,334	47,693	35,767
Mogno	already decomposed	monoculture	1,511	44,123	29,198
Seringueira	alive from tree	monoculture	2,848	49,971	17,547
Seringueira	freshly fallen	monoculture	1,826	49,275	26,986
Seringueira	dry on ground	monoculture	1,555	50,749	32,649
Pupunha	decomposed	monoculture	2,342	31,603	13,494
Pueraria	fresh leaves	polyculture	3,937	45,378	11,526
Pueraria	dry leaves on ground	polyculture	2,203	44,728	20,303

3.2 Litterstock

From the monthly sampled litterstock only 6 dates (the first six faunal sampling events) were selected for analyses of mixed samples from each area. Samples from the primary forest area showed slightly higher relative N-contents (1.36 %) than samples from the other areas with secondary forest area at the lower end (1.29 %). Mean C-contents were rather similar for all areas except POA, where it was lower. C/N-ratios were similar in all areas (table 5). Differences between areas in relative N-content are not significant (fig. 5), but absolute N-contents of the litterstock of the different areas become significantly different (fig. 6; SEC versus all other areas, $p < 0.001$).

Table 5: Mean C and N-content in the litterstock of the four study areas

	N-content	in %	C-content	in %	C/N-ratio	
	mean	stds in %	mean	stds in %	mean	stds in %
POA	1.30	6.85	40.43	13.52	31.01	10.29
POC	1.33	3.36	42.81	6.06	32.11	7.33
SEC	1.29	4.96	42.14	9.05	32.69	8.86
FLO	1.36	6.76	42.53	7.49	31.44	13.15

3.3 Litterbag first series

C- and N-contents of the original material used for the litterbag exposure at 27.10.97 are N 0.74, C 48.76, C/N 65.9. Retrieved litterbags were always analysed individually. Mean contents of the retrieved material are shown in table 5. Within the three subsamples of each litterbag recognizable outliers were eliminated when the standard deviation was above 2 % of the mean. Standard deviations from the means of N-content and C/N-ratios of the samples of one mesh size from one area are usually between 4 and 15 %, in one case (coarse litterbags at 5. retrieval) reached 29 %. Standard deviations of C-content are often under 2 %, but in once case exceed 10 % (18.2%); standard deviation of C/N-ratios varied between 2 and 15 % of the means. After exposure of the leaves in litterbags in the areas the relative N-content decreased (and C/N increased) during the first month in the polyculture areas, but not in the forests (figs 7 - 14). From the second retrieval (after 2 months) on the relative N-content increased in all areas (from 0.66 - 0.81 to 1.1 - 1.75), but the increase was highest in FLO, followed by POC, SEC and POA. C/N-ratios decreased consequently (from 61-74 to 29-46, Figs. 7 - 14).

Samples of the 6. retrieval (6.7.98, after 8.5 months) were compared statistically. Differences in N-content and C/N-ratio between areas were significant for all three mesh sizes (ANOVAs $P<0.05$). Litterbags exposed in the primary forest had higher relative N-content and lower C/N-ratio than all other areas, but in multiple comparison procedures (Tukey) differences were significant only for FLO-SEC (the extremes). Over all mesh width differences between all areas become significant ($P<0.01$).

Differences in N-content and C/N-ratio between mesh sizes over all areas were highly significant ($P<0.001$). Litter exposed in bags with coarse mesh size allowing entrance of the whole fauna had a higher relative N-content as litter in bags where macrofauna and mesofauna were excluded. In multiple comparison only differences between coarse and medium and coarse and fine mesh size were significant (both with $P<0.01$). Within the single areas, differences were only significant in POA and POC ($P<0.05$).

Table 5: C- and N-contents of retrieved litterbag material (first series)

		1. retrieval			2. retrieval			4. retrieval		
	mesh	N	C	C/N	N	C	C/N	N	C	C/N
POA	coarse	0,67	49,56	74,48	0,75	49,02	66,04	0,87	49,24	57,14
	medium	0,73	49,34	68,30	0,77	49,06	64,90	0,87	50,54	60,13
	fine	0,66	49,18	75,80	0,78	49,13	64,38	0,93	49,13	52,91
POC	coarse	0,74	49,86	67,97	0,77	48,85	63,37	1,06	48,99	46,33
	medium	0,71	49,92	71,00	0,71	49,02	69,61	0,91	49,50	54,94
	fine	0,72	49,36	69,61	0,69	49,07	71,54	0,84	49,01	58,21
SEC	coarse	0,77	49,31	64,27	0,79	49,11	62,46	0,83	49,21	60,59
	medium	0,76	49,52	65,29	0,76	49,14	65,08	0,88	50,04	58,29
	fine	0,78	49,54	63,69	0,78	49,26	63,26	0,89	50,18	58,65
FLO	coarse	0,77	49,27	63,89	0,81	48,79	60,71	1,04	48,91	47,75
	medium	0,77	49,27	63,95	0,83	48,85	60,49	0,98	49,04	51,00
	fine	0,81	49,35	61,33	0,86	49,05	57,14	1,04	49,57	48,85

3.4 Litterbag second series

C- and N-contents of the original material used for the litterbag exposure at 22.4.98 are N 0.86, C 50.97, C/N 59.3. Litterbags from the first (26 days after exposure), third (111 days), fifth (278 days) and sixth retrieval (350 days) were analysed individually. Mean contents of the retrieved material are shown in table 6.
In the second series differences between mesh widths and differences between areas were both highly significant after one year. Litter exposed in the primary forest area again showed highest relative N-contents and lowest C/N-ratios (table 6). In multiple comparison FLO differed from SEC and from POA. In contrast to the first series highest N-contents in all areas were found in the medium mesh litterbags, but also the lowest C-contents (except in POA), so that C/N ratios of coarse and medium mesh litterbags were equally lower than of fine mesh litterbags (figs 15 - 22).

Table 6: C- and N-contents of retrieved litter bag material (second series)

		1. retrieval			3. retrieval			5. retrieval			6. retrieval		
	mesh	N	C	C/N	N	C	C/N	N	C	C/N	N	C	C/N
POA	coarse	0,59	49,06	71,11	1,09	50,02	46,36	1,16	50,91	45,77	1,22	47,54	39,81
	medium	0,97	49,66	51,34	1,10	50,20	45,99	1,16	50,69	44,91	1,54	49,78	32,37
	fine	0,87	49,72	58,27	0,98	50,34	52,57	1,29	50,85	39,54	1,27	49,52	39,94
POC	coarse	0,74	49,52	66,97	0,93	50,21	54,33	1,40	51,92	37,15	1,48	48,36	33,06
	medium	0,91	49,74	55,13	1,12	50,33	44,94	1,30	50,61	39,12	1,52	49,40	32,97
	fine	0,83	49,39	61,28	0,96	50,06	53,18	1,42	50,69	36,40	1,39	49,81	36,09
SEC	coarse	0,77	49,61	64,86	0,89	50,31	57,44	1,21	50,80	42,32	1,43	48,90	34,69
	medium	0,88	50,05	57,36	0,99	50,08	50,94	1,20	51,09	42,99	1,46	49,52	34,25
	fine	0,90	50,23	56,77	0,90	50,25	57,57	1,19	50,83	43,28	1,22	49,37	40,64
FLO	coarse	0,81	49,74	63,00	1,08	49,96	47,01	1,49	47,75	32,45	1,44	42,01	29,71
	medium	0,95	49,87	53,26	1,12	50,28	45,29	1,53	50,51	33,55	1,73	50,98	29,53
	fine	0,91	49,82	56,02	0,99	50,26	51,23	1,28	50,55	40,38	1,54	50,26	33,11

3.5 Mini-container first series

The original material used for the minicontainer exposure is the same as in litterbags. From the retrieved minicontainers leaf material of all containers of all bars of one mesh width was joined and mixed for the analyses. Within the three subsamples of each minicontainer-series recognizable outliers were eliminated when the standard deviation was above 2 % of the mean. After exposure of the leaves in litterbags in the areas the relative N-content increased continuously from the beginning until the last (third) retrieval in all areas from original 0.72 % to 0.81 (POA and POC) - 0.96 (in FLO). N contents were highest in FLO. FIlowed by SEC, POC and POA. The C-content increased only slightly from 48,9 to 50.6 at maximum. C/N ratios decreased from 68 to about 60 (POA and POC), 59 (SEC) and 52 (FLO) (fig. 23). Compared with the litterbag series the N-accumulation seems to be slightly faster, probably because of the small cut pieces of leaves, which facilitate mesofaunal and microbiological activities. Differences between the two mesh widths are not very clear (contradictory) when looking at all areas (fig. 23).

3.6 Mini-Container second series

N-content of the original material was 0.875 %, C-content 50.2 %, C/N-ratio 57.5. N-content increased slightly during the first month of exposure (decreased slightly in POC) and generally stronger during the second month. The third retrieval of the second series was done after 4 months of exposure in the field. During this period N-content had increased strongly in both mesh widths and all areas. Highest N-content was encountered in leaf material exposed in the primary forest area, lowest in the secondary forest area. C/N-ratios reflect almost exactly the N-content, decreasing strongly during the exposure (fig. 24). There is no obvious difference in C/N between the two mesh widths.

N-content of the the original material of the second series was higher than of the first series. The increase of N during exposure was comparable with 1.0 - 2.5 %, the decrease in C/N was slightly lower during the second series (6-10 versus 8-16 in the first series). Considering the longer exposure of the second series, decomposition in terms of C/N change seems to have been slower during the second series, which is in contrast to the data of weight loss.

		5. retrieval			6. retrieval			7. retrieval		
	mesh	N	C	C/N	N	C	C/N	N	C	C/N
POA	coarse	0,88	48,32	54,96	1,23	46,33	38,96	1,26	49,82	40,18
	medium	0,93	49,05	53,35	0,98	47,60	49,13	1,17	50,17	43,08
	fine	0,89	49,34	56,14	0,95	48,71	52,25	1,11	50,03	45,84
POC	coarse	1,09	48,17	44,44	1,27	46,06	36,49	1,75	49,99	29,39
	medium	0,93	49,00	52,87	1,07	48,08	45,87	1,26	50,02	40,06
	fine	0,94	48,70	52,14	1,03	48,50	47,27	1,35	50,48	37,48
SEC	coarse	0,99	48,53	49,23	1,14	47,51	42,10	1,27	49,71	39,27
	medium	0,89	48,98	55,12	1,06	49,16	47,47	1,16	50,14	43,56
	fine	0,91	49,19	53,93	1,09	49,23	46,12	1,18	50,32	42,86
FLO	coarse	1,30	47,75	38,85	1,35	46,97	34,99	1,72	49,17	28,79
	medium	1,12	49,36	44,26	1,28	48,39	38,53	1,45	50,01	34,81
	fine	1,23	49,26	40,62	1,29	48,27	37,53	1,57	50,48	32,56

3.7 Soil

Only mixed samples of the three monthly sampling events were analysed. N-contents are very low (0.2 - 0.31 %) and always highest in the primary forest (Fig. 25), but standard deviations of single samples often exceeded 2 % (max. 6.7 %). C-contents are also low (3.0 - 4.5, fig. 26). C/N-ratios are between 12 and 16.

3.8 Special substrates

Several arthropod groups and a few gastropods have been analysed for C/N (table 5). Spiders showed the highest N-content (11.2 %, C/N-ratio 3.6), due to their predatory lifestyle and the fact that they do not excrete but accumulate N-containing metabolic products. The probably detrivorous cockroaches (Blattodea) and some gastropods (*Lesma* sp.) also showed high N-contents of 9.8 to 11.0 % and C/N-ratios of 4.0 to 5.0. Isopods and Diplopods showed N-contents between 4.2 and 6.9 % and C/N-ratios from 4.2 to 6.6. Isopods collected in POC showed a lower N-content (4.8 %, C/N: 5.8) than animals from the pupunha-monoculture (5.4, C/N: 5.4).

