BIODIVERSIDADE DE ORGANISMOS EDÁFICOS E CICLAGEM DE NUTRIENTES EM ECOSSISTEMAS NATURAIS E PLANTIOS DE EUCALIPTO NO CERRADO

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TESE DE DOUTORADO EM CIÊNCIAS FLORESTAIS
DEPARTAMENTO DE ENGENHARIA FLORESTAL

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JONAS INKOTTE

TESE DE DOUTORADO SUBMETIDA AO DEPARTAMENTO DE ENGENHARIA FLORESTAL DA FACULDADE DE TECNOLOGIA DA UNIVERSIDADE DE BRASÍLIA COMO PARTE DOS REQUISITOS NECESSÁRIOS À OBTENÇÃO DO GRAU DE DOUTOR EM CIÊNCIAS FLORESTAIS.

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“Earth provides enough to satisfy every man’s needs, but not every man’s greed”

Mahatma Gandhi

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SUMÁRIO

LISTA DE TABELAS

CAPÍTULO I

CAPÍTULO II

CAPÍTULO IV

LISTA DE FIGURAS

CAPÍTULO I

CAPÍTULO II

CAPÍTULO III

CAPÍTULO IV

LISTA DE APÊNDICES

CAPÍTULO II

CAPÍTULO III

BIODIVERSIDADE DE ORGANISMOS EDÁFICOS E CICLAGEM DE NUTRIENTES EM ECOSSISTEMAS NATURAIS E PLANTIOS DE EUCALIPTO NO CERRADO

RESUMO GERAL

O entendimento do funcionamento de variáveis que influenciam a estabilidade de um ecossistema terrestre é crucial para manejá-lo com sustentabilidade. Dentre estes processos, a ciclagem de nutrientes sustenta as funções vitais do bioma Cerrado por meio do aporte de serapilheira e sua decomposição realizada por organismos edáficos; entretanto, pouco se sabe a respeito da dinâmica da serapilheira e sua relação com os atributos do solo nas áreas de Cerrado. Sendo assim, a tese tem como objetivo avançar nos estudos referentes a ciclagem de nutrientes e atributos edáficos em áreas de cerrado sensu stricto e floresta de eucalipto, visando investigar as relações entre a dinâmica da serapilheira, os parâmetros químicos, físicos e biológicos do solo e sua relação com os fatores climáticos. Os estudos foram realizados na estação experimental da UnB, Fazenda Água Limpa, localizada no Distrito Federal. Foram alocadas de forma aleatória 12 parcelas em cada uma das três áreas de estudo, sendo a A1 composta por área de cerrado sentido restrito preservado e A2 composta por dois plantios de Eucalipto com diferentes idades de implantação. Foi realizada revisão sistemática dos estudos sobre aporte e decomposição de serapilheira desenvolvidos no bioma Cerrado. Os procedimentos metodológicos em A1 envolveram a avaliação dos processos da ciclagem de nutrientes, pelo período de dois anos, por meio da combinação de dados meteorológicos, deposição e decomposição de serapilheira, abundância e diversidade da fauna epígeica e variáveis físicas e químicas do solo. Em A2 avaliou-se a ciclagem de nutrientes em dois plantios de diferentes idades (8 e 5 anos de implantação), pelo período de dois anos, com ênfase nas implicações da remoção da camada de serapilheira depositada ao solo. Por fim, avaliou-se os impactos da mudança de uso do solo de cerrado sentido restrito em plantios de eucalipto nas comunidades de fauna epigeica. Os dados coletados foram submetidos a análises uni e multivariadas, paramétricas e não paramétricas. A revisão sistemática indicou grande variação metodológica nos estudos de aporte e decomposição da serapilheira no Cerrado, com coletores e bolsas de decomposição de diferentes dimensões, composições e tempos totais de experimento e coleta. Para várias fitofisionomias não foram observados estudos e constatou-se carência de pesquisas de longa data e estudos sobre a decomposição de outras frações da serapilheira que não a foliar. Os resultados obtidos para A1 evidenciaram que a precipitação modulou a diversidade da fauna epigeica, com maiores valores na estação chuvosa, com destaque para os grupos: Isoptera, Collembola e Formicidae. A decomposição de folhas teve alta correlação com a abundância de fauna epigeica, enquanto os galhos apresentaram alta correlação com a diversidade da fauna epigeica, entretanto as taxas de decomposição destas duas frações foram semelhantes. De forma geral, a decomposição da serapilheira foi mais rápida onde a diversidade e abundância de fauna epigeica foi maior e apresentou correlação com pH, estoque de carbono e fósforo disponível. Houve forte influência da precipitação sazonal na comunidade da fauna epigeica, na deposição e decomposição de serapilheira e suas relações com os parâmetros químicos do solo. Os resultados obtidos em A2 evidenciaram que a remoção da camada de serapilheira reduziu a decomposição foliar e a abundância dos grupos Hemíptera, Díptera e Diplopoda da fauna do solo, além de reduzir o crescimento das árvores na área de eucalipto juvenil. A diversidade da fauna epigeica, os parâmetros de P remanescente e umidade do solo, bem como as taxas de decomposição de galhos foram altamente correlacionados com as parcelas que não sofreram a remoção da camada de resíduos. Houve influência da remoção da camada de serapilheira na composição da fauna edáfica, no crescimento das árvores, na decomposição da serapilheira, no balanço de fósforo e umidade do solo, sendo assim, a prática de remoção de resíduos pode gerar prejuízos aos plantios e a ciclagem de nutrientes como um todo. Ao comparar os diferentes usos do solo A1 e A2 pôde-se observar que no período de seca os grupos Collembola, Isoptera e Díptera foram mais abundantes na área de cerrado e Formicidae mais abundante nas áreas de Eucalipto, sendo estes responsáveis por 85% das diferenças encontradas entre os dois usos do solo. Já no período chuvoso, Formicidae, Isoptera e Díptera foram mais abundantes em A1, enquanto Diplopoda foi mais abundante em A2, sendo estes grupos também responsáveis por 85% da dissimilaridade entre as áreas. Observou-se que a maioria dos grupos de fauna epigeica foram mais abundantes em A1, indicando o impacto ocasionado pela introdução de monocultivo de espécies exóticas nas comunidades de fauna epieica do solo. Pôde-se observar alta correlação de alguns grupos de fauna epigeica com os teores de matéria orgânica, potássio, cálcio, fósforo e pH do solo, sendo estes considerados bons indicadores da composição destas comunidades edáficas. Ao abordar a ciclagem de nutrientes em área de cerrado nativo e plantios de eucalipto, esta pesquisa ressaltou a importância das propriedades edáficas e dos processos que envolvem a serapilheira na manutenção dos serviços ecossistêmicos e as implicações das práticas de manejo e da mudança de uso do solo na comunidade da fauna do solo.

Palavras-chave: serapilheira; solos florestais; ciclagem de nutrientes, eucalipto; cerrado

BIODIVERSITY OF EDAPHIC ORGANISMS AND NUTRIENT CYCLING IN NATURAL ECOSYSTEMS AND EUCALYPTUS STANDS IN THE CERRADO

GENERAL ABSTRACT

Understanding the dynamics of factors that influence the structure and function of a terrestrial ecosystem is crucial to managing it sustainably. Thus, the thesis aims to advance studies concerning the nutrients cycling and soil attributes in areas of cerrado sensu stricto and eucalyptus forest, aiming to investigate the relationships between litter dynamics, chemical, physical and biological parameters of the soil and how those relate to climatic factors. The studies were carried out at the UnB experimental station, Fazenda Água Limpa, located in the Federal District. Twelve plots were randomly allocated in each of the three study areas, A1 being composed of a preserved cerrado sensu stricto area and A2 composed of two Eucalyptus plantations with different implantation ages. A systematic review of studies on input and decomposition of litter developed in the Cerrado biome was carried out. The methodological procedures in A1 involved the assessment of nutrient cycling, for a period of two years, through the combination of meteorological data, litter deposition, and decomposition, abundance and diversity of soil epigeic fauna, and physical and chemical variables of the soil. In A2, nutrient cycling was evaluated in two plantations of different ages (8 and 5 years after implantation), for a period of two years, with emphasis on the implications of continuous removal of litter layer deposited on the soil. Finally, the impacts of land-use change on soil epigeic fauna communities were evaluated, due to the conversion of cerrado sensu stricto ecosystems into eucalyptus plantations. The collected data were submitted to univariate and multivariate, parametric, and non-parametric analyzes. The systematic review indicated great methodological variation in the studies of contribution and decomposition of litter in the Cerrado, with collectors and decomposition bags of different dimensions, compositions, and total times of experiment and collection. For several phytophysiognomies, no studies were observed and there was a lack of long-standing research and studies on the decomposition of fractions of litter other than leaves. The results obtained for A1 showed that precipitation modulated the diversity of soil epigeic fauna, with higher values in the rainy season, with emphasis on the groups: Isoptera, Collembola, and Formicidae. The decomposition of leaves had a high correlation with the abundance of epigeic fauna, while the branches showed a high correlation with the diversity of the epigeic fauna, however, the decomposition rates of these two fractions were similar. In general, the decomposition of litter was faster where the diversity and abundance of epigeic fauna were greater and showed a correlation with pH, carbon stock, and available phosphorus. There was a strong influence of seasonal precipitation on the soil epigeic fauna community, on litter deposition and decomposition, and its relationship with soil chemical parameters. The results obtained in A2 showed that the litter layer removal reduced the leaf decomposition and the abundance of the groups Hemíptera, Díptera, and Diplopoda of the soil epigeic fauna, besides reducing the growth of the trees in the area of juvenile eucalyptus. The diversity of soil epigeic fauna, the parameters of P remaining and soil moisture, as well as the rates of decomposition of branches were highly correlated with the plots that did not undergo litter removal. There was an influence of the removal of the litter layer on the epigeic fauna edaphic composition, on tree growth, on litter decomposition, on the balance of phosphorus and soil moisture, and the nutrient cycling as a whole. When comparing the different uses of soil A1 and A2, it was observed that in the dry season the groups Collembola, Isoptera, and Díptera were more abundant in the cerrado area and Formicidae more abundant in the Eucalyptus areas, being these groups responsible for 85% of the differences found between the two land uses. In the rainy season, Formicidae, Isoptera, and

Díptera were more abundant in A1, while Diplopoda was more abundant in A2, these groups also being responsible for 85% of the dissimilarity between the areas. It was observed that the majority of soil epigeic fauna groups were more abundant in A1, indicating the impact caused by the introduction of monoculture of exotic species in soil epigeic fauna communities. When addressing the cycling of nutrients in the native cerrado area and eucalyptus plantations, this research highlighted the importance of the edaphic properties and of the processes that involve litter in the maintenance of ecosystem services and the implications of management practices and land-use change in the soil fauna community.