Using our preliminary data for biomass of macrofauna, collected with the large soil core sampler, about 0.6 - 1.5 g/m² N would be deposited in form of living animals in the soil of the primary forest. In comparison equally rough estimates of N in litterfall result in 13.35 g/m² per month and in litterstock 12.7 g/m².

sample	group	N (%)	C (%)	C/N Ratio
leg. Ott	**spiders**	11,20	40,80	3,60
Sp/Wer.1	cockroaches sp.1	11,00	46,30	4,22
Sp/Wer.1	cockroaches sp.1	11,09	46,78	4,22
Sp/Wer.1	cockroaches sp.1	11,06	46,77	4,23
SP/Wer.2	cockroaches sp.2	10,60	46,91	4,43
SP/Wer.2	cockroaches sp.2	10,60	46,93	4,43
SP/Wer.2	cockroaches sp.2	10,64	46,99	4,42
SP/Wer.3	cockroaches sp.3	11,04	47,45	4,30
SP/Wer.3	cockroaches sp.3	11,02	47,46	4,31
SP/Wer.3	cockroaches sp.3	11,03	47,41	4,30
SP/Wer.9	cockroaches sp. juv.	9,84	49,74	5,06
SP/Wer.9	cockroaches sp. juv.	9,84	49,80	5,06
SP/Wer.9	cockroaches sp. juv.	9,83	49,85	5,07
SP/Wer.10	cockroaches, adult, wings	10,16	49,11	4,83
SP/Wer.10	cockroaches, adult, wings	10,16	49,13	4,84
SP/Wer.10	cockroaches, adult, wings	10,17	49,08	4,82
	Diplopoda			
SP/Wer.5	Polydesmida sp.2	4,28	28,04	6,55
SP/Wer.5	Polydesmida sp.2	4,18	27,55	6,60
SP/Wer.5	Polydesmida sp.2	4,27	28,06	6,58
SP/Wer.7	Polydesmida sp.2	4,50	28,04	6,23
SP/Wer.7	Polydesmida sp.2	4,54	28,24	6,23
SP/Wer.7	Polydesmida sp.2	4,46	27,68	6,20
SP/Wer.8	Polydesmida sp.3	4,39	26,03	5,94
SP/Wer.8	Polydesmida sp.3	4,28	25,59	5,97
SP/Wer.8	Polydesmida sp.3	4,32	25,73	5,96
SP/Wer.6	Spirobolida sp.1	7,21	30,58	4,24
SP/Wer.6	Spirobolida sp.1	6,68	29,14	4,36
SP/Wer.6	Spirobolida sp.1	6,88	29,56	4,29
	Gastropoda			
SP/Wer.12	Caracol sp.1	4,64	28,11	6,06
SP/Wer.12	Caracol sp.1	4,16	26,31	6,32
SP/Wer.12	Caracol sp.1	4,13	26,37	6,39
SP/Wer.4	Caracol sp.2	3,49	24,67	7,07
SP/Wer.4	Caracol sp.2	3,14	23,38	7,46
SP/Wer.4	Caracol sp.2	3,49	24,64	7,06
SP/Wer.11	Lesma sp.1	11,04	44,33	4,02
SP/Wer.11	Lesma sp.1	11,04	44,33	4,02
SP/Wer.11	Lesma sp.1	11,02	44,35	4,02
	Isopoda			
leg. Höfer	from POC	4,80	27,70	5,80
leg. Höfer	from Pupunha monoculture	5,40	29,70	5,40
SP/Wer.13	Isopoda("Circoniscus gaigei")	5,55	32,04	5,78
SP/Wer.13	Isopoda("Circoniscus gaigei")	5,54	32,15	5,80
SP/Wer.13	Isopoda("Circoniscus gaigei")	5,61	32,19	5,74
SP/Wer.14	Isopoda("Circoniscus gaigei")	5,63	32,10	5,70
SP/Wer.14	Isopoda("Circoniscus gaigei")	5,74	32,29	5,63
SP/Wer.14	Isopoda("Circoniscus gaigei")	5,67	32,15	5,67
SP/Wer.15	Isopoda("Circoniscus gaigei")	5,67	31,76	5,60
SP/Wer.15	Isopoda("Circoniscus gaigei")	5,68	31,74	5,59
SP/Wer.15	Isopoda("Circoniscus gaigei")	5,68	31,70	5,58
SP/Wer.16	Isopoda("Circoniscus gaigei")	5,38	31,45	5,85
SP/Wer.16	Isopoda("Circoniscus gaigei")	5,38	31,41	5,84
SP/Wer.16	Isopoda("Circoniscus gaigei")	5,41	31,45	5,82
SP/Wer.17	Isopoda("Circoniscus gaigei")	5,57	31,57	5,66
SP/Wer.17	Isopoda("Circoniscus gaigei")	6,15	34,84	5,66
SP/Wer.17	Isopoda("Circoniscus gaigei")	5,57	31,68	5,69

Table 7: N and C contents and C/N-ratios of soil fauna collected within the study areas (page above)