Keywords: litter; forest soils; nutrient cycling, eucalyptus; cerrado

1 INTRODUÇÃO GERAL

1.1 GENERALIDADES E JUSTIFICATIVA

O Cerrado brasileiro é o segundo maior bioma da América do Sul ocupando cerca de 21% do território nacional (aproximadamente 1,8 milhão de km²). Além de sua grande extensão, este bioma é considerado a savana mais rica do mundo, apresentando grande diversidade de espécies, muitas delas endêmicas (MORANDI et al., 2018). Apesar de sua grande importância ambiental, nas últimas décadas, o Cerrado tem sofrido uma contínua fragmentação de seus habitats devido à expansão agrícola. Aproximadamente, 40% do território original do Cerrado já foi desmatado, 40% foi degradado, enquanto apenas 19% ainda estão cobertos por áreas preservadas de vegetação nativa (ZUIN, 2020), tornando-o assim um hotspot para a conservação (MYERS et al., 2000).

Tendo em vista tal situação, a implantação e utilização de povoamentos florestais equiâneos com espécies de rápido crescimento em áreas degradadas pode se tornar uma boa alternativa para suprir a crescente demanda florestal mundial, e assim, reduzir as taxas de desmatamento de áreas nativas (BOULMANE, et al., 2017). O reflorestamento de áreas degradadas por meio de plantios de árvores tem sido amplamente utilizado e tem demonstrado resultados significativos na restauração da produtividade original do solo, promovendo mineralização de nutrientes e aumento da capacidade de retenção de água (PAULUCIO et al., 2017; SENA et al., 2017).

Estudos demonstram que plantios de eucalipto quando comparados com outros usos da terra, como monoculturas agrícolas, são considerados um dos menos impactantes para as comunidades da fauna do solo (ROSA et al., 2015; SOUZA et al., 2016). Neste sentido. Boeno et al., (2020) afirmam que após oito anos de conversão de solo sem cobertura em povoamentos de eucalipto, a qualidade biológica edáfica foi reestabelecida. No entanto, a introdução de monoculturas permanece controversa, especialmente por causa dos impactos negativos na biodiversidade do solo (SOUZA et al., 2016; BALIEIRO et al., 2020; CORREA et al., 2020), uma vez que a diversidade da composição de substratos (serapilheira provinda de diversas espécies) é reduzida a um único tipo de material, podendo ocasionar um desiquilíbrio biológico (BARETTA et al., 2003).

Sendo assim, o entendimento do funcionamento e variáveis que influenciam a estabilidade de uma comunidade vegetal é crucial para que se possa manejá-las buscando a sustentabilidade dos ecossistemas florestais e savânicos (MORANDI et al., 2018). Dentre estes processos se destaca a ciclagem de nutrientes, a qual ocorre por meio da deposição de material vegetal ao solo (chamado de serapilheira), que por meio da sua decomposição realizada por organismos edáficos, proporciona o retorno dos nutrientes novamente a solução do solo para que possam ser reabsorvidos pelas plantas (PRITCHETT, 1979; GARLET et al., 2019).

De acordo com Pritchett (1979) e Neves et al. (2001), a ciclagem de nutrientes pode ser analisada e dividida em três ciclos distintos, sendo estes: o ciclo geoquímico, o biogeoquímico e o bioquímico. O Ciclo geoquímico compreende as entradas de nutrientes – por meio do intemperismo das rochas matrizes, da precipitação e deposição atmosférica, da fixação de nitrogênio e da aplicação de fertilizantes – e suas saídas do sistema, não levando em consideração os processos referentes à serapilheira.

Já o segundo ciclo – biogeoquímico – é definido pelos mesmos autores por envolver os processos de translocação dos nutrientes no sistema solo-planta-serapilheira. O processo inicia na absorção dos elementos pelas raízes da planta e sua incorporação na biomassa, onde o retorno dos nutrientes ao solo ocorre principalmente através da produção e decomposição da serapilheira. E por fim, o terceiro ciclo ocorre pela translocação dos nutrientes entre as diferentes partes da planta, movendo-se da raiz para as demais estruturas.

Dentre os processos envolvidos na ciclagem de nutrientes, destacam-se o aporte e a decomposição da serapilheira, sendo este o principal meio para reciclagem de nutrientes em ecossistemas com solos altamente intemperizados e nutricionalmente deficientes, que cobrem cerca de 46% das áreas do Cerrado (DJUKIC et al., 2018).

A decomposição de serapilheira é realizada pela atividade de organismos edáficos, onde a fauna epigeica explica cerca de 7% da decomposição da serapilheira através de sua fragmentação (WALL et al., 2008), e contribui para o equilíbrio biológico através do controle de microrganismos e da provisão de alimentos para outros grupos de fauna, sendo indispensáveis para o bom funcionamento dos ecossistemas. É, portanto, essencial investigar o papel ecológico da diversidade e abundância da fauna edáfica, os quais são também considerados importantes indicadores de qualidade ambiental (ROSA et al., 2015). No entanto, existem poucos estudos relacionados as interações entre a abundância e a diversidade de fauna epigeica do solo e a decomposição da serapilheira, e ainda, como parâmetros climáticos e propriedades do solo, que podem alterar as taxas de decomposição de serapilheira, e esta, por sua vez, pode afetar as comunidades de fauna edáfica no Cerrado (GUERRA et al., 2020).

Neste contexto, as taxas de decomposição de serapilheira são geralmente calculadas através de sacos de decomposição, onde folhas são armazenadas e deixadas no campo para medir o tempo de perda de massa da serapilheira (OLSON, 1963). No entanto, essa técnica não avalia a decomposição de todos os componentes da serapilheira. Frações que não as folhas, especialmente galhos, podem perfazer até 30 a 40% do material vegetal total depositado no solo (CORREIA; ANDRADE, 2008), o que pode implicar numa superestimação da velocidade de decomposição, uma vez que a composição química das diferentes frações são distintas, em especial, em relação a quantidade de lignina de cada material (HALL et al., 2020).

A serapilheira não é apenas essencial no processo de ciclagem de nutrientes, que fornece os nutrientes necessários ao desenvolvimento das plantas nos ecossistemas, mas também atua como uma camada protetora que reduz as oscilações no conteúdo da água no solo e da temperatura do solo, previne a erosão e lixiviação do solo, além de servir como habitat e alimento para fauna edáfica (GIWETA, 2020). Devido ao fato desta camada de resíduos vegetais afetar tantos processos do solo, quantificar as consequências de possíveis alterações na dinâmica da serapilheira se faz necessário, promovendo assim, uma quantificação direta de sua importância (SAYER, 2006; CHEN et al., 2014).

Ainda, mesmo com a suma importância da serapilheira para a sustentabilidade dos ecossistemas florestais e savânicos, o conhecimento sobre as dinâmicas da serapilheira são limitados, carecendo de demais estudos em ecossistemas tropicais (GIWETA, 2020). De acordo com Guerra et al., (2020), os estudos sobre a biodiversidade do solo e o funcionamento dos ecossistemas em florestas tropicais podem ser denominados como um ponto cego, ou seja, uma lacuna a ser preenchida.

1.2 REFERÊNCIAS BIBLIOGRÁFICAS

BALIEIRO F. C. et al., Ecosystem Services in Eucalyptus Planted Forests and Mixed and Multifunctional Planted Forests. In: Cardoso B. N. E., Gonçalves J., Balieiro F., Franco A. (eds) **Mixed Plantations of Eucalyptus and Leguminous Trees**. Springer, Cham. pp. 193-219, 2020.

BOENO, D. et al., Influence of eucalyptus development under soil fauna. **Brazilian Journal of Biology**, v. 80, n. 2, p. 345-353, 2020.

BOULMANE, M. et al., The potential of Eucalyptus plantations to restore degraded soils in semi-arid Morocco (NW Africa). **Annals of Forest Science**, v. 74, n. 57, p. 1-10, 2017.

CHEN, H. et al., Effects of Litter Manipulation on Litter Decomposition in a Successional Gradients of Tropical Forests in Southern China. **PLoS ONE** v.9, n.6 e99018, 2014. doi:10.1371/journal.pone.0099018

CORREA C. M. A. et al., Exotic pastureland is better than Eucalyptus monoculture: β-diversity responses of flower chafer beetles to Brazilian Atlantic Forest conversion. **International Journal of Tropical Insect Science**, v.1, p. 1-8, 2020. Doi:<https//:10.1007/s42690-020-00186-9>.