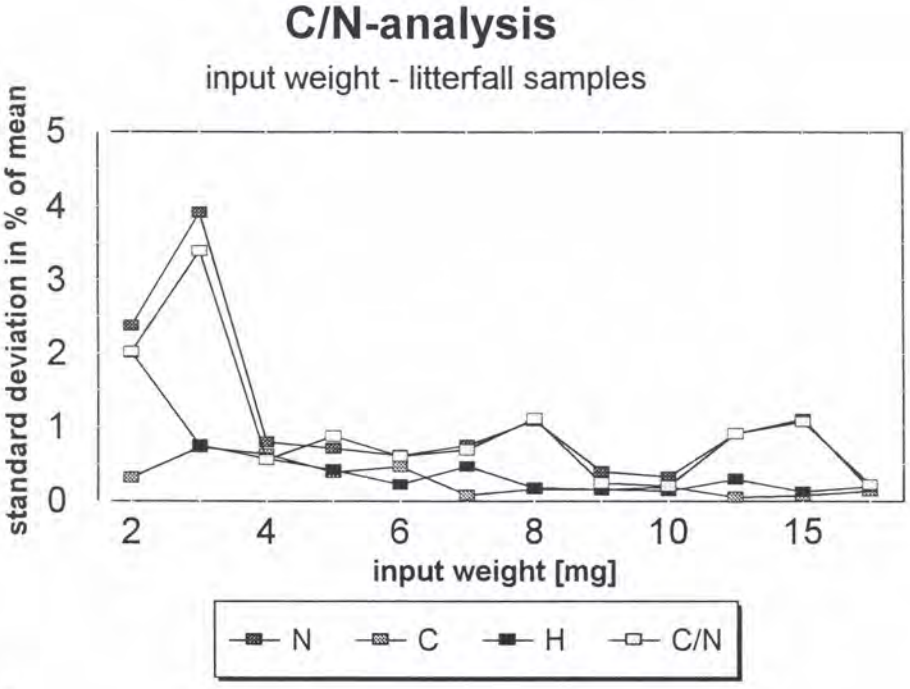


Figure 1

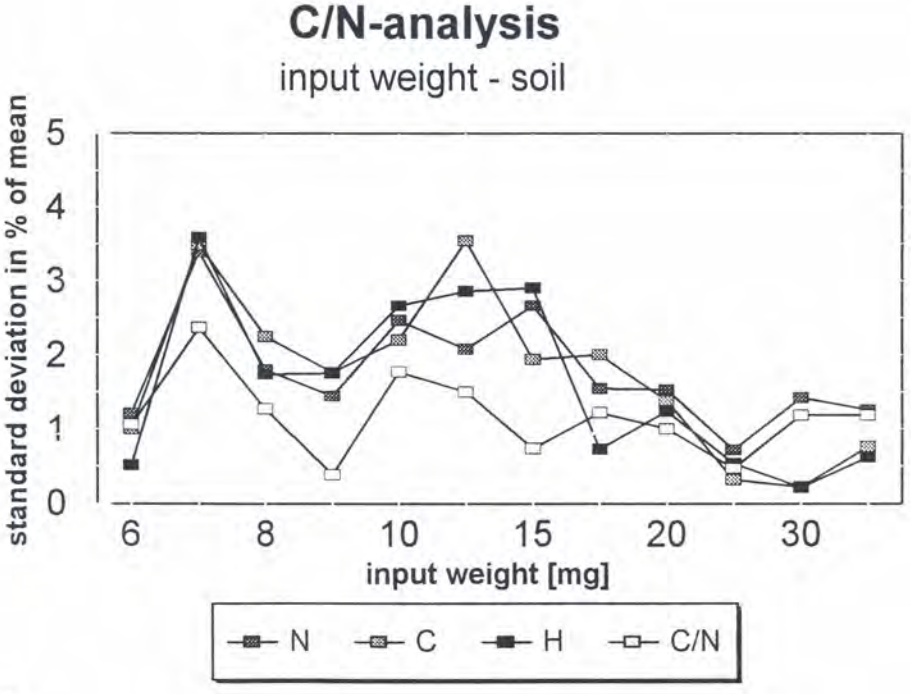


Figure 2

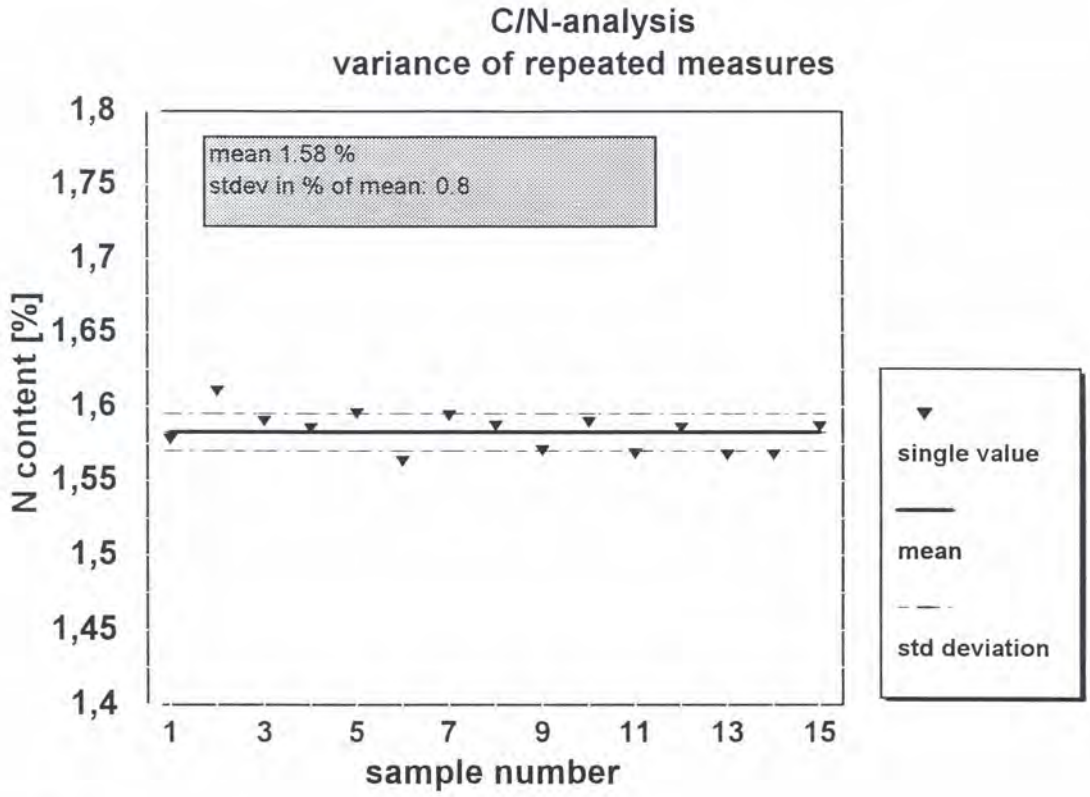


Figure 3

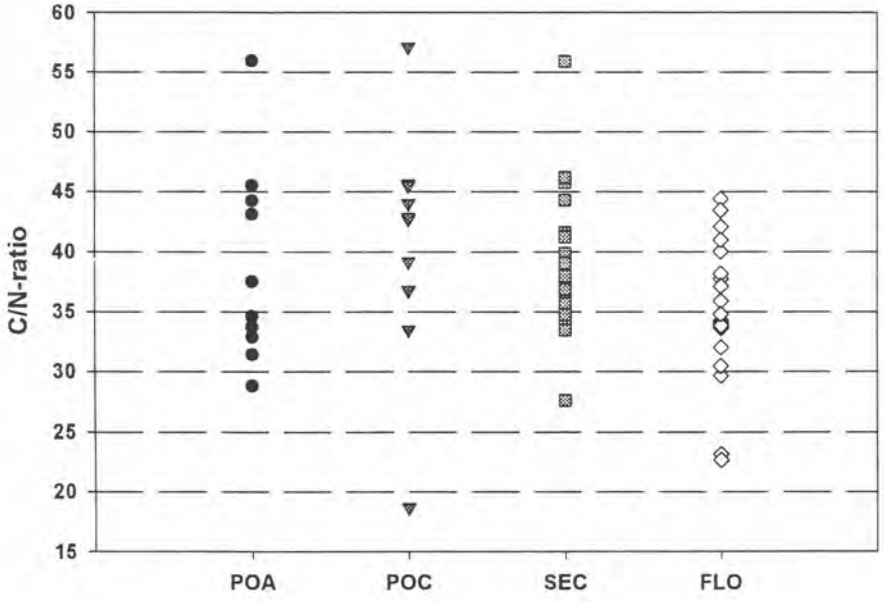
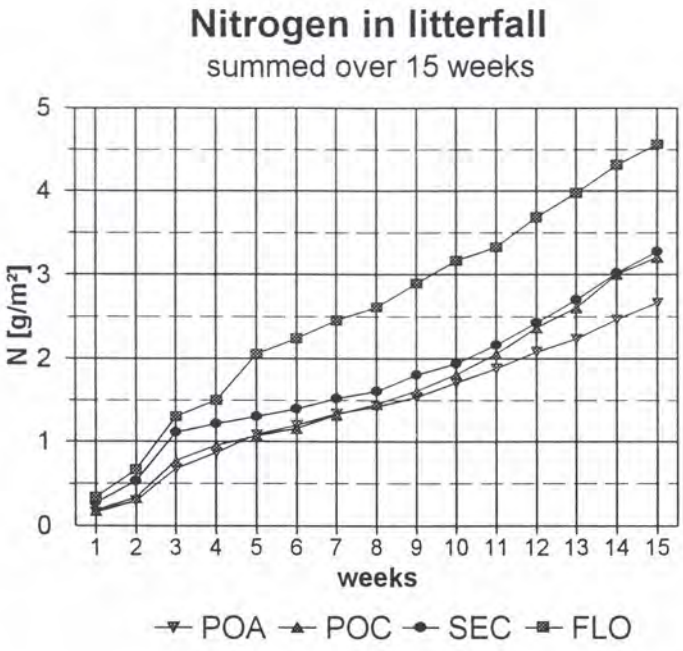


Figure 4: Variation of C/N-ratios within the areas by analyses of samples from single collectors (from 11.8.97).



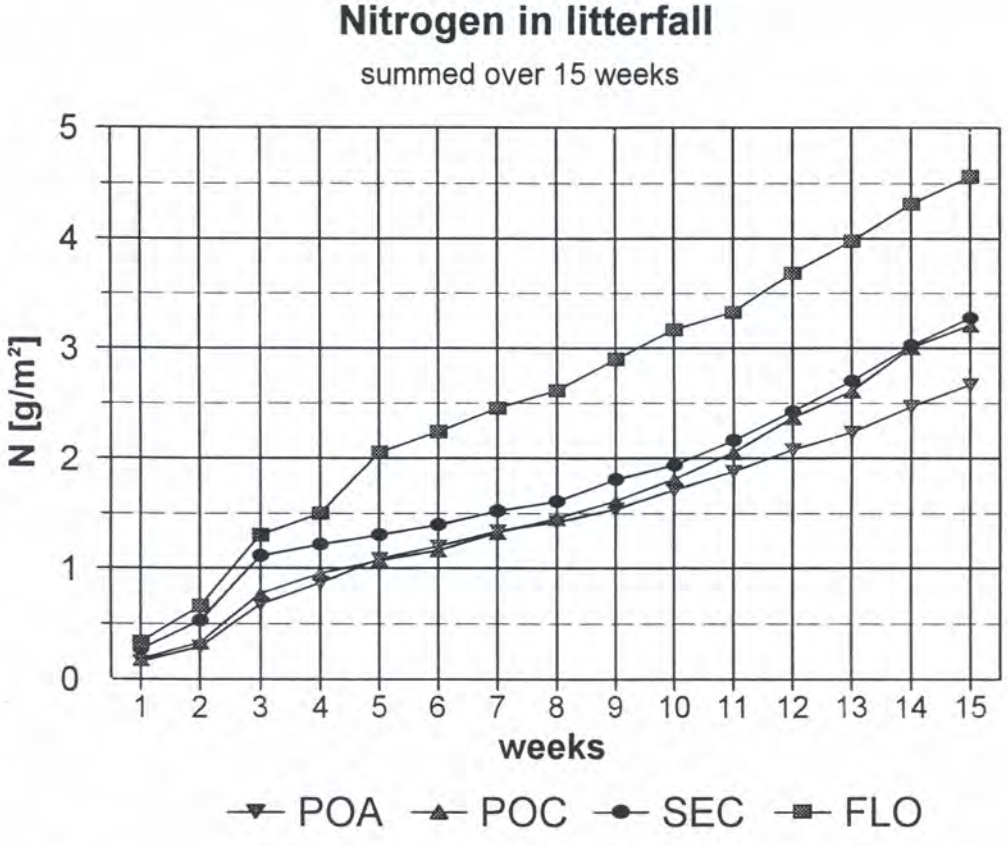
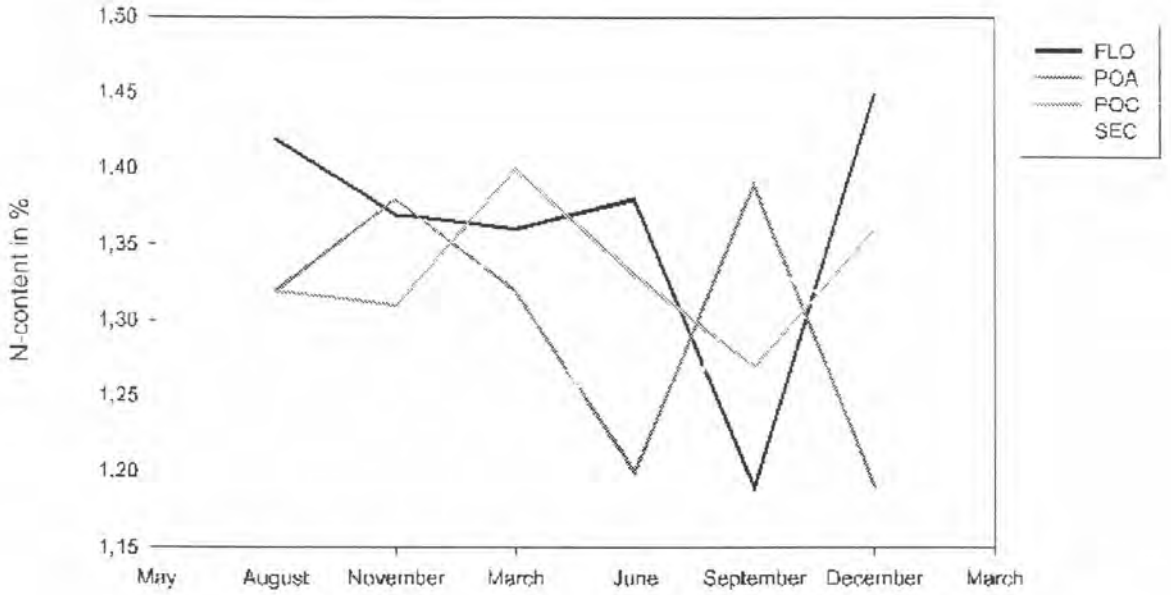
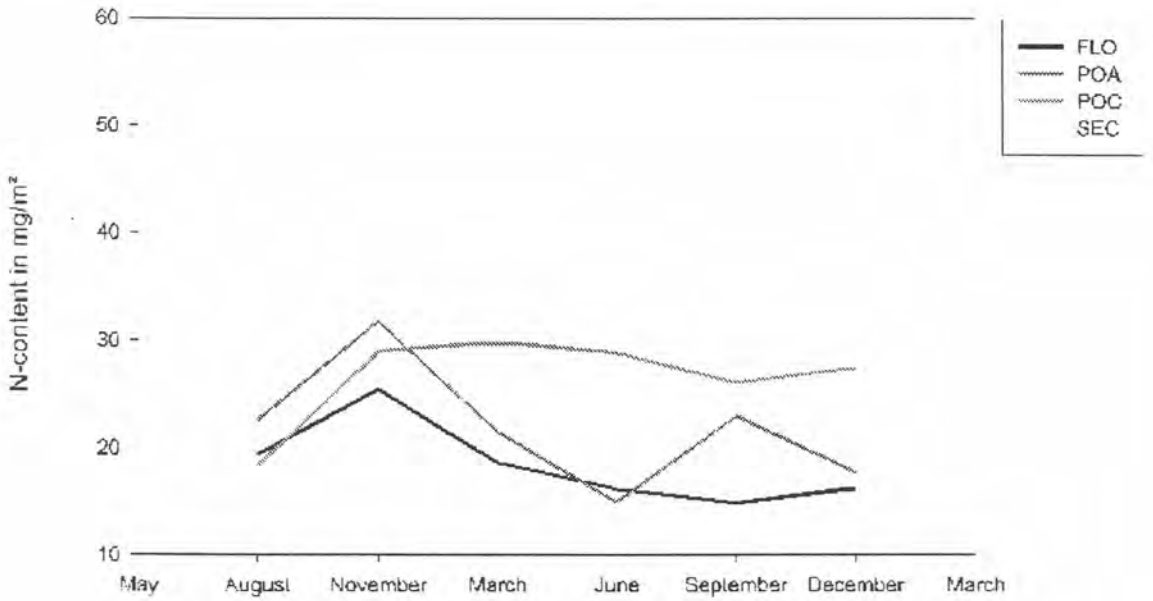
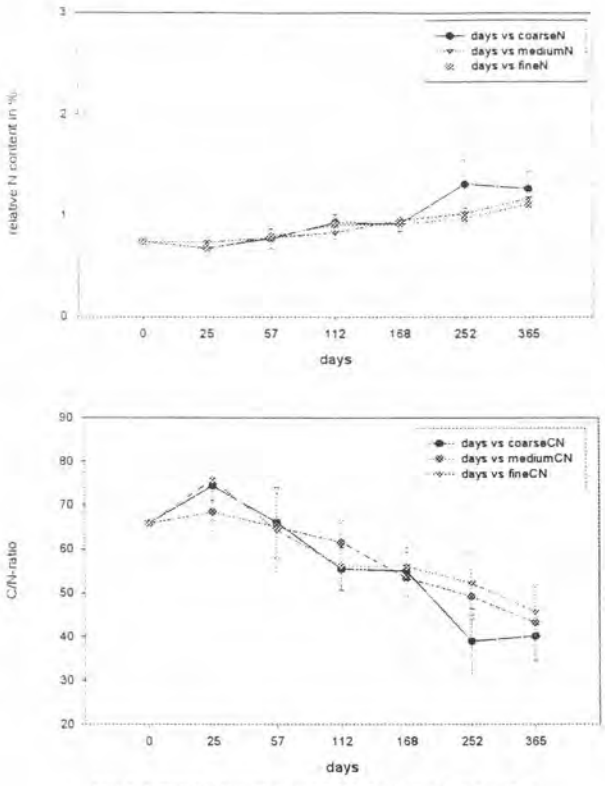


Figure 5: Accumulated differences in N-input by litterfall over 15 analyzed weeks