CORREIA, M. E. F.; ANDRADE, A. G. **Formação de serapilheira e ciclagem de nutrientes**. In: SANTOS, G. de A.; SILVA, L. S. da; CANELLAS, L.P.; CAMARGO, F.A.O. (2ªed.). Fundamentos da matéria orgânica do solo: ecossistemas tropicais & subtropicais. Porto Alegre: Metrópole, p. 137-157. 2008.

DJUKIC, I. et al., Early stage litter decomposition across biomes. **Science of the Total Environment**, v. 628–629, p. 1369–1394, 2018.

GUERRA, C. A. et al., Blind spots in global soil biodiversity and ecosystem function research**. Nature communications**, v. 11, p. 3870 - 3883, 2020.

HALL, S. J. et al. Lignin lags, leads, or limits the decomposition of litter and soil organic carbon. **Ecology**, v. 101, n. 9, set. 2020.

GARLET, C. et al., Ciclagem de nutrientes em povoamento de Eucalyptus dunnii Maiden: produção de serapilheira e devolução de macronutrientes no bioma Pampa. **Ecologia e Nutrição Florestal**, v. 7, n. 5, p. 1-9, 2019.

GIWETA, M. Role of litter production and its decomposition, and factors affecting the processes in a tropical forest ecosystem: a review. **Journal of Ecology and Environment**, v. 44, n. 1, p. 1-9, 2020.

OLSON, J. S. Energy storage and the balance of producers and decomposers in ecological systems. **Ecology**, Hoboken. v. 44, n. 2, p. 322-331, 1963.

MORANDI, P. S. et al., Tree diversity and above-ground biomass in the South America Cerrado biome and their conservation implications. **Biodiversity and Conservation**, v. Online, p. 1–18, 2018.

MYERS, N. et al., Biodiversity hotspots for conservation priorities. **Nature**, v. 403, p. 853–858, 2000.

NEVES, E. J. M. et al., Deposição de serapilheira e de nutrientes de duas espécies da Amazônia. **Boletim de Pesquisa Florestal**, n. 43, p. 47-60, 2001.

PAULUCIO, V. O. et al., Reforestation of a degraded area with eucalyptus and sesbania: microbial activity and chemical soil properties. **Revista Brasileira de Ciência do Solo**; v. 41, e0160239, 2017.

PRITCHETT, W. **Properties and management of forest soils**. 2nd ed. New York, John Wiley, 1979, 494 p.

ROSA, M. G. et al., Macrofauna Edáfica e Atributos Físicos e Químicos em Sistemas de Uso do Solo no Planalto Catarinense. **Revista Brasileira de Ciência do Solo**, v. 39, n.6, p. 1544-1553, 2015.

SAYER, E. J. Using experimental manipulation to assess the roles of leaf litter in the functioning of forest ecosystems. **Biological Reviews**, v.81, p.1–31, 2006.

SENA, K. N. et al., Organic carbon and physical properties in sandy soil after conversion from degraded pasture to eucalyptus in the brazilian cerrado. **Revista Brasileira de Ciência do Solo**, v. 41, e0150505, 2017.

SOUZA, S. T. de. et al., Abundance and Diversity of Soil Macrofauna in Native Forest, Eucalyptus Plantations, Perennial Pasture, Integrated Crop-Livestock, and No-Tillage Cropping. **Revista Brasileira de Ciência do Solo**, v. 40, n. 1, p. 1-14, 2016.

ZUIN, V. G. What Can Be Learnt from the Brazilian Cerrado? In: Mammino L. (eds) **Biomass Burning in Sub-Saharan Africa**. Springer, Dordrecht. 2020, p. 143-160.

WALL, D. H. et al. Global decomposition experiment shows soil animal impacts on decomposition are climate-dependent. **Global Change Biology**, v. 14, p. 2661–2677, 2008.

1.2 OBJETIVOS

O objetivo geral da pesquisa foi avaliar, através de experimentação a campo e análises laboratoriais, a ciclagem de nutrientes em área de vegetação nativa denominada cerrado sentido restrito e em plantios de eucalipto e sua relação com os atributos químicos, físicos e biológicos do solo e variáveis climáticas, para fins de aplicação em práticas de manejo e conservação do bioma Cerrado. Como objetivos específicos citam-se:

a) Averiguar as metodologias empregadas em estudos envolvendo a decomposição e o aporte de serapilheira no bioma Cerrado;

b) Investigar o efeito da sazonalidade das estações seca e chuvosa na diversidade e abundância da fauna epigeica do solo e na produção de serapilheira em áreas de cerrado sentido restrito;

c) Investigar a correlação da decomposição da serapilheira com os atributos físicos, químicos e biológicos (fauna epigeica) do solo.

d) Verificar os efeitos da remoção da camada de serapilheira nos atributos edáficos, na deposição e decomposição da serapilheira e no crescimento vegetal, para avaliar as contribuições deste componente na ciclagem de nutrientes e a manutenção dos serviços ecossistêmicos promovidos pelos resíduos vegetais em plantios de Eucalipto com diferentes idades de implantação.

e) Analisar os efeitos decorrentes da conversão do uso do solo de áreas de cerrado sentido restrito para floresta de eucalipto nas comunidades de fauna epigeica edáfica, e como estes organismos se correlacionam com os parâmetros químicos do solo.

1.3 QUESTÕES DE PESQUISA

a. Existe uniformidade nas metodologias utilizadas nos estudos de aporte e decomposição de serapilheira realizados no bioma Cerrado?

b. Como a diversidade e abundância da fauna epigeica do solo e a queda de serapilheira são afetadas pela sazonalidade das chuvas no Cerrado?

c. Como a fauna epigeica se correlaciona com os atributos biogeoquímicos do solo e a decomposição de folhas e material lenhoso da serapilheira?

d. De que forma a remoção da camada de serapilheira pode interferir nos atributos físicos, químicos e biológicos do solo, bem como na dinâmica de aporte e decomposição de serapilheira e ainda, no crescimento vegetal em plantios de Eucalipto no bioma Cerrado?

e. Como a comunidade da fauna epigeica do solo responde aos impactos ocasionados pela mudança de uso do solo de áreas de cerrado sentido restrito em plantios de eucalipto? E ainda, como estes organismos se relacionam com os parâmetros químicos do solo?

1.4 ESCOPO DO TRABALHO

A presente tese encontra-se estruturada em quatro capítulos e considerações finais. O primeiro capítulo aborda uma revisão sistemática dos trabalhos de aporte e decomposição de serapilheira desenvolvidos no bioma Cerrado. O segundo capítulo apresenta um estudo com 24 meses de duração a respeito da ciclagem de nutrientes em uma área de cerrado sentido restrito por meio da combinação de dados meteorológicos, deposição e decomposição de serapilheira, abundância e diversidade fauna epigeica do solo e 16 variáveis físicas e químicas do solo. Já o terceiro capítulo avaliou, pelo período de 24 meses, a ciclagem de nutrientes em dois plantios de eucalipto, com idades distintas, tendo ênfase nas implicações da remoção da camada de serapilheira depositada ao solo nos atributos físicos, químicos e biológicos do solo, bem como nos processos de deposição e decomposição da serapilheira, e ainda no crescimento diamtétrico das árvores. O quarto capítulo abordou estudo relacionado aos impactos da mudança de uso do solo de cerrado sentido restrito em plantios de eucalipto nas comunidades de fauna edáfica, e a relação destes organismos com os atributos químicos do solo.

2 CAPÍTULO I *

MÉTODOS DE AVALIAÇÃO DA CICLAGEM DE NUTRIENTES NO BIOMA CERRADO: UMA REVISÃO SISTEMÁTICA

METHODS OF EVALUATION OF NUTRIENT CYCLING IN THE CERRADO BIOME: A SYSTEMATIC REVIEW

RESUMO

Em sistemas florestais, a forma natural de aporte de nutrientes se dá através da serapilheira, a qual compreende todo material vegetal depositado ao solo. Logo, vista a importância do tema, o presente trabalho objetivou realizar uma revisão sistemática sobre as diferentes metodologias utilizadas na temática da serapilheira e ciclagem de nutrientes nas diversas fitofisionomias do bioma Cerrado. Foram avaliadas todas as publicações, independentemente do período de publicação, e catalogadas as que se enquadraram na temática: quantificação da produção e decomposição da serapilheira no bioma Cerrado, por meio de buscas no portal periódicos CAPES. Foram selecionados 26 artigos com estudos nas seguintes formações florestais: Cerrado sentido restrito; Cerradão; Matas de Galeria; Florestas de transição Cerrado-Amazônia e plantios homogêneos. A respeito das metodologias, os coletores mais comuns nos trabalhos de produção foram os de formato quadrado (0,25 m²) e o número de coletores variou bastante entre os trabalhos (de 10 a 60 coletores). As folhas contribuíram em torno de 70% ou mais do total da serapilheira. A decomposição apresentou grande variação na massa acondicionada nas bolsas e nos tempos de coleta. Com exceção de um trabalho, os manuscritos avaliados não apresentaram estudos sobre a decomposição de outros componentes da serapilheira, que não a foliar, evidenciando assim a necessidade de estudos nesta temática. Os trabalhos apresentaram tempo total de 12 meses de avaliação em quase sua totalidade, o que evidencia a necessidade dos monitoramentos de longo prazo, pois estudos com curta duração não permitem avaliar os efeitos de alterações interanuais. As metodologias utilizadas nos trabalhos avaliados apresentaram alto grau de variação, evidenciando a necessidade de padronização que permita a comparação entre estes. Por fim, pôde-se observar que algumas fitofisionomias não possuem nenhuma publicação sobre os temas avaliados, o que reforça a necessidade de estudo da dinâmica da ciclagem de nutrientes nestes locais.