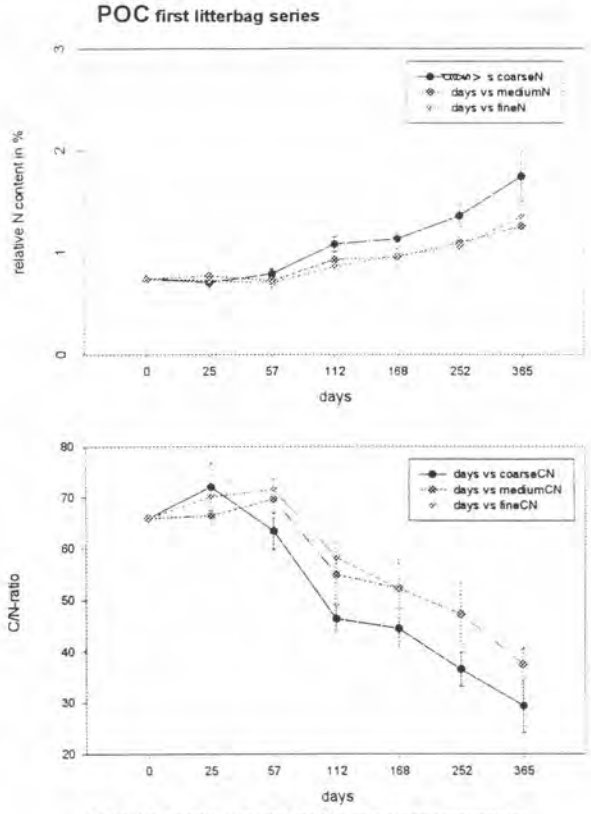




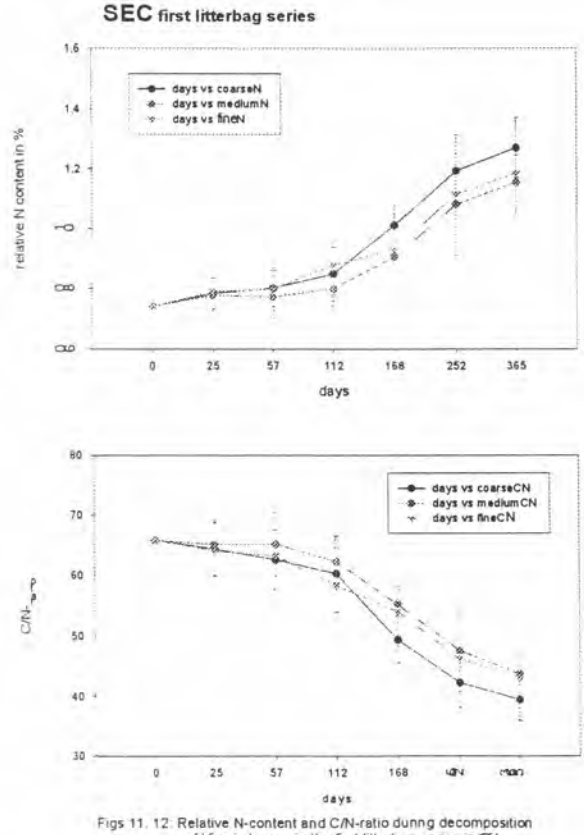
Figs 6a, b. Relative and absolute N-content in litterstocks.



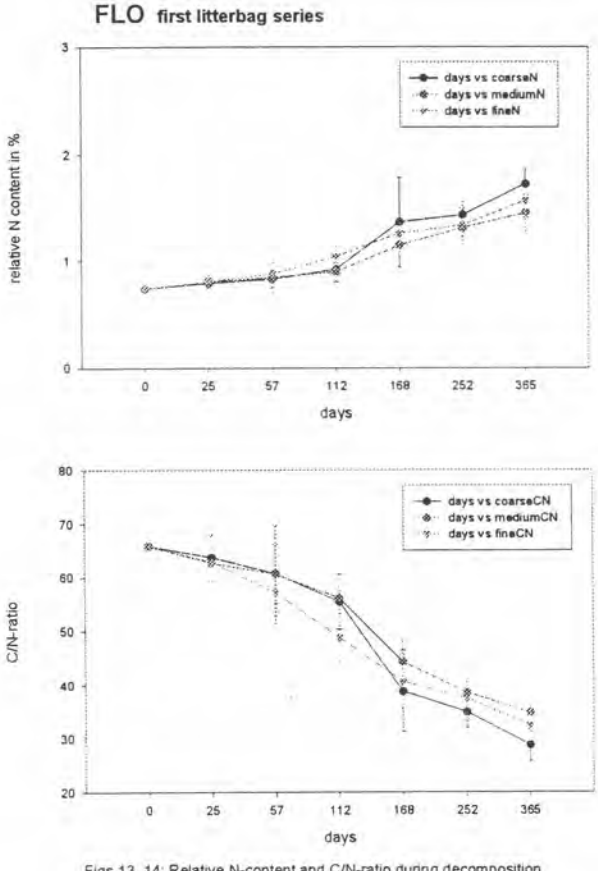
Figs 7, 8: Relative N-content and C/N-ratio during decomposition of Vismia leaves in the first litterbag series in POA.



Figs 9, 10: Relative N-content and C/N-ratio during decomposition of Vismia leaves in the first litterbag series in POC.

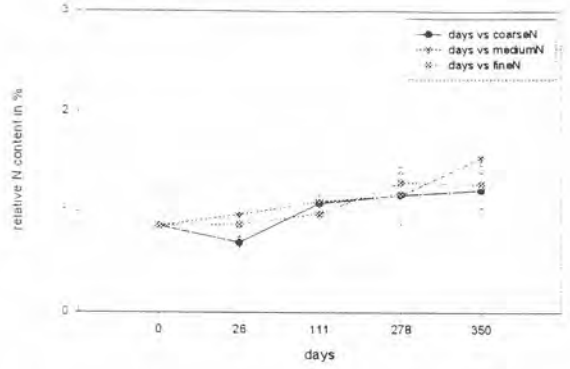


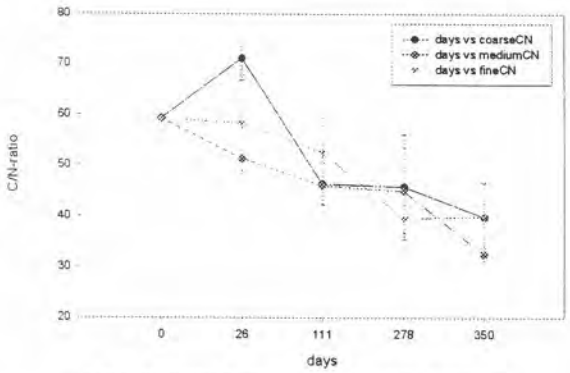
Figs 11, 12: Relative N-content and C/N-ratio during decomposition of Vismia leaves in the first litterbag series in SEC.



Figs 13, 14: Relative N-content and C/N-ratio during decomposition of Vismia leaves in the first litterbag series in FLO.

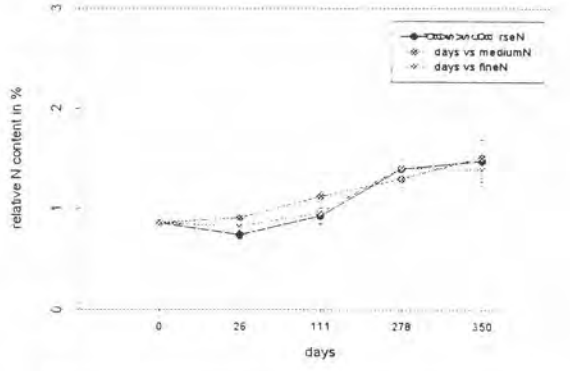
POA second litterbag series

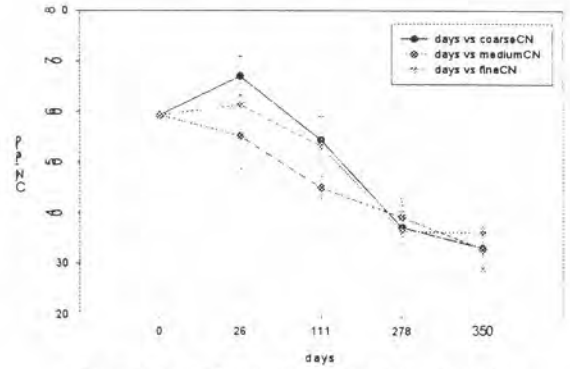




Figs 15, 16: Relative N-content and C/N-ratio during decomposition of Vismia leaves in the second litterbag series in POA.

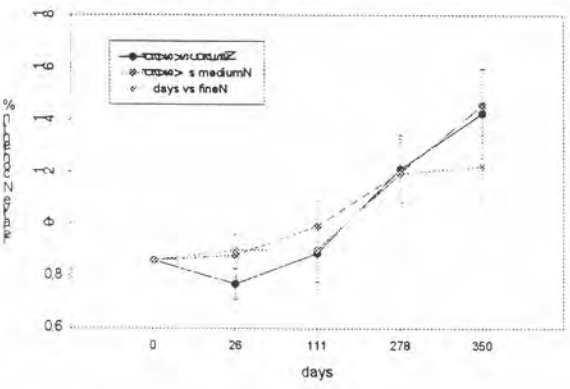
POC second litterbag series

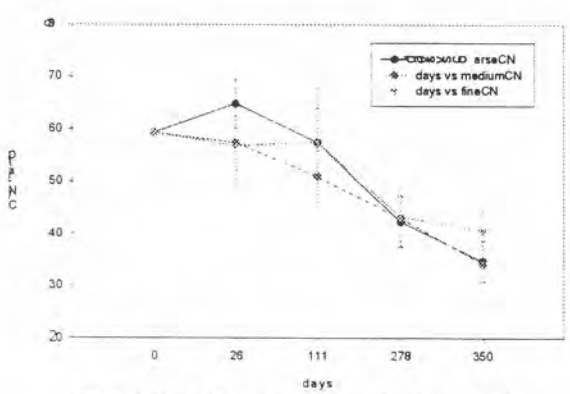




Figs 17, 18: Relative N-content and C/N-ratio during decomposition of Vismia leaves in the second litterbag series in POC.

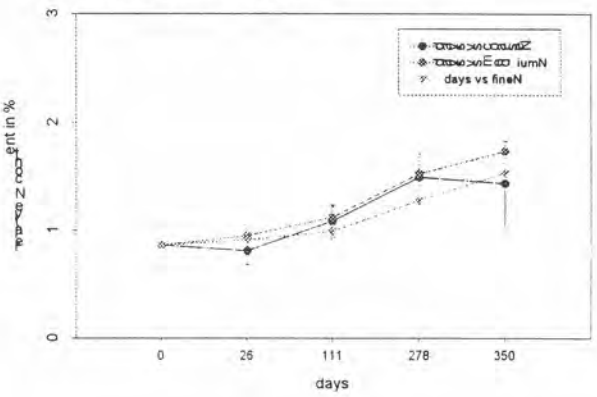
SEC second litterbag series

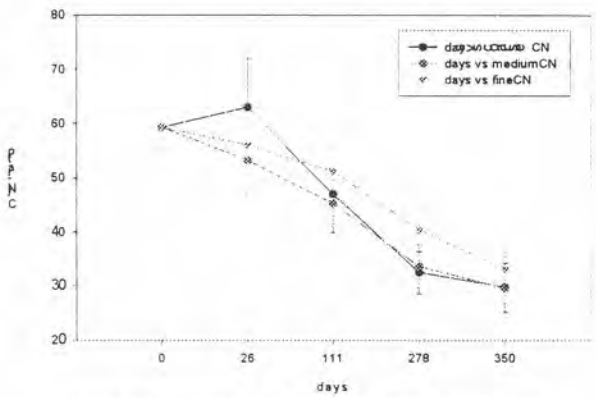




Figs 19, 20: Relative N-content and C/N-ratio during decomposition of Vismia leaves in the second litterbag series in SEC.

FLO second litterbag series





Figs 21, 22: Relative N-content and C/N-ratio during decomposition of Vismia leaves in the second litterbag series in FLO.

Phenole in Streubeuteln

Christopher Martius[1], Hubert Höfer[2, 3], Wulf Amelung[4]

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[2]Institute of Zoology, University of Göttingen, Germany
[3]Staatliches Museum für Naturkunde Karlsruhe (SMNK), Germany
[4]Universität Bayreuth

Zusammenfassung
Die Phenolgehalte im Blattmaterial von *Vismia*, welches zum Abbau, in Streubeuteln drei verschiedener Maschenweiten eingeschlossen, auf den Probeflächen des Projektes SHIFT 52 ausgebracht war, unterscheiden sich weder zwischen den Flächen noch zwischen den verschiedenen Maschenweiten. In allen Fällen geht der Phenolgehalt in 250 Tagen auf 10-20% des Ausgangsgehaltes zurück. Es ist deshalb davon auszugehen, daß der Pehenolabbau ein rein chemischer Zerfallsprozess ist, der am ehesten noch vom Mikroklima, aber nicht durch Zersetzerfauna oder Mikroflora bestimmt wird.

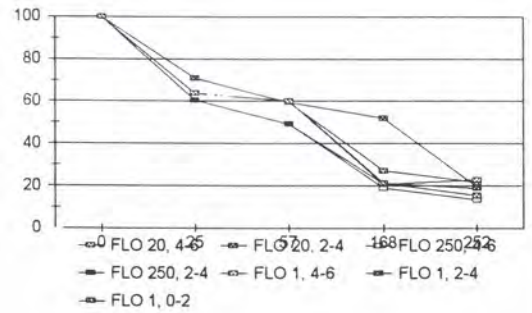
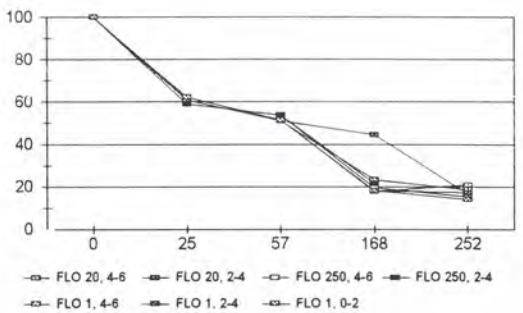
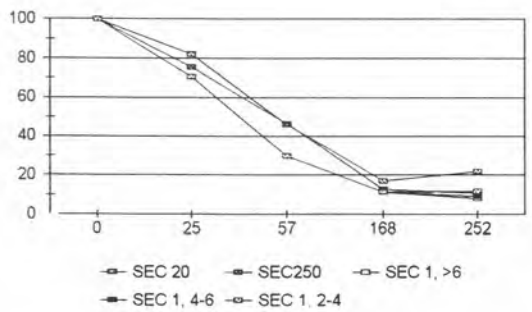
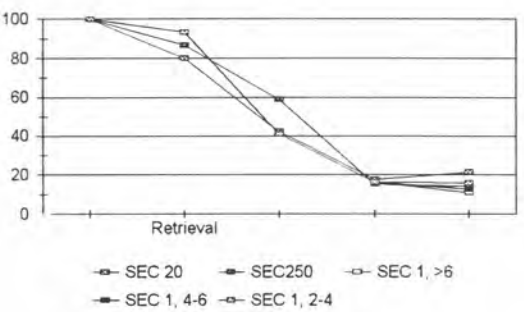
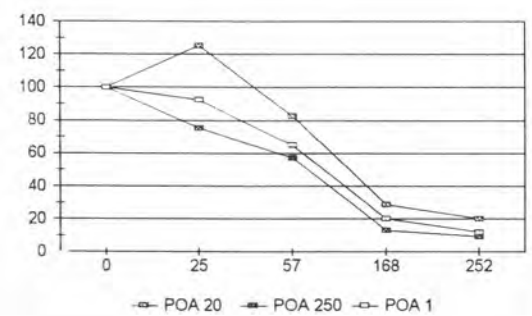
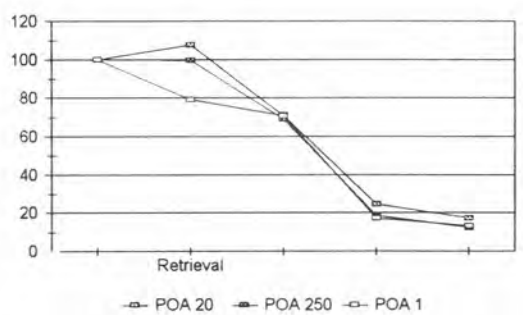
Einführung
Phenole in Pflanzenmaterial sind ligninbürtige Substanzen, die die Geschwindigkeit des biogenen Abbaus beeinflussen. Im Rahmen des vorliegenden Unterprojektes wurde ihre Konzentration im Blattmaterial von *Vismia* untersucht, welches, in Streubeuteln drei verschiedener Maschenweiten eingeschlossen, zum Abbau auf den Probeflächen ausgebracht war (s Bericht über Litter bags).

Material und Methoden
Das Pflanzenmaterial aus den Streubeuteln (s. Bericht über Streubeutel) wurde in Brasilien gemahlen und getrocknet in Glasflaschen bis zum Transport nach Deutschland aufbewahrt. Hier wurde die Analysen am Lehrstuhl für Bodenkunde und Bodengeographie der Universität Bayreuth durchgeführt. Von jeder Probe wurden zwei Messungen genommen und daraus der Mittelwert gebildet.

Ergebnisse
Tabelle 1 zeigt die Phenolwerte im Ausgangsmaterial (nicht zersetztem *Vismia*-Laub). Leider zeigte sich hier, daß zwischen den einzelnen "Serien" von *Vismia*-Material, die im Streubeutelversuch zum Einsatz kamen (es handelt sich um zu unterschiedlichen Zeitpunkten gesammeltes *Vismia*-Blattmaterial), sehr starke Unterschiede im Phenolgehalt exisitierten. Serie 1 A und B unterschieden sich stark (bzw. 1 B unterschied sich stark von 1a und 2). Um festzustellen, ob ein systematischer Fehler vorliegt, wurden zwei Auswertungen vorgenommen. Einmal wurde anhand der Originallisten überprüft, welche Probe aus welchen Ausgangsproben besteht. So besteht z.B. die Sekundärwaldprobe der Maschenweite 20µ (SEC 20) aus 8 Beuteln der Serie 1A und 2 Beuteln der Serie 1B (Tabelle 2). Entsprechend wurde aus ((8*8.66) + (2*14.53))/10 ein "Ausgangswert" berechnet, auf den dann prozentual die Phenolwerte der einzelnen Rückholungen bezogen sind. Damit wurden die prozentualen Phenol-Werte (% vom Ausgangsmaterial bei "Start") berechnet, auf denen die linke Spalte der Abbildung 1 beruht. Alternativ wurden Phenolwerte berechnet, die sich prozentual auf den Mittelwert aus Serie 1A, 1B und 2 beziehen (also auf 10.09 mg/g Boden; Tabelle 1; rechte Spalte in Abb. 1). Der Grund für diese zweite Auswertung ist darin zu sehen, daß in der ersten Auswertung bei mehreren Proben des ersten Rückholtermins die Phenolgehalte auf 120-130% des Ausgangswertes zurückgehen hochgehen. Auch so ist bei diesen Proben noch ein Anstieg auf ca. 110% sichtbar.

Unabhängig davon, welche Auswertungsart gewählt wird, zeigt die Phenoldynamik im Blattmaterial, unabhängig von Maschenweite und Fläche deutlich, in allen Fällen einen ähnlichen Kurvenverlauf. Allenfalls ist der Initialabbau des Phenols in FLO etwas höher als auf den anderen Flächen, aber alle Kurven enden bei ca. 10-20%. Auch eine Analyse nach Gewichtsklassen (des verbleibenden Blattmaterials; hierbei wurde geprüft, ob sich Pehnolgehalte in Blattmaterial mit einem hohen von denen im Blattmaterial mit einem niedrigen Restgewicht unterscheiden) zeigt keine Unterschiede. Anscheinend ist der Abbau der Phenole im Blattmaterial ein rein chemischer Zerfallsprozess, der etwas durch das Mikroklima, aber nicht durch Fauna oder Mikroflora bestimmt wird.

Abbildung 1. Phenoldynamik in zerfallendem Vismia-Blattmaterial im Streuabbauversuch mit Streubeuteln nach bis zu 252 Tagen. X-Achse: Zeitverlauf nach Exposition der Streubeutel; Y-Achse: Phenolgehalte in % des Ausgangsgehaltes

Berechnung nach Anteilen von 1A und 1B im Probenmaterial	Berechnung m. Phenol-Mittelwert = 10.09 f.Ausgangsmaterial
	
	
	

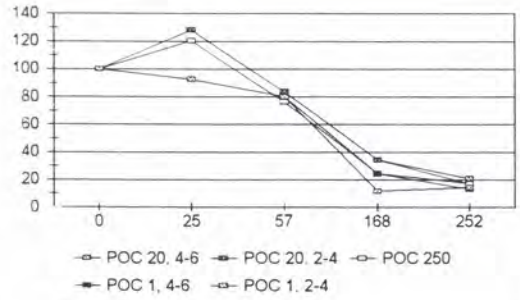
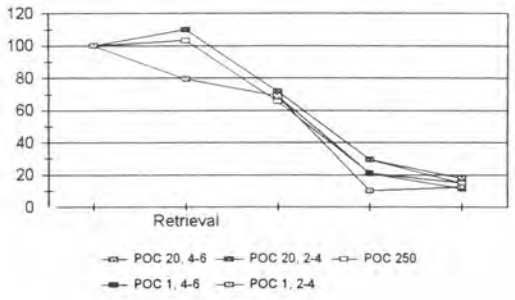
Berechnung nach Anteilen von 1A und 1B im Probenmaterial	Berechnung m. Phenol-Mittelwert = 10.09 f.Ausgangsmaterial
	

Tabelle 1. Phenolwerte im *Vismia*-Ausgangsmaterial (alle Angaben in mg/g Boden)

Original Material	Erste Messung	Zweite Messung	Mittelwert	Stdabw
Serie 1A	8,12	9,2	8,66	0,76
Serie 1B	14,71	14,35	14,53	0,25
Serie 2	6,71	7,44	7,08	0,52
Mittelwert			10,09	3,93

Streuabbau und Bodenmikroorganismen-Aktivität auf drei agroforstlichen Versuchsflächen in Zentralamazonien (Monokulturen von *Bactris gasipaes* und *Hevea brasiliensis* sowie Mischkultur aus vier Baumarten) - Kurzreport

D. Kurzatkowski[1], C. Martius[2], H. Höfer[3,4]

[1]Magisterarbeit von Dariusz Kurzatkowski, Göttingen 1999 (betreut von Prof. Dr. P. Vlek und Dr. C. Martius)
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[3]Institute of Zoology, University of Göttingen, Germany
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Zusammenfassung

Streuabbau und Bodenatmung wurden in zwei Monokulturflächen (Bactris; Hevea) und eine Mischkultur, die aus 4 kommerziell genutzten Baumarten bestand, untersucht. Die Bactrisplantage diente als ein Beispiel für beschattete und die Heveaplantage als eine offene Fläche. Ob die Pflanzendiversität auf die Bodenfaunaaktivität wirkt, wurde in der Mischkultur untersucht. In der Bactrisplantage wurden der schnellste Streuabbau in Beuteln mit mittlerer und feiner Maschenweite und die höchste Bodenatmung und mikrobielle Biomasse nachgewiesen. Die höchste Makrofaunaaktivität wurde in der Heveaplantage festgestellt, wo die Makrofauna, im Schutz einer dichten Krautschicht aus Pueraria-Bodendeckern, vermutlich sehr gute Lebensbedingungen fand. Die Pflanzendiversität in der Mischkultur verbesserte den Abbau organischer Materie nicht. Besonders die Makrofaunaaktivität war dort sehr niedrig. Entscheidend für die Mikroorganismenaktivität war das durch die hohe Beschattung entstandene Mikroklima mit gleichmäßiger Bodentemperatur und Luftfeuchtigkeit, und die Pflanzendiversität spielte hierbei eine sekundäre Rolle.
Aus bodenbiologischer Sicht zeigte von allen in dieser Arbeit untersuchten Anbausystemen die Bactrisplantage die besten Bedingungen. Dabei spielt vermutlich vor allem das günstige Mikroklima auf diesen von der geschlossenen Bactris-Kronenschicht stark beschatteten Flächen eine wichtige Rolle.

Einführung

Der Abbau der organischen Substanz durch Makro- und Mikroorganismen wie auch die Faktoren, die diese Prozesse beeinflussen, sind von großer Bedeutung für die Rekultivierung und Bewirtschaftung zerstörter Flächen in Zentralamazonien. Die Anbausysteme beeinflussen durch ihre Pflanzendiversität oder z.B. unterschiedliche Beschattung für die Aktivität der Bodenorganismen wichtige Faktoren wie Bodentemperatur, Bodenfeuchte, pH-Wert etc.

Zur Untersuchung der Bodenfaunaaktivität wurden zwei Monokulturflächen (*Bactris*- und *Hevea*plantage) und eine Mischkultur, die aus 4 kommerziell genutzten Baumarten bestand (System IV), ausgewählt. Auf den ausgewählten Flächen wurde die Aktivität der Bodenorganismen mit zwei Methoden untersucht: Der Streuabbau durch verschiedene Faunengruppen wurde mit Streubeuteln (Litter-bags) untersucht, und die Mikroorganismenaktivität wurde durch Untersuchungen der Bodenatmung bestimmt.