Palavras-chave: Serapilheira; Decomposição; Aporte; Revisão sistemática.

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ABSTRACT
In forest systems, the natural form of nutrient supply is through the litter, which comprises all plant material deposited in the soil. Therefore, the present work aimed to perform a systematic review on the different methodologies used in the litter and nutrient cycling topics in the diverse phytophysiognomies of the Cerrado biome. All publications were evaluated, regardless of the period of publication, and cataloged those that fit the theme: quantification of the production and decomposition of litter in the Cerrado biome, through searches in the Periódicos CAPES gate. Twenty-six (26) articles were selected with studies in the following forest formations: Cerrado restricted sense; Cerradão; Gallery Woods; Cerrado-Amazonian transition forests and homogeneous plantations. About the methodologies, the most common collectors in the production works were those with square format (0.25 m²) and the number of collectors varied widely between works (from 10 to 60 collectors). The leaves contributed around 70% or more of the total litter. The decomposition showed great variation in the mass conditioned in the litter bags and also in times of collection. Except one study, the evaluated manuscripts did not present studies on the decomposition of other litter components, other than the leaves, thus evidencing the need for studies in this topic. The studies presented a total time of one-year evaluation in almost all of them, which shows the need for long-term monitoring, since short-term studies do not allow the evaluation of the inter-annual changes effects. The methodologies used in the evaluated works presented a high degree of variation, evidencing the need for standardization that allows the comparison between them. Finally, it could be observed that some phytophysiognomies do not have any publications on the subjects evaluated, which reinforces the need to study the dynamics of the nutrient cycling in these sites.

Keywords: litter; decomposition; litterfall; systematic quantitative literature review.

2.1 INTRODUÇÃO

O entendimento do funcionamento e variáveis que influenciam a estabilidade de uma comunidade vegetal é crucial para que se possa manejá-las buscando a sustentabilidade dos ecossistemas florestais. E, dentre estas, a produção e decomposição da serapilheira são fundamentais para funcionalidade ecossistêmica e o estabelecimento destes ecossistemas. Parte do processo de retorno da matéria orgânica e dos nutrientes ao solo ocorre pela produção de serapilheira, sendo este o meio natural mais importante da transferência de elementos necessários ao crescimento e desenvolvimento das plantas (LOPES et al., 2009).

A serapilheira é um dos componentes mais importantes de um ecossistema florestal, contemplando todo material vegetal depositado ao solo pelas árvores, como: folhas, galhos, e estruturas reprodutivas (flores, sementes, frutos), além de outros materiais orgânicos de origem não vegetal. Estes materiais produzidos e posteriormente depositados no solo florestal proporcionam a ciclagem de nutrientes, que por meio de sua decomposição liberam os nutrientes absorvidos pelas plantas (COSTA et al., 2010).

Este processo de ciclagem de nutrientes é de suma importância em solos com alto intemperismo e baixos teores nutricionais, como é o caso de muitos solos brasileiros, nos quais a biomassa vegetal é o principal reservatório de nutrientes. Dentre os diversos tipos de solos ocorrentes no Brasil, destacam-se os Latossolos, os quais compreendem entre 32 e 46% do território nacional, sendo solos muito intemperizados e com altas taxas de lixiviação, estes ocorrem em locais planos e com relevo suave, sendo geralmente solos ácidos, bem profundos e pobres na disponibilidade de nutrientes devido aos intensos processos de intemperismo (FONTES, 2012).

Os solos predominantes dos Cerrados se enquadram nestas características e originalmente apresentam deficiências nutricionais e são classficados como Latossolos distróficos com alta saturação de Al. Esta baxa fertilidade reflete na menor concentração de nutrientes nas folhas das espécies nativas ocorrentes nestes solos, o que reforça a necessidade de estudos sobre a ciclagem de nutrientes nas diferentes fitofisionomias deste bioma (HARIDASAN, 2000).

Existem diferentes tipos de estudos de revisão de literatura, e dentre estes, está a revisão sistemática ou "systematic quantitative assessment", proposta por Pickering e Byrne (2014), a qual utiliza uma padronização na busca e catálago de todos os artigos encontrados, para a posterior análise quantitativa, evitando assim, erros de amostragem por utilizar um padrão de pesquisa. Este tipo de revisão proporciona ao pesquisador mapear os limites existentes na literatura dentro de cada tema escolhido, permitindo identificar onde as generalizações ocorrem (locais em que a maior parte dos estudos vem sendo realizados) e suas limitações - lacunas não preenchidas dentro de determinados temas de estudo - o que facilita o avanço das pesquisas, além de poder verificar as possíveis discrepâncias metodológicas dentro de uma mesma linha de pesquisa (BORENSTEIN et al., 2009).

Sendo assim, o presente estudo teve como objetivo caracterizar os trabalhos de produção e decomposição da serapilheira no bioma Cerrado quanto a sua forma de publicação e as metodologias utilizadas e seus resultados, buscando compreender sua área de abrangência em cada fitofisionomia para verificar quais assuntos possuem potencial para novas linhas de pesquisa.

2.2 DESENVOLVIMENTO

2.2.1 Descrição dos procedimentos metodológicos

Os procedimentos metodológicos que conduziram o presente trabalho fundamentam-se nos estudos de revisão sistemática propostos por Pickering e Byrne (2014). O levantamento utilizou como fonte de dados todos os artigos publicados em revistas científicas que apresentavam correlação com a temática acerca da serapilheira, buscando identificar sua presença e relação como o foco de estudo. A busca ocorreu na base de dados Periódicos CAPES, por ser uma das maiores bases de dados, contendo artigos nacionais e internacionais.

O levantamento dos trabalhos ocorreu no período entre março e junho de 2017, utilizando o mecanismo de "buscar assunto" do banco de dados dos Periódicos CAPES, e dentro deste, a escolha da ferramenta intitulada "Busca avançada". Os termos inseridos como palavras-chave foram: "Serapilheira e Cerrado"; "Litterfall and Cerrado", sendo então analisados todos os trabalhos científicos que foram encontrados, sem definição de um período de tempo, compreendendo assim, todas as publicações catalogadas na plataforma até a data da realização do levantamento. Cabe ressaltar que as pesquisas foram realizadas nos domínios da Universidade de Brasília - UnB com acesso total e irrestrito ao banco de dados da Periódicos CAPES.

O critério de inclusão dos artigos encontrados nas buscas se deu pelo enquadramento ou não nos temas específicos preestabelecidos, compreendendo assim todos os trabalhos referentes à quantificação da produção e decomposição da serapilheira nas áreas dentro do bioma Cerrado, sendo elas compostas por áreas de formação florestal nativa ou plantada.

Após tal triagem, os aspectos gerais dos artigos incluídos na base dados foram analisados sob os seguintes aspectos: ano de publicação dos artigos, o meio de publicação, ou seja, quais revistas científicas publicaram os artigos; os locais em que foram realizados os estudos, com a finalidade de conhecer quais fitofisionomias foram mais avaliadas. Por fim, os artigos foram divididos em duas áreas específicas dentro da temática da serapilheira: os trabalhos que abordavam a deposição/aporte/produção de serapilheira e os estudos envolvendo as taxas de decomposição de serapilheira.

Dentro de cada área específica, foram avaliadas as metodologias utilizadas, sendo assim necessária a abertura de subdivisões para melhor perceber suas semelhanças ou diferenças. Os trabalhos referentes ao aporte de serapilheira foram avaliados em relação ao formato e área do coletor, quanto à forma da classificação dos materiais vegetais na triagem e a quantificação da contribuição destas diferentes estruturas. Os artigos sobre a decomposição da serapilheira foram avaliados quanto à quantidade e o tipo de material vegetal adicionado nas bolsas de decomposição (*litter bags*), tempos de exposição da primeira coleta e tempo total de exposição dos *litter bags*.

Cabe ressaltar que os trabalhos realizados em ambientes aquáticos não fizeram parte das análises por possuírem implicações, metodologias e formas de análise diferentes dos aplicados nos ambientes terrestres.

2.2.2 Resultados das buscas e enquadramento dos artigos nos critérios de inclusão

Os estudos sobre a quantificação da produção e as taxas de decomposição foram catalogados e analisados, sendo encontrados 77 artigos científicos, para a busca com os termos "Serapilheira e Cerrado" e que dentre os quais, 11 se enquadraram nas categorias preestabelecidas – nove destes em áreas de Cerrado nativo e dois em florestas plantadas em áreas orginalmente ocupadas por Cerrado. Utilizando os termos "Cerrado and Litterfall" foram encontrados 252 resultados, sendo que destes, 15 se enquadraram nas categorias, das quais 12 destes foram realizados em áreas de Cerrado nativo, três em florestas plantadas em áreas orginalmente ocupadas por Cerrado e um em áreas de plantio de pinus comparado a áreas de Cerrado nativo. Os demais artigos foram descartados em virtude de não se enquadrarem nos critérios preestabelecidos referentes à temática analisada, resultando em um total de 26 artigos catalogados e analisados.