Methoden

Die Untersuchungen liefen zwischen Mai und November 1998. Die Flächen sind wie folgt beschrieben: Bei den Monokulturen handelt es sich um die Pupunha-Palme (*Bactris gasipaes*) als Beispiel für eine Fläche mit relativ starkem Kronenschluss und dementsprechend starker Bodenbeschattung. Eine weitere Monokultur bestand aus Gummibäumen (*Hevea brasiliensis*), die sehr stark offen strukturiert war (großer Pflanzabstand zwischen den Bäumen). Der Boden war allerdings durch *Pueraria* als bodendeckende Krautschicht fast vollständig bedeckt. Die Mischkultur (System IV) bestand aus 4 Baumarten: Cupuaçu (*Theobroma grandiflorum*), Pupunha (*B.gasipaes*), Paranuss (*Bertholletia excelsa*) und Orleansbaum (*Bixa orellana*); hier bestand die Bodenbedeckung überwiegend aus spärlich deckenden Gräsern. Die Flächen maßen 48x32 m und wurden in 480 imaginäre Quadrate eingeteilt, als Grundlage für eine randomisierte Probenahme und Ausbringung der Streubeutel. Von jedem Flächentyp wurden drei Replikate untersucht (A, B, C).

Die Streubeutel waren identisch zu den im Teilbericht "Streubeutel" beschriebenen. Auf jeder der Flächen wurden Beutel aller drei Maschenweiten ausgebracht; nach 27, 88, 115, und 140 Tagen wurden jeweils 5 Beutel jeder Maschenweite entnommen.

Die Bodenatmung wurde entsprechend dem im Bericht "Bodenatmung" beschriebenen Verfahren durchgeführt. Die Bodenatmungsmessungen erfolgten mit dem Infrarot-Gas-Analysator in einem kontinuierlichen Belüftungssystem. Die mikrobielle Biomasse wurde auf der Basis der SIR-Werte kalkuliert. Auf jeder Fläche wurden Bodenproben an zwei Terminen untersucht (1. Juni und 28. Oktober), am ersten Termin jeweils 13 Proben, am zweiten waren es 8 Proben pro Fläche.

Ergebnisse

Der höchste Streuabbau wurde in Beuteln mit grober (1 cm) Maschenweite nachgewiesen. Das zeigt, daß die Abbaurate in allen Flächen von der Makrofauna determiniert wird. In Beuteln mit mittlerer (250 µm) Maschenweite, wo die Makrofauna ausgeschlossen war, nahmen die Zersetzungsraten deutlich ab. Ein weiterer Ausschluß der Mesofauna, der durch die Verwendung von Gaze sehr feiner Maschenweite (20 µm) erreicht wurde, hatte keine wesentlichen Auswirkungen auf die Zersetzungsrate. Der Abbau in Beuteln mit grober Maschenweite unterscheidet sich statistisch signifikant vom Abbau in Beuteln mittlerer und feiner Maschenweite ($P<0,05$). Zwischen dem Abbau in Beuteln mit mittlerer und feiner Maschenweite wurden keine statistische Unterschiede nachgewiesen.

In Beuteln grober Maschenweite wurde der schnellste Abbau in der Hevea-Plantage nachgewiesen. In Beuteln mittlerer und feiner Maschenweite wurde der schnellste Abbau in der Bactris-Plantage festgestellt. Generell unterscheidet sich aber der Abbau der Vismia-Blätter in den Bactris- und Hevea-Plantagen und in der Mischkultur statistisch nicht signifikant.

Die höchste Bodenatmung und mikrobielle Biomasse wurde an beiden Untersuchungsterminen und in der Bodentiefe 0-5 cm wie auch 5-15 cm in der Bactris-Plantage festgestellt. In dieser Plantage wurde auch die höchste Basalatmung und mikrobielle Biomasse in der Streu nachgewiesen. In der Mischkultur und in der Hevea-Plantage war die Basalatmung und mikrobielle Biomasse in der Bodentiefe 0-5 cm und 5-15 cm viel niedriger als in *Bactris*. Die Streuatmung war am ersten und zweiten Untersuchungstermin in der Mischkultur am niedrigsten. Die Werte der mikrobiellen Biomasse in der Streu lagen am ersten und zweiten Termin in der Mischkultur zwischen den Bactris- und Heveawerten.

In der Bactris-, Mischkultur und Hevea-Plantage wurden zwischen den Werten der Basalatmung, der mikrobiellen Biomasse in der Tiefe 0-5 cm, 5-15 cm und in der Streu wurden keine statistischen Unterschiede nachgewiesen.

In allen Anbausystemen war die Basalatmung in der Tiefe von 0-5 cm ca. 3x höher als die Basalatmung in der Tiefe von 5-15 cm. Der Unterschied war statistisch signifikant ($P=0,026$). Auch die mikrobielle Biomasse war in der oberen Bodenschicht höher und unterschied sich statistisch signifikant von der in der Tiefe 5-15 cm ($P=0004$). In der Streu waren die Atmungswerte ca. 100 mal und die mikrobielle Biomasse ca. 10 mal höher als auf der Bodenoberfläche. Zwischen den Boden- und Streuatmungwerten wie auch der mikrobiellen Biomasse wurden am ersten und zweiten Untersuchungstermin keine statistischen Unterschiede nachgewiesen.

Die besten mikrobiologischen Bedingungen wurden auf der Bactris-Plantage festgestellt. Dort war der Streuabbau in Beuteln mit mittlerer und feiner Maschenweite am schnellsten, und die höchste Bodenatmung und mikrobielle Biomasse wurden hier nachgewiesen. Die höchste Makrofauna-Aktivität fand sich in der Heveaplantage. Dort, auf dem von Purearia-Leguminosen dicht bewachsenem Boden, hat die Makrofauna vermutlich sehr gute Lebensbedingungen gefunden. Wir vermuten, daß das durch die hohe Beschattung entstandene Mikroklima mit gleichmäßiger Bodentemperatur und Luftfeuchtigkeit für die Mikroorganismenaktivität entscheidend war. Die Pflanzendiversität spielte hierbei eine sekundäre Rolle.

Aus bodenbiologischer Sicht zeigte von allen in dieser Arbeit untersuchten Anbausystemen die Bactris-Plantage -obwohl Monokultur - die besten Bedingungen.

Towards modelling of soil fauna and litter decomposition in agroforestry sites in Amazonia

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Abstract
An overview over the approaches to modelling used to analyse the project data is given, and first data are presented.

Introduction

Modelling the role of soil fauna and microflora in the processes of litter decomposition is a final goal towards which the studies carried out in the project SHIFT 52 should converge. However, a model is no goal *per se*; it is a research tool to be used for certain purposes and the type of model chosen depends on the purpose. Depending on the context, models in the form of rather simple two-factor relationships (regressions and correlations) are preferable over complicated efforts to take "everything" into consideration (cf. Peters 1983). Four purposes are easily identified within the context of the project:

- Modelling the determination of the decomposition rate in the different stands by soil organisms as a measure of the functionality of existing biogenic nutrient cycling
- Modelling the quantitative role of soil fauna in carbon cycling of natural and man-managed (agro-)ecosystems in tropical rain forest and the studied plantations
- Modelling the role of soil biota in the nitrogen cycle
- Modelling the prediction of soil fauna abundance using site-specific microclimatic factors

Models can be descriptive or predictive; description being more easily obtained than prediction which requires additional steps of testing before it may be considered reliable. Only recently, the main quantitative data to be used in this project's modelling (biomass of soil fauna groups) have become available, and the modelling exercise has only been started. Here, a short overview is given over the status of our conceptual considerations and on first results.

Two types of approaches are dominant. One is the classical quantitative modelling of stocks and fluxes (that can be easily implemented with modeling software like Stella 5.0 or Modelmaker). The other is an attempt to build classification and regression trees using the software program CART (Breiman et al.1984; Steinberg & Colla 1998, Yohannes & Webb 1999). This software classifies data into "trees" based on decisions made at every bifurcation upon whether a given data set is to be sent to the right- or to the left-hand node. The decision at each bifurcation is based on a single question (e.g., "is soil temperature >25.04°C?"). The decision upon where the threshold for the split is set is made upon a complicated iterative procedure, based on "misclassification costs" that occur when a case is sent to the wrong side of the split (cf. literature for details). In our context, the procedure allows to detect factors that might be used to classify situations (e.g., extreme microclimatic factors, soil temperature thresholds) critical for the survival (biomass) of the soil fauna.

1. Modelling the role of soil organisms in determining the decomposition rate

The role of the macrofauna in determining the decomposition rate has clearly been shown in the litter bag experiments which can be seen as "model experiments", simplifying the very complex decomposition processes by using standardized leaf material as a basic resource. It was to be expected that decomposition rates determined with the litter bag approach (cf. Litter bag report) are in a different range as those established using litter stocks and production (cf. litter report). Litter bags use only one litter material, which in the case of Vismia is rather recalcitrant leading to a lower decomposition rate, whereas litter of many plant species (some easily decomposable, others recalcitrant) in several different stages of pre-decay is recorded in the stand *in situ*. Nevertheless, the rates from the litter bag experiments reflect the relative decomposition rates between the stands well, FLO having larger decay rates than the other sites, followed by POC, POA and SEC. Only the very

low decomposition rate in SEC is not reflected in the results of the litterbag experiment. This might have to do with the fact that the litter in SEC is mainly of one type.

To further understand the role of soil organisms, the data of the single sub-reports must be analyzed. The microbial biomass in the upper soil stratum (0-5 cm) of the four study sites is not significantly different. Therefore, it can be derived from population data that it is mainly the macrofauna that drives the decomposition process. In fact, the role of the macrofauna has been shown in both series of the litter bag experiments, where the exclusion of macrofauna in litterbags of 250 µm resulted in a reduction of the decomposition rates to 30 % in the primary forest area FLO, to slightly below 50 % in the secondary forest area (SEC) and in polyculture area POC, and below 70 % in one polyculture area (POA). Obviously, the macrofauna is the key group that triggers decomposition rates in the studied Amazonian ecosystems. These relationships will be elaborated further.

2. Modelling the role of soil organisms in the carbon cycle

The data gathered in the project can be arranged into a conceptual model (Figure 1). It depicts the pools and fluxes which constitute the main aspects of nutrient cycling through microflora and soil fauna in tropical forest areas. Square boxes are pools, round/oval boxes and arrows indicate fluxes and "speech" boxes indicate methods we used in SHIFT 52 to study the pools and fluxes. Lozenges are used to indicate that the main influence factors in the model are the treatments (i.e.; POA, POC, SEC, FLO) and the accompanying factors (air and soil temperature, humidity, etc.). This means that the model must be run at least three times, one simulation for every treatment using stand-specific data for the different pools and fluxes.

A short description is given here: Litter is produced by the vegetation (**Litter production**) and deposited on the forest floor (**litter stocks**). (Stand biomass is not assessed.). There, the litter is consumed by the primary and secondary **decomposers** (macro- and mesofauna). **Consumption** has not been measured, but can be assessed from the literature, and **bait lamina** may give an idea of the stand-specific feeding rate. The ingested material is stored in the soil fauna biomass, then deposited again in the soil and litter layer as feces, detritus and dead bodies. We do not measure the detailed and complicated interrelationships of defecation, life cycle and life duration, mortality and so on, but rather use **respiration rate,** together with a measure of **soil fauna biomass**, as an indicator of turnover by the soil fauna. The next step is mineralization by soil microbes (the IRGA gives both a measurement of the **microbial biomass** and of the **microbial respiration rate**).

A side loop might be introduced for **predatory fauna**, but we excluded it from this model for clarity. It would describe the pathway which leads from soil fauna to detritus via predators, which have a large proportion (about 25%) of the total biomass.

A shortcut of this whole process is achieved by measuring the decomposition rate directly. This was achieved in two ways: With **Litter bag experiments** in which a determined litter quality and quantity was exposed to decomposition of different soil fauna groups separated by the mesh size used in the litter bags; and by calculating the decay rate from litter production and litter stocks. Therefore, three measurements of decomposition have been obtained in the project:

1. litter bags
2. litter quantity (X_{ss} = litter stocks in the steady state of an ecosystem) vs. litter production (L) (Olson 1963; cf. Martius 1989). In fact, this formula should only be used in climax ecosystems which achieved a steady state.
3. litter data together with soil fauna/microbial biomass and soil fauna/microbial respiration rates

A short outline of what can be achieved with the data is given as follows. The annual carbon input via litter can be calculated from the litter fall and the C content in the litter. It amounts to 0.32-0.46 kg C m^{-2} yr^{-1}. This equals 26% of the carbon stocks in the topsoil. The annual loss of carbon via microbial respiration in the top soil is about 23% of the stocks. In other words, C input from litter fall and output from microbial respiration are almost balanced. Using the few animal respiration data available, Förster (unpubl.) calculated that the C output from animal respiration is only about 1% of the annual C input. This means that although soil fauna is an extremely important determinant of the

decomposition processes, its direct contribution to the mineralization of carbon is very low. They pre-eminent role must be seen as primary decomposers or "fragmentators"; agents that prepare the raw litter for microbial decomposition.

Concerning termites, the modelling process will be taken one step further. A thorough model of the role of fungus-growing ants and termites in carbon cycling has been developed by Ackerman (1999), based in turn on the rather complex Carnegie-Ames-Stanford approach (CASA) biosphere model (Potter et al. 1993), and a sub-model for termites, according to functional groups, is being created by C.Hanne in her Ph.D. thesis.

3. Modelling the role of soil organisms in the nitrogen cycle

Figure 2 gives an example of the qunatitative modelling of nitrogen in litter production, litter stocks, fauna biomass and soil of the study sites. The data are based on nitrogen concentrations in these fractions in the different plots.Also shown is the turnover of nitrogen as calculated form weight loss in the litter bags. As N concentration of a given fraction is not too different between the sites, the nitrogen balance mainly reflects the biomass of the different fractions in the sites. It is interesting to see that although most pools and fluxes are of similar size (only the N pool in the litter stocks of SEC is larger, due to the high litter stocks here), the turnover of N from soil fauna in POA is one order of magnitude below that in the other sites. The plots POA and POC are similarly structured, the only difference between both being that POC is adjacent to a rain forest, whereas POA is not. This could be an interesting hint to the importance of landscape mosaic for the preservation of ecological function in man-managed sites.

4. Modelling the soil fauna determinants

Figure 3 gives an example of a typical output of a CART modelling (classification) run, using the termite presence/absence in the topsoil (0-5 cm) as the target (dependent) variable, and plot number, sampling date, and microclimatic data as predictors (independent variables). Microclimatic data consist of the average soil temperature, the air humidity, rainfall and evaprotranspiration 5 days before each sampling event. The original data set consists of 480 cases, which are split at the first node upon the question "Is plot number below 1.5?". As plot number 1 = FLO, all 160 cases from FLO are sent to the left-hand node, the others to the right-hand node. Here, further splits occur based on average evapotranspiration and average rainfall 5 days before the sampling was made. Soil temperature and air humidity were not used by the program as discriminatory predictor variables for splits. This is no final analysis of the data which requires further testing; the example only shows how the data are being analyzed with CART.

Here, only a general description of the first approaches modelling could be given. Further efforst will be necessary in this area in order to make the full potential of the data available.

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Figure 1: A conceptual model for soil fauna and litter decomposition

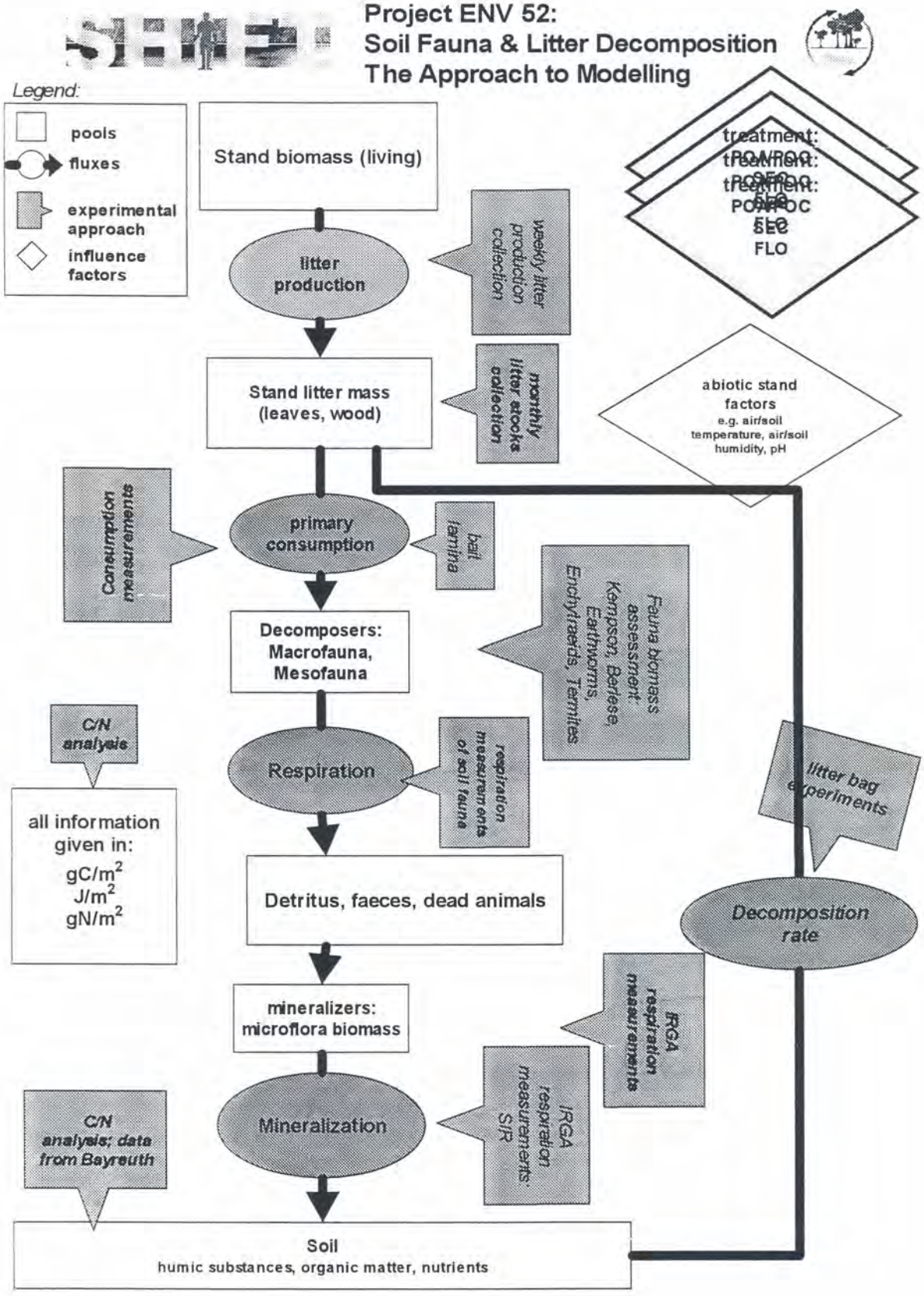


Figure 2: Example for a tentative nitrogen balance in the study sites

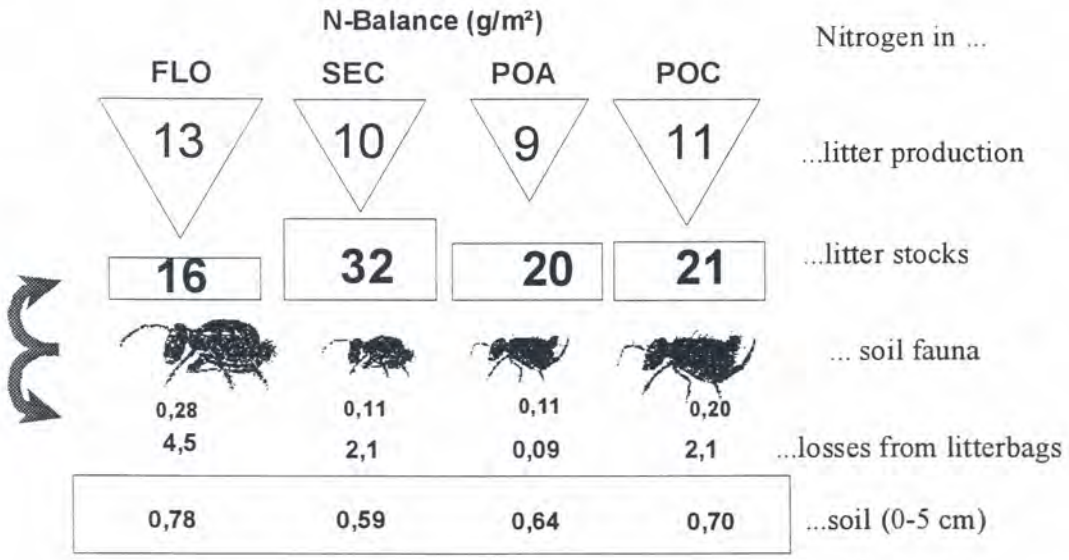
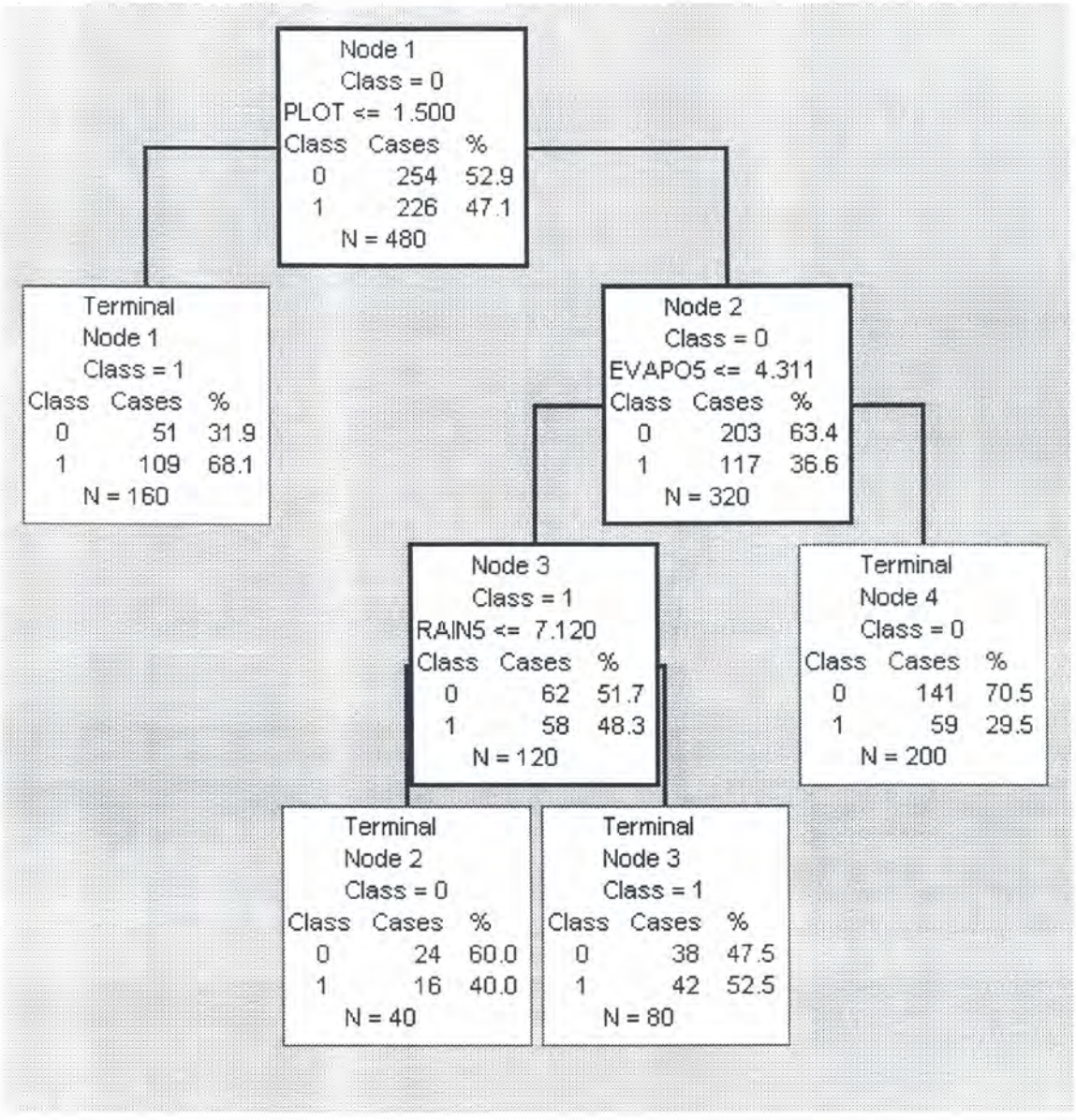


Figure 3: Example for a classification tree generated by CART. For details cf. text.



Dissertations

Efeito dos oligoquetas na decomposição de liteira e na mobilização de nutrientes em floresta primária e secundária.