2.2.3 Aspectos gerais dos manuscritos avaliados

Os trabalhos realizados sobre a ciclagem de nutrientes que se enquadraram nos parâmetros de seleção anteriormente descritos, entre florestas plantadas em áreas originais de Cerrado em diferentes fitofisionomias do bioma em seu estado natural totalizaram 26 artigos publicados em 16 diferentes revistas, sendo que quatro delas foram responsáveis por quase a metade do total das publicações (46,15%), sendo elas: Forest Ecology and Management, Brazilian Journal of Biology, Plant and Soil e Plant Ecology com três publicações cada. O fato de tais revistas possuírem alto fator de impacto e serem revistas internacionais ressalta a importância da temática do estudo.

Avaliando as datas de publicações dos trabalhos pôde-se perceber notório aumento no número de trabalhos nos últimos seis anos, o que evidência uma tendência de crescimento nos trabalhos sobre o referido tema (Figura 1). Destacam-se os anos de 2011, 2012 e 2016 com sete, três e três publicações, respectivamente.

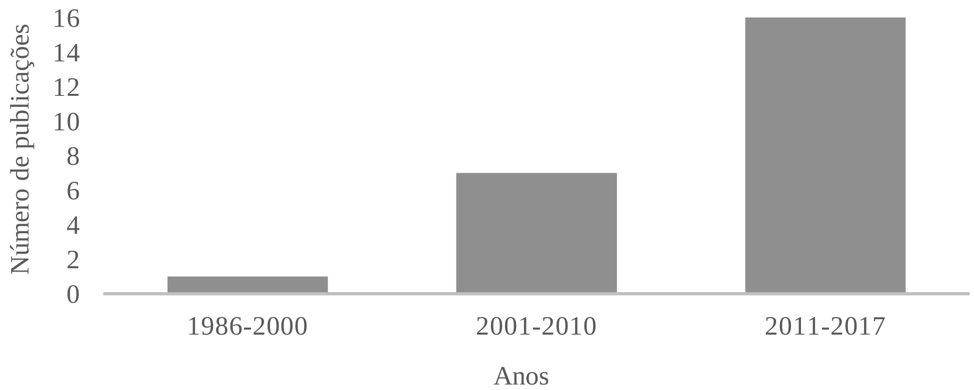

Figura 1. Evolução do número de publicações analisadas com o passar dos anos.

Figure 1. Evolution in the number of publications analyzed over the years.

Dos 26 manuscritos avaliados, a temática do aporte/deposição/produção da serapilheira foi abordada em 22 trabalhos, perfazendo ampla maioria. Já a quantificação das taxas de decomposição foi abordada em 13 publicações. Cabe ressaltar que muitos dos artigos apresentavam análise de ambas temáticas de forma simultânea, o que beneficia a consistência dos trabalhos a respeito da dinâmica da ciclagem de nutrientes.

O bioma Cerrado é composto por diversas fitofisionomias e classificada de formas diferentes dependendo de cada autor, conforme relatado por Bastos e Ferreira (2010). Escolheu-se então utilizar uma adaptação da classificação proposta por Ribeiro e Walter (2008), a qual utiliza um total de 11 diferentes fitofisionomias, como base, sendo assim classificadas as áreas de trabalho dos manuscritos (Figura 2), entretanto, destas, foram registrados trabalhos em apenas quatro delas, o que evidencia uma lacuna para novos estudos nas demais fitofisionomias ainda não avaliadas até o momento. Foram realizados 12 estudos em áreas de Cerrado sentido restrito; cinco em áreas de Cerradão; quatro em Matas de galeria e cinco em Florestas de transição Cerrado Amazônia. Com relação aos estudos desenvolvidos em plantios homogêneos de espécies exóticas, em área natural de Cerrado, foram cinco trabalhos em áreas de plantio de *Eucalyptus* sp. e dois trabalhos em plantios de outras espécies, uma área de plantio de *Pinus caribaea* e uma área de plantio de *Acacia mangium*.

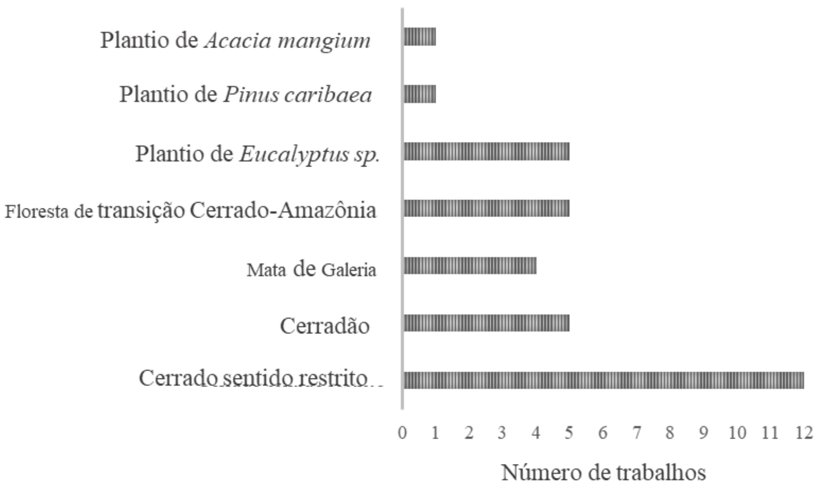

Figura 2. Análise das fitofisionomias e usos de solo avaliados nos manuscritos.

Figure 2. Analysis of the phytophysiognomies and soil uses evaluated in the manuscripts.

2.2.4 Análise dos trabalhos de aporte da serapilheira no Cerrado

Os 22 manuscritos referentes ao aporte de serapilheira no bioma Cerrado foram avaliados com enfoque nas metodologias utilizadas, suas composições florestais e resultados. Dentre os trabalhos avaliados, foram realizados experimentos em nove áreas de Cerrado sentido restrito, quatro em áreas de Mata de galeria, quatro em áreas de Cerradão, quatro em Florestas de transição entre os biomas Cerrado e Amazônia, cinco em áreas de plantios de Eucalipto, dois artigos de revisão (sem experimentos a campo), e um em área de *Pinus caribaea* e uma área de plantio de *Acacia mangium*.

Fica evidente que a formação florestal com o maior número de trabalhos sobre a quantificação da produção de serapilheira foram as áreas de Cerrado Sentido restrito, indicando que as demais formações necessitam de mais estudos, gerando assim, resultados mais confiáveis e passíveis de comparação entre as mesmas formações e outras fitofisionomias do bioma Cerrado. Tal fato auxiliará em um maior entendimento dos processos que contribuem para a sustentabilidade e diversidade entre os ecossistemas. Cabe ressaltar que algumas fitofisionomias não possuem nenhum tipo de trabalho com essa temática, o que ressalta a necessidade da expansão destes estudos dentro do bioma Cerrado entre seus diferentes ecossistemas.

O tempo de coleta de dados variou bastante entre os trabalhos conforme pode ser observado na Tabela 1, entretanto, uma grande maioria realizou as coletas com o tempo total de experimento de um ano, totalizando 10 trabalhos. Com dois anos de avaliação, cinco trabalhos foram publicados, outros três manuscritos analisaram a decomposição por três anos e apenas um trabalho ultrapassou o período de três anos, em um estudo com 8 anos realizado por Laclau et al., (2010), em povoamentos de *Acacia mangium* e *Eucalyptus* sp. A incidência reduzida de trabalhos de médio e longo prazo evidenciam a necessidade da realização de avaliações mais duradouras, uma vez que muitas espécies possuem produções de flores, frutos e folhas sazonais e com alterações interanuais (RUBIM; NASCIMENTO; MORELLATO, 2010; ZIMMERMAN et al., 2007).

Tabela 1. Classificação dos manuscritos avaliados quanto ao tempo total de avaliação da deposição de serapilheira.

Table 1. Classification of the evaluated manuscripts according to the total time of litter deposition evaluation.

Tempo de estudo	N	Referências
1 Ano	10	Aquino et al., (2016); Paiva; Silva; Haridasan (2015); Epron et al., (2012); Butler et al., (2012); Epron et al., (2011); Silva et al., (2009); Quesada et al., (2008); Kozovits et al., (2007); Silva et al., (2007); Cianciaruso et al., (2006)
2 anos	5	Oliveira et al., (2017); Villalobos-Veja et al., (2011); Balch et al., (2008); Valenti; Cianciaruso; Batalha (2008); Wilcke e Lilienfein (2002);
3 anos	3	Silva; Poggiani e Laclau (2011); Almeida et al., (2010); Sanches et al., (2009)
8 anos	1	Laclau et al., (2010)

Em que: N = Número de trabalhos.

A utilização de coletores é a metodologia mais comumente adotada nos trabalhos referentes à produção de serapilheira, pois permite a quantificação do material aportado em uma pequena área, a qual será posteriormente extrapolada para hectare. Normalmente, os resultados são apresentados nas unidades de medida: Mg (Megagrama) hectare^{-1} ano^{-1} ou ton hectare^{-1} ano^{-1} (SCORIZA et al., 2012). Alguns aspectos importantes devem ser levados em consideração, para a padronização dos procedimentos metodológicos, como é o caso do número de coletores instalados por uma determinada área, formato dos coletores – mesmo que estas diferenças sejam diluídas na extrapolação para área de um hectare, posicionamento dos coletores na área de estudo, entre outros.

Com relação ao número de coletores instalados em cada experimento, os trabalhos divergiram bastante entre si, tendo trabalhos como apontado em Silva et al. (2007), com 10 coletores por tratamento e trabalhos com 60 e 52 coletores por tratamento, conforme Aquino et al., (2016) e Paiva, Silva e Haridasan (2015), respectivamente. Ficando assim evidenciado que não há um consenso a respeito do número de coletores a serem utilizados, o que também pode gerar alterações na amostragem da serapilheira aportada.