Yelinda Maria A. Vergara

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Este estudo teve como objetivos a avaliação das mudanças nas populações de oligoquetos devido à adição de liteira ao solo de floresta secundária num experimento no campo, assim como analisar a relação de duas espécies de minhocas com a biomassa microbiana (Bio-N) e a disponibilidade de nitrogênio em mesocosmos em casa-de-vegetação. O estudo de campo foi feito na Estação Experimental da EMBRAPA, situada 30 km ao nordeste de Manaus. Em quatro parcelas de floresta secundária de 6 anos, deixadas como pousio (capoeira), foram demarcadas 20 mini-parcelas de 2 x 2 m em cada capoeira. Foram feitos quatro tratamentos diferentes, com adição de folhas de diferentes qualidades nutricionais: (1) folhas de *Hevea brasiliensis* (C/N=27); (2) folhas de *Carapa guianensis* (C/N=32); (3) mistura de folhas destas duas espécies e *Vismia sp.* em proporções iguais (C/N=34) e (4) permanência da liteira da capoeira nativa da área, dominada por *Vismia sp.* (controle, C/N= 42). Coletas de liteira e solo (0-10 cm) foram feitas ao longo de 10 meses, determinando-se a umidade da liteira e do solo, e a densidade e biomassa de oligoquetos. Adicionalmente, também foi feito um estudo em casa-de-vegetação, em mesocosmos de 30 x 30 x 40 cm, inoculados com a espécie *Rhinodrilus sp.* e mesocosmos de 20 x 20 x 20 cm, inoculados com a espécie *Pontoscolex corethrurus*. Os mesocosmos foram preenchidos com solo de capoeira e cobertos com folhas de diferentes qualidades nutricionais (as mesmas do experimento no campo). Depois de 97 dias de experimento, foram medidos o nitrogênio mineral e Bio-N do solo e a perda de peso da liteira. No experimento de campo, os Enchytraeidae foram mais abundantes no solo (0-5 cm) do que na liteira, enquanto que os Naididae foram mais abundantes na liteira e praticamente não foram encontrados na época seca. A densidade e a biomassa de minhocas foram significativamente maiores aos 0-5 cm (40,3 ind/m^2 e 2,3 g/m^2) do que aos 5-10 cm do solo (15,6 ind/m^2 e 0,6 g/m^2). Embora as mudanças nas populações de oligoquetos não tenham sido significantes com os tratamentos, as folhas de *Hevea brasiliensis*, devido à sua rápida decomposição, devem ter representado um recurso alimentício estável para os oligoquetos do solo, durante todo o período do estudo; por outro lado, o grande tamanho e dureza das folhas de *Carapa guianensis*, de lenta decomposição, ofereceu também uma proteção física para os oligoquetos. No experimento em casa-de vegetação, a inoculação de ambas espécies de minhocas teve um efeito significativo nas concentrações de nitrato e amônio do solo ($p<0,05$). A Bio-N foi sempre mais alta nos mesocosmos com minhocas (principalmente com *Rhinodrilus sp.*) e nos mesocosmos com folhas de *Hevea brasiliensis* (6 µg/g), espécie de mais rápida decomposição, do que nos outros tratamentos (0,1-1,6 µg/g). Estes resultados indicam que a atividade das minhocas aumentou as concentrações de nitrogênio mineral, possivelmente pelo consumo da biomassa microbiana do solo, o que poderia incrementar a ciclagem e a mineralização dos tecidos microbianos. Possivelmente sejam precisos experimentos de maior duração para determinar o efeito das minhocas na decomposição da liteira.

Effects of Oligochaeta on litter decomposition and nutrient mobilisation in primary and secondary forest.

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The aims of the experiments were: to relate Oligochaeta abundance, biomass and composition to changes in litter quality, and to evaluate the effect of inoculation of two species of earthworms in mesocosms on mineral-N and soil microbial biomass-N. The field experiment was conducted at Embrapa's Field Station, located 30 km Northeast of Manaus in central Amazonia. Four plots of 6-years old second growth were selected, and twenty 2 x 2 m quadrats were assigned at random in each one. In the quadrats, the original litter layer was removed and replaced by freshly-fallen leaf litter of: (1) *Hevea brasiliensis* (C:N ratio= 27); (2) *Carapa guianensis* (C:N ratio =32); and (3) a mix of the two species plus *Vismia* sp (C:N ratio= 34). Five quadrats in each plot remained with the original litter layer and were used as a control. Samplings of soil (0– 10 cm depth) and litter were taken from the quadrats along a 10-months period. Additionally, a glasshouse essay was conducted using wooden mesocosms of two sizes: 30 x 30 x 40 cm, inoculated with *Rhinodrilus sp.*, and 20 x 20 x 20 cm, inoculated with *Pontoscolex corethrurus*. The mesocosms were filled with soil from second growth and then covered with a layer of leaf litter of different nutricional values (the same as in the field essay). After 97 days, the earthworms were taken and soil mineral-N, soil microbial biomass-N (Bio-N), and litter weight loss were measured. In the field essay, Enchytraeidae were more abundant in the soil (0-5 cm) than in the litter layer, while Naididae were more abundant in the litter, being virtually absent in the dry season. Earthworms density and biomass were significantly higher in the 0-5 cm soil layer (40,3 ind/m^2; 2,3 g/m^2) than in the 5-10 cm layer (15,6 ind/ m^2; 0,6 g/m^2). Despite the lack of significance of the differences between treatments, it was clear that Oligochaeta density was stable under the treatment with *Hevea brasiliensis*, the faster-decomposing litter, but greater under *Carapa* leaves, because of their physical protection on soil surface. In the glasshouse essay, *t*he inoculation of both earthworm species had a significantly positive effect ($p<0,05$) in the concentrations of soil nitrate and ammonium. Microbial biomass-N (Bio-N) was always greater in the mesocosms with earthworms (especially with *Rhinodrilus*), and also visibly greater under the faster-decomposing species, *Hevea brasiliensis* (6 µg/g) than under the other treatments (0,1-1,6 µg/g). The general increase of soil mineral-N forms with inoculation of earthworms (especially with *Rhinodrilus*) can be attributed to earthworm grazing on soil microbial biomass, which increase the mineralization of microbial tissues, releasing mineral-N.

Efeito da qualidade do substrato na biomassa microbiana do solo de uma capoeira da Amazônia Central.

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A comunidade microbiana é extremamente importante para a manutenção do funcionamento da ciclagem de nutrientes nos ecossistemas terrestres. Ela depende da qualidade do substrato, que pode ser manipulado para otimizar a reciclagem de nutrientes e sua conservação no ecossistema. As plantas possuem as mesmas classes de compostos orgânicos, mas suas proporções podem influenciar o grau e a taxa de decomposição. Os conteúdos de carbono e nitrogênio totais do solo e a relação C:N são extensivamente utilizados como índice de qualidade do substrato, enquanto o conteúdo de lignina é considerado para substratos mais recalcitrantes. Para testar a influência da qualidade da liteira em decomposição sobre a biomassa microbiana do solo. Esse estudo foi conduzido na Estação Experimental da Embrapa Amazônia Ocidental, localizada a 30 km ao noroeste da cidade de Manaus na Amazônia Central. O presente estudo consiste de um experimento de manipulação de liteira fina numa capoeira com o objetivo de quantificar o efeito de diferentes tipos de substratos (*Carapa guianensis*, *Hevea brasiliensis* e *Vismia* spp.) sobre a biomassa microbiana do solo e nos conteúdos totais de carbono e nitrogênio do solo. Na área experimental, foram selecionadas quatro parcelas de vegetação secundária com sete anos e nas quais 20 subparcelas de 3 m^2 foram feitas de modo randômico. Nas subparcelas, a liteira original foi substituída por liteira recém-caída de: (i) *Carapa guianensis* (relação C:N=37 e % inicial de lignina=19,2); (ii) *Hevea brasiliensis* (relação C:N=23 e % inicial de lignina=26,8); e (iii) uma mistura das duas espécies e mais *Vismia* spp. (relação C:N=34 e % inicial de lignina=19,5). Cinco subparcelas de cada parcela permaneceram com a camada original de liteira (C:N= 42 e % inicial de lignina=13,8) e foram utilizadas como controle. Foram feitas cinco amostragens de solo (0-10 cm) e de liteira no período de um ano, abrangendo as estações chuvosa e seca. Foram medidos os conteúdos totais de carbono e nitrogênio do solo por combustão seca e a biomassa microbiana do solo pelo método de fumigação-extração. Os conteúdos totais de carbono e nitrogênio e relação C:N do solo, ao longo do experimento, não mostraram diferenças significativas entre os tratamentos. Somente o tratamento com a mistura das diversas espécies de liteira mostrou biomassa microbiana do solo significativamente maior do que a do controle. Houve uma tendência para maior biomassa microbiana do solo nos outros tratamentos, mas estas não foram significativas porque as diferenças entre as parcelas foram tão grandes quanto entre os tratamentos. A biomassa microbiana do solo também é alimentada pela entrada de carbono orgânico, proveniente das raízes, que neste experimento era a mesma (principalmente *Vismia* spp.) sob todos os tratamentos, sugerindo que a camada de liteira adicionada em cada subparcela não foi suficiente para suprimir a contribuição de nutrientes liberados pelos exsudados e pela decomposição das raízes. Esses resultados também indicam que o tempo de experimento é importante para que ocorram mudanças no ecossistema do solo e que onze meses foi apenas suficiente para mostrar a influência da diversidade de liteira, e não de sua qualidade, na biomassa microbiana do solo. Se a biomassa microbiana for utilizada como bio-indicador de recuperação do solo, este estudo sugere que em sistemas agroflorestais a diversificação nos substratos é mais importante do que as características nutricionais específicas para provocar mudanças na microbiota do solo.

Effects of litter quality on soil microbial biomass in secondary forest in central Amazonia

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Microbial community is extremely important for the maintenance of functional nutrient cycles in the ecosystems. Among other factors, the community depend upon resource quality, which may be manipulated to optimize the nutrients recycling and their conservation in the ecosystem. Plants in general contain the same classes of organic compound but their proportion, which is species-dependent, may influence the degree and rate of decomposition. Soil carbon and nitrogen content and C:N ratio in soil have been extensively used to measure resource quality while lignin content is also considered for recalcitrant organic compounds. Thus, to test the influence of the litter quality decomposition on soil microbial biomass and their activities in soil, an experiment with litter manipulation was designed. The experiment was conducted at Embrapa's Field Station located 30 km northeast of Manaus in central Amazonia. This study is a manipulation experiment aiming the effect of litter types (*Carapa guianensis*, *Hevea brasiliensis* and *Vismia* spp.) on soil microbial biomass and on total carbon and nitrogen contents. Therefore, four plots of 7-years old second growth were selected, and twenty 3 m^2 quadrats were assigned at random in each one. In the quadrats, the original litter layers was removed and replaced by freshly-fallen leaf litter of: (i) *Carapa guianensis* (C:N ratio =37 and % initial lignin = 19.2); (ii) *Hevea brasiliensis* (C:N ratio = 23 and % initial lignin = 26.8); and (iii) a mixing of the two species plus *Vismia* spp. (C:N ratio = 34 and % initial lignin = 19,5). Five quadrats in each plot remained with the original litter layer (C:N ratio = 42 and % initial lignin = 13.8) and were used as control. Five sampling of soil (0–10 cm depth) and litter were taken from the quadrats along 11-months period covering both the wet and dry season. Soil carbon and nitrogen content were measured by dry combustion, soil microbial biomass were estimated by the fumigation-extraction method. Results on C and N content and C:N did not show any significant treatment effects. Only the treatment with a mixing of the various litter showed soil microbial biomass significantly higher than the control. Though showing some tendency for higher microbial biomass the other treatments were not significant because differences between replicates were as large as those between treatments. Apart from litter, soil microbial biomass is fueled by organic carbon inputs from roots deposition, which is this essay were the same (mainly *Vismia* spp.) for all treatments suggesting that the litter layer added to the experiment were not enough to surpass the contribution of nutrients from root exudates and decomposition. These results also pointed out that time is an important component of soil ecosystem change and that 11months were barely adequate to show that litter diversity is more important than its quality for soil microbial biomass. So, if soil microbial biomass was consider a bio-indicating of soil quality this study suggest high diversity is more important that high quality species in promote changes in soil microbial biomass.

Densidade, diversidade e biomassa da fauna do solo em "mini-plots" com manipulação da liteira numa floresta secundária na Amazônia

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Tese em andamento

Efeito dos ácaros oribatídeos (Acari: Oribatidae) no processo de decomposição no solo em floresta primária e secundária

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Tese em andamento

Dinâmica de população de *Syntermes* (Isoptera , Termitidae) em floresta de terra firme na Amazônia central

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Tese em andamento