Os resultados das análises referentes ao formato dos coletores e suas dimensões podem ser visualizados na Tabela 2. Puderam-se verificar basicamente dois tipos de metodologias distintas: os coletores com formato circular e os coletores com formato quadrado. O formato mais utilizado foi o quadrado, com um total de 15 trabalhos que optaram por este tipo de coletor (cerca de 68,2% dos trabalhos), outras três publicações utilizaram coletores de formatos circulares/cônicos (13,65%) e outros quatro não descreveram o formato utilizado.

As dimensões dos coletores encontradas nos trabalhos avaliados variaram bastante, indo de 0,02 m² até 1,00 m². Ainda, mesmo dentro do mesmo tipo de coletor (formato), as dimensões utilizadas apresentam muitas diferenças, cujos coletores quadrados variaram entre 0,21 m² e 1,00 m², e essa diferença foi ainda maior para os coletores circulares, os quais variaram entre 0,02 e 0,44 m².

Tabela 2. Caracterização dos coletores utilizados nos trabalhos de aporte da serapilheira.

Table 2. Characterization of the collectors used in the litterfall works.

Formato	Dimensões (m²)	N	Referências
Quadrado	0,25	7	Paiva; Silva; Haridasan (2015); Silva et al., (2011); Villalobos-Veja et al., (2011); Valenti, Cianciaruso e Batalha (2008); Kozovits et al., (2007); Cianciaruso et al., (2006); Wilcke; Lilienfein (2002)
	0,21	2	Almeida et al. (2010); Laclau et al. (2010)
	0,50	3	Epron et al., (2012); Epron et al., (2011); Balch et al., (2008)
	1,00	3	Sanches et al., (2009); Silva et al., (2009); Silva et al., (2007)
Circular Funil	0,28	1	Oliveira et al., (2017)
	0,44	1	Butler et al., (2012)
	0,02	1	Quesada et al., (2008)
Não especificado	0,33	1	Aquino et al., (2016)
	Não especificado	3	Bustamante et al., (2012); Parron; Bustamante; Arkewitz (2011); Lathwell; Grove (1986)

Em que: N = Número de trabalhos.

A escolha das dimensões e formatos dos coletores de aporte de serapilheira, de acordo com Scoriza et al. (2012) fica a cargo de cada pesquisador, uma vez que a quantificação do material aportado é feita por meio de equação na qual a área do coletor é uma variável. Entretanto, os diferentes formatos e dimensões podem acabar implicando em alterações na amostragem da serapilheira aportada, facilitando ou dificultando a queda dos materiais vegetais nos coletores.

Tais discrepâncias metodológicas podem dificultar a comparação entre diferentes trabalhos com fidedignidade, pois, mesmo que ainda as áreas dos coletores sirvam como uma amostra para posterior extrapolação para área de um hectare, as florestas, mas em específico o Cerrado, apresentam formações fisionômicas bastante distintas entre si, e isto implica em uma maior variabilidade de produção intra e interespecífica, devido aos diferentes padrões nas composições florísticas encontradas.

Ainda, mesmo dentro de um mesmo local, a variação espacial pode se tornar um fator importante, o que foi constatado por Aquino et al. (2016) em um experimento realizado em uma Mata de galeria do córrego Lava-pés, em Ipameri - GO, onde os autores verificaram a existência de dependência espacial na produção de serapilheira, para o total depositado e para a fração folhas, o que também não foi levado em conta na grande maioria das publicações desta temática.

A produção anual de serapilheira foi avaliada comparando estudos realizados dentro da mesma fitofisionomia do bioma Cerrado, a qual apresentou valores bastante distintos entre os trabalhos. Para os estudos realizados em áreas de Cerrado sentido restrito, os valores variaram entre 0,62 Mg $hectare^{-1}$ ano^{-1} encontrado em Silva et al., (2007) e 5,8 Mg $hectare^{-1}$ ano^{-1} conforme trabalho de Valenti, Cianciaruso e Batalha (2008). Para as áreas de Cerradão a variação foi ainda maior, indo de 1,04 Mg $hectare^{-1}$ ano^{-1}, conforme apresentado por Silva et al., (2007) e 9,27 Mg $hectare^{-1}$ ano^{-1} conforme descrito em Oliveira et al., (2017). Estas variações bastante amplas podem estar atreladas a diversos fatores, como: estado de conservação e estágio sucessional da floresta estudada, posição espacial da alocação dos coletores, condições microclimáticas diferentes, ocorrência de diferentes composições florísticas dentro da mesma fitofisionomia, com espécies com maior ou menor produção de serapilheira, entre outros fatores (GIÁCOMO; PEREIRA; MACHADO, 2012; NASCIMENTO; CERQUEIRA; HENDERSON, 2015; AQUINO et al., 2016).

Alguns trabalhos de produção da serapilheira apresentaram além da quantificação do aporte total anual, a triagem dos materiais vegetais em diferentes frações, de acordo com sua composição anatômica, e têm por finalidade a verificação da contribuição de cada fração da serapilheira no aporte total. Nos trabalhos analisados, 16 estudos apresentaram algum tipo classificação (aproximadamente 72,7%), entretanto, os trabalhos utilizaram classificações bastante distintas entre si, e muitos deles não quantificaram a contribuição das diferentes frações no total depositado, conforme apresentado na Tabela 3.

Tabela 3. Tipos de classificação dos materiais vegetais aportados observados nos manuscritos avaliados.

Table 3. Types of classification of the litterfall observed in the evaluated papers.

Triagem do material aportado	N	Referências
Folhas, Ramos, Estruturas reprodutivas e Miscelânea	7	Oliveira et al., (2017); Aquino et al., (2016); Sanches et al., (2009); Silva et al., (2009); Valenti; Cianciaruso; Batalha (2008); Silva et al., (2007); Cianciaruso et al. (2006)
Folha	4	Butler et al., (2012); Silva; Poggiani; Laclau (2011); Almeida et al., (2010); Kozovits et al., (2007)
Folhas, Cascas e Galhos mortos	2	Epron e al., (2012) e Epron et al. (2011)
Folhas e Miscelânea (frutos, galhos e etc.)	1	Paiva; Silva; Haridasan (2015)
Retirada de Galhos > 1 cm	1	Balch et al., (2008)
Folhas, Estruturas reprodutivas e Outros materiais	1	Villalobos-Vega et al., (2011)
Total	16	

Em que: N = Número de trabalhos.

A classificação dos materiais vegetais aportados nas frações "folhas, ramos, estruturas reprodutivas e miscelânea" foi a forma de classificação mais comum, sendo evidenciada quase metade do total dos trabalhos avaliados (43,75%), seguidos pela quantificação da contribuição somente foliar com um quarto dos trabalhos avaliados. Levando em consideração que tais diferenças metodológicas já vêm ocorrendo há um certo tempo, e não só nos trabalhos referentes ao bioma Cerrado, mas em todas as formações florestais, Scoriza et al., (2012) recomendam o preeestabelecimento da forma de classificação destes materiais, com base em uma revisão científica, possibilitando desta forma, realizar comparações com outros trabalhos de forma mais apropriada.

Os manuscritos que realizaram a triagem do material vegetal aportado algumas vezes realizaram também a quantificação da participação de cada uma destas classes de material vegetal aportado, no entanto, esta prática foi realizada em poucos trabalhos. Os valores encontrados para a contribuição das folhas no total produzido variaram entre 42,92 e 75,3% nas áreas de Cerrado *sensu stricto*, sendo que os valores em torno de 75% foram mais comuns. O valor de 42,92% apresentado no trabalho de Silva et al., (2007) encontra-se bastante abaixo dos demais resultados apresentados nas outras áreas de Cerrado sentido restrito, tal fato está possivelmente atrelado à alta contribuição de frutos no total produzido, com 32,31% (201 kg ha^{-1} ano^{-1}). A quantificação da participação dos galhos na serapilheira ficou abaixo de 20%, aproximadamente entre 17,51 e 18%.

Com relação à contribuição da fração de folhas, independentemente da fitofisionomia, os resultados apresentaram valores semelhantes, todos com contribuições acima dos 70%. Para os três trabalhos realizados em áreas de Cerradão, os resultados variaram entre 72,27 e 82,95%. Os trabalhos em Matas de Galeria apresentaram valores entre 71,50% e 75%. Já nas florestas de transição entre Amazônia e Cerrado, os valores da contribuição das folhas na composição da serapilheira foram de 70%, 84,48% e um trabalho apontando uma contribuição da fração folha com valores entre 60 a 93% da produção total. Estes valores superiores nas áreas de cerradão, floresta de transição e mata de galeria em comparação ao Cerrado sentido restrito se dá devido à diferente composição florística e dossel mais fechado (RIBEIRO; WALTER, 2008), o que consequentemente acarreta em uma maior produção de serapilheira.

A maior parte dos valores encontrados nos trabalhos realizados nos diferentes ecossistemas do bioma Cerrado condizem com o que afirma Poggiani (2012), que por meio de estudos em diversos biomas florestais apontaram que a média da contribuição das folhas na serapilheira varia entre 60 a 80% do total da produção. Cabe ressaltar que a análise dos demais componentes da serapilheira não foram avaliados em razão da grande diferença em sua classificação, ficando assim evidenciado a necessidade de uma uniformidade entre os estudos, mesmo que de forma mais abrangente como para todo um bioma, possibilitando assim a comparação entre os trabalhos.

2.2.5 Análise dos trabalhos de decomposição da serapilheira no Cerrado

Referente aos trabalhos sobre a decomposição da serapilheira nas áreas do bioma Cerrado, sete em Cerrado sentido restrito foram avaliadas, quatro em áreas de Cerradão, três experimentos em Floresta de transição entre Cerrado e Amazônia e outros dois em áreas de plantios homogêneos de Eucalipto. Cabe ressaltar que não existe nenhum tipo de trabalho a respeito da quantificação da decomposição nas demais fitofisionomias do bioma Cerrado, o que ressalta a necessidade da expansão destes estudos dentro do bioma Cerrado entre seus diferentes ecossistemas.

Para a realização deste tipo de trabalho, a utilização de bolsas de decomposição ou "litter bags" é a prática mais comum, onde uma porção de material vegetal (geralmente folhas) é acondicionada nestas bolsas, e a partir da diferença da massa inicial e a massa final após algum tempo de exposição destas bolsas a campo é realizada a quantificação da decomposição da serapilheira. Após esta quantificação, por meio de uma equação é então obtida a taxa de decomposição (k), normalmente anual (WIEDER; LANG, 1982).

Ao analisar os trabalhos puderam-se constatar quatro dimensões distintas na confecção das bolsas de decomposição, variando entre 5 x 5 cm e 30 x 30 cm, sendo o tamanho mais comum o de 20 x 20 cm (cinco dos 13 trabalhos avaliados). Além das dimensões das “litter bags”, as malhas de *nylon* utilizadas na confecção divergiram entre o tamanho de suas aberturas, onde as mais comuns foram as de 2 mm e 1 mm, conforme apresentado na Tabela 4. A abertura das malhas tem interferência direta na decomposição, uma vez que suas dimensões determinará a entrada ou não da fauna edáfica decompositora (SETALA; MARSHALL; TROFYMOW, 1996).

Sendo assim, recomenda-se utilizar aberturas maiores como as de 2 mm, e evitar espaços muito maiores que este, pois ao deslocar as bolsas para o campo, pode-se perder material acondicionado nas bolsas e ocasionar erros nas determinações da decomposição.

Apenas um dos trabalhos não utilizou a metodologia de “litter bags”, que foi o de Miatto e Batalha (2016), no qual os autores utilizaram a metodologia de *tea bags*, Keuskamp et al., (2013) em que sacos de folhas são enterrados no solo e retirados após três meses de decomposição destas.

Tabela 4. Quantificação dos trabalhos de acordo com as dimensões e abertura das malhas de *nylon* das bolsas de decomposição**.**

Table 4. Quantification of the works according to the dimensions and opening of the nylon mesh of the litter bags.

Dimensões (cm)	**Abertura da malha (mm)**	**Referências**
N.E.	1	Carvalho et al., (2014)
N.E.	N.E.	Freitas; Cianciaruso; Batalha (2012)
N.E.	N.E.	Bambi et al., (2011)
N.E.	1	Valenti; Cianciaruso; Batalha (2008)
20x20	1	Cianciaruso et al., (2006)
20x20	1	Villalobos-Vega et al., (2011)
20x20	2	Kozovits et al., (2007)
20x20	5	Silva; Poggiani; Laclau (2011)
20x20	2	Laclau et al., (2010)
20x24	2	Oliveira et al., (2017)
30x30	N.E.	Sanches et al., (2009)
30x30	2	Silva et al., (2009)
5x5 (*tea bag*)	0-25	Miatto; Batalha (2016);

Em que: N.E. = Não especificado.

A quantidade de gramas de material vegetal acondicionados nas bolsas de decomposição foi avaliada nos trabalhos analisados nesta revisão sistemática, com seus resultados apresentados na Tabela 5. A utilização de cinco g por bolsa foi a metodologia mais comum entre os trabalhos, sendo observada em cinco publicações, seguida por quatro trabalhos que utilizaram 10 g. Outro trabalho utilizou 20 g de material vegetal por bolsa e, contrariando o meio comum, dois trabalhos apresentaram intervalos de valores para a quantidade de gramas por *litter bag*, com valores entre 2-5 g e 3-5 g. Tais alternâncias nas massas das bolsas podem acarretar em grandes variações nos dados coletados, em caso de não se ter um controle rigoroso da quantificação do peso destas bolsas, uma vez que a velocidade de decomposição e sua taxa k serão estimadas por meio destes valores.

Com a constatação de tão grande variação nas massas iniciais das bolsas, pôde-se evidenciar uma falta de padrão na quantidade de material acondicionado nas bolsas de decomposição, o que pode de alguma forma influenciar nas taxas k estimadas, bem como na ação dos organismos decompositores, sendo assim, necessária uma padronização para evitar possíveis desvios e informações desencontradas, para permitir a comparação entre os diferentes trabalhos de forma mais confiável.

Tabela 5. Quantificação dos trabalhos de acordo com a massa de material vegetal acondicionada nas bolsas de decomposição.

Table 5. Quantification of the works according to the mass of vegetal material placed in the decomposition bags.

Massa acondiconada nas *litter bags*	**N**	**Referências**
5 g	5	Carvalho et al., (2014); Freitas; Cianciaruso; Batalha (2012); Bambi et al., 2011; Valenti; Cianciaruso; Batalha (2008); Cianciaruso et al. (2006)
10 g	4	Villalobos-Veja et al., (2011); Kozovits et al., (2007); Silva; Poggiani; Laclau (2011); Laclau et al., (2010)
20 g	1	Oliveira et al., (2017)
2 a 5 g	1	Sanches et al., (2009)
3 a 5 g	1	Silva et al., (2009)
2 g (*tea bag*)	1	Miatto e Batalha (2016);

Em que: N = Número de trabalhos.

Em quase a totalidade dos trabalhos avaliados, o material vegetal acondicionado nas bolsas de decomposição foram apenas compostos por folhas, e apenas um trabalho dentre os 13 avaliados utilizou outras partes vegetais componentes da serapilheira, entretanto, Laclau et al., (2010) estudaram a decomposição de resíduos da colheita em área de plantio de eucalipto, em que constataram que a decomposição das folhas e raízes finas foi mais rápida do que a decomposição galhos e raízes mais grossas.

Além disso, plantas do bioma Cerrado possuem um crescimento subterrâneo bastante significativo, e em alguns locais, a maior parte da biomassa se encontra alocada no subsolo (LOIOLA; SCHERER-LORENZEN; BATALHA, 2015). Tendo em vista tal fato, cabe ressaltar que nenhum dos trabalhos avaliou a quantificação da decomposição das raízes de espécies nativas do Cerrado, o que poderia gerar dados para o melhor entendimento da dinâmica da ciclagem de nutrientes nestes ecossistemas.

Sendo assim, uma vez que as folhas representam, em média, 70% ou mais da constituição da serapilheira, a velocidade e as taxas de decomposição apresentadas na grande maioria dos artigos podem estar sendo superestimadas, pois as outras partes componentes da serapilheira não estão sendo avaliadas, e estas por sua vez, possuem composições químicas e velocidades de decomposição bastante distintas (LACLAU et al., 2010).

Dentre as diferentes frações da serapilheira, os galhos e ramos são responsáveis por aproximadamente 20% do total de materiais depositados sobre os solos florestais, e estes possuem altos teores de lignina. Pegoraro et al., (2011) afirmam que a lignina é um importante componente da parede celular das árvores, sendo este um biopolímero abundante e que fornece carbono ao solo de forma expressiva, pois apenas alguns microrganismos são capazes de decompô-la devido a sua alta complexidade estrutural, contribuindo assim, substancialmente, para a formação de carbono estável no solo.

Os tempos de coleta das bolsas a campo apresentaram também discrepâncias metodológicas entre os trabalhos, sendo que a data da primeira coleta variou entre duas semanas de exposição das bolsas a campo como nos trabalhos de Bambi et al., (2011) e Silva et al., (2009) com entre 14 e 15 dias, respectivamente, indo até o extremo de cinco meses de exposição para a primeira e única coleta como observado no trabalho dos autores Kozovits et al., (2007). A grande maioria dos trabalhos fez a primeira coleta com 30 dias de exposição das bolsas à decomposição, como nos trabalhos: Oliveira et al. (2017); Carvalho et al., (2014); Freitas, Cianciaruso e Batalha, (2012); Silva, Poggiani e Laclau, (2011); Laclau et al., (2010); Valenti, Cianciaruso e Batalha (2008); Cianciaruso et al. (2006).

De forma geral, a decomposição da serapilheira tem comportamento exponencial de decaimento, em que os primeiros dias de exposição apresentam as maiores taxas de decomposição, devido ao fato da rápida degradação dos elementos mais facilmente decomponíveis (celulose e holocelulose), restando apenas os elementos com estruturas e composições químicas mais complexas, como é o caso da fração húmica que possui decomposição mais lenta (GOYA et al., 2008).

Tendo em vista tais padrões de decomposição, os trabalhos que apresentaram a primeira coleta de forma tardia podem ter estimado suas curvas de decomposição de forma não representativa à realidade, não sendo provavelmente percebidos com clareza os pontos de inflexão da curva de decomposição. Esta diferença entre os tempos de coleta evidenciada na análise dos trabalhos, novamente ratifica a necessidade de uma padronização das metodologias, para que a comparação entre os trabalhos possa ser realizada de forma mais segura.

Com relação ao tempo total de análise e exposição das bolsas à decomposição, os seus resultados podem ser visualizados na Tabela 6, na qual oito dos 13 trabalhos tiveram duração máxima de um ano, com apenas dois trabalhos publicados em que o tempo total de análise foi superior a um ano, e apenas um trabalho com mais de um ano e meio, como foi observado no trabalho de Laclau et al., (2010), com experimento realizado em área de plantios de eucalipto no Brasil e no Kongo. Outros dois trabalhos apresentaram tempo total de experimento inferior a um ano, com foi o caso de Kozovits et al., (2007) e Carvalho et al. (2014) com cinco e seis meses, respectivamente.

Publicações contendo estudos de longa duração para a decomposição da serapilheira no bioma Cerrado não foram encontrados, sendo assim este um ponto a ser explorado nas futuras pesquisas, verificando a existência ou não de possíveis alterações interanuais entre as taxas de decomposição, uma vez que diversos fatores afetam a degradação dos materiais, tais como: umidade, temperatura, constituição da serapilheira e atividade e diversidade biológica do solo (SANTANA et al., 2011; SOUTO et al., 2009).

Tabela 6. Classificação dos manuscritos avaliados quanto ao tempo total de exposição das bolsas de decomposição.

Table 6. Classification of the evaluated manuscripts regarding the total time of exposure of the decomposition bags.

Tempo total do experimento	N	Referências
3 meses (*tea bag*)	1	Miatto e Batalha (2016)
5 meses	1	Kozovits et al. (2007)
1 ano	8	Oliveira et al. (2017); Freitas; Cianciaruso; Batalha (2012); Bambi et al. (2011); Silva; Poggiani; Laclau (2011); Sanches et al. (2009); Silva et al. (2009); Cianciaruso et al. (2006)
1 ano e 2 meses	1	Villalobos-Vega et al. (2011)
1,5 e 2 anos	1	Laclau et al. (2010)

Em que: N = Número de trabalhos.

Entre as várias formas fisionômicas de vegetação nativa ocorrentes no Cerrado, fatores determinantes para estas diferenciações são: profundidade efetiva do solo, presença de concreções no perfil, proximidade à superfície do lençol freático, drenagem e fertilidade. Além das variações na fisionomia, ocorrem alterações também na composição florística, fitossociologia e produtividade desses ecossistemas, em decorrência das variações nas características químicas e físicas dos solos (HARIDASAN, 2000).

Sendo assim, trabalhos sobre a quantificação da produção e decomposição da serapilheira nas demais fitofisionomias que ainda não possuem estudos publicados se tornam essenciais para o melhor entendimento da dinâmica destes ecossistemas. Vale ressaltar também que estudos comparando diferentes metodologias aplicadas nos distintos ecossistemas do bioma Cerrado, com o intuito de verificar quais os procedimentos mais adequados a cada situação, os quais possibilitem também a comparação entre os trabalhos dentre uma mesma formação fisionômica e entre diferentes fitofisionomias são também indicados.

2.3 CONSIDERAÇÕES FINAIS

Os trabalhos avaliados referentes à temática de decomposição da serapilheira, com exceção a um trabalho desenvolvido sobre os resíduos da colheita de plantios de eucalipto, não apresentaram avaliações da decomposição de outros materiais vegetais componentes da serapilheira, que não as folhas, isto pode implicar em uma superestimação da velocidade de decomposição destes, sendo assim, é necessária a realização de estudos que visem a este tipo de investigação, em especial nas áreas de Cerrado nativo.

Dentre as diferentes fitofisionomias do Cerrado, pôde-se observar que algumas delas, como: veredas, palmeirais, parque de Cerrado, campo sujo, campo rupestre e campo limpo, ainda não possuem nenhum tipo de trabalho referente à produção e decomposição da serapilheira, e ainda, a escassez de trabalhos com monitoramentos de longo prazo desta temática apresentam-se como uma linha de pesquisa a ser seguida, uma vez que estudos com breve duração não permitem avaliar os efeitos de alterações sazonais e interanuais que possivelmente estejam correlacionadas com as mudanças climáticas.

A falta de estudos comparativos entre as metodologias apresenta um caminho para pesquisas futuras, pois o preenchimento desta lacuna implicará na possibilidade de comparação dos trabalhos realizados em ambientes semelhantes de forma mais confiável, e até mesmo entre ecossistemas diferentes, caso suas metodologias permitam tais análises.

De forma geral, as metodologias utilizadas nos trabalhos de aporte e decomposição da serapilheira apresentaram alto grau de variação entre si, evidenciando assim, a necessidade da criação de um protocolo único, o qual permitiria a comparação dos estudos, sendo que este deve ser construído com base nos trabalhos já realizados e com encontros dos pesquisadores da área para debater quais os melhores procedimentos.

Com base nos artigos avaliados, sugere-se como metodologia para avaliação da produção de serapilheira que o formato de coletores deva ser quadrado, pois facilita a extrapolação para um hectare, com as frações da serapilheira definidas em: folhas, galhos, partes reprodutivas e miscelânea e com um número mínimo de 10 coletores. Já para os estudos de decomposição, sugere-se litter bags com dimensões de 20 x 20 cm e malha com abertura de 2 mm, com acondicionamento de diferentes matérias (não somente folhas) para se ter uma estimativa mais real das taxas de decomposição da serapilheira como um todo, além de estudos com mais de um ano de avaliação, para evidenciar os efeitos das possíveis alterações interanuais.

2.4 REFERÊNCIAS BIBLIOGRÁFICAS

ALMEIDA, J. C. R. et al., A positive growth response to NaCl applications in Eucalyptus plantations established on K-deficient soils. **Forest Ecology and Management**, Amsterdam, v. 259, p. 1786-1795, 2010.

AQUINO, P. S. R. et al., Análise espacial da produtividade de serapilheira em uma mata de galeria. **Ciência Florestal**, Santa Maria, v. 26, n. 2, p. 489-500, 2016.

BALCH, J. et al., Negative fire feedback in a transitional forest of southeastern Amazonia. **Global Change Biology**, Nova Jersey, v. 14, p. 2276-2287, 2008.

BAMBI, P. et al. Decomposição e redistribuição de nutrientes das folhas de espécies da floresta de transição Amazônia - Cerrado, MT. **Ciência e Natura**, Santa Maria, v. 33, n. 1, p. 17-31, 2011.

BASTOS, L. A.; FERREIRA, I. M. Composições fitofisionômicas do bioma cerrado: estudo sobre o subsistema de Vereda. **Espaço em Revista**, Catalão, v. 12, n. 2, p. 97-108, 2010.

BORENSTEIN, M. et al., **Introduction to metaanalysis**. Londres: Wiley, 2009. 421 p.

BUSTAMANTE, M. M. C. et al. Potential impacts of climate change on biogeochemical functioning of Cerrado ecosystems. **Brazilian Journal of Biology**, São Carlos, v. 72, n. 3, p. 655-671, 2012.

BUTLER, A. et al., Annual variation in soil respiration and its component parts in two structurally contrasting woody savanas in Central Brazil. **Plant and Soil**, Heidelberg, v. 352, p. 129-142, 2012.

CARVALHO, G. H. et al., Are fire, soil fertility and toxicity, water availability, plant functional diversity, and litter decomposition related in a Neotropical savanna? **Oecologia**, Heidelberg, v. 175, p. 923-935, 2014.

CIANCIARUSO, M. V. et al., Produção de serapilheira e decomposição do material foliar em um cerradão na Estação Ecológica de Jataí, município de Luiz Antônio, SP, Brasil. **Acta Botanica Brasilica**, Feira de Santana, v. 20, n. 1, p. 49-59, 2006.

COSTA, C. C. A. et al., Análise comparativa da produção de serrapilheira em fragmentos arbóreos e arbustivos em área de caatinga na Flona de Açu - RN. **Revista Árvore**, Viçosa, MG, n. 34, v. 2, p. 259-265, 2010.

EPRON, D. et al., Do changes in carbon allocation account for the growth response to potassium and sodium applications in tropical. **Tree Physiology**, Oxford, v. 32, p. 667-679, 2011.

EPRON, D. et al., Partitioning of net primary production in Eucalyptus and Acacia stands and in mixed-species plantations: Two case-studies in contrasting tropical environments. **Forest Ecology and Management**, Amsterdam, v. 301, p. 102-111, 2012.

FONTES, M. P. F. Intemperismo de rochas e minerais. In: KER, J. C.; CURI, N.; SCHAEFER, C. E. G. R.; VIDAL-TORRADO, P. (ed.). **Pedologia**: fundamentos. Viçosa, MG: SBCS, 2012, p. 171-202.

FREITAS, J. R.; CIANCIARUSO, M. V.; BATALHA, M. A. Functional diversity, soil features and community functioning: a test in a cerrado site. **Brazilian Journal of Biology**, São Carlos, v. 72, n. 3, p. 463-470, 2012.

GIÁCOMO, R. G.; PEREIRA, M. G.; MACHADO, D. L. Aporte e decomposição de serapilheira em áreas de cerradão e mata mesofítica na estação ecológica de pirapitinga – MG. **Ciência Florestal**, Santa Maria, v. 22, n. 4, p. 669-680, 2012.

GOYA, J. F. et al., Decomposition and nutrient release from leaf litter in Eucalyptus grandis plantations on three different soils in Entre Ríos, Argentina. **Revista Bosque**, Valdivia, v. 29, n. 3, p. 217-226, 2008.

HARIDASAN, M. Nutrição mineral de plantas nativas do cerrado. **Revista Brasileira de Fisiologia Vegetal**, Londrina, v. 12, n. 1, p. 54-64, 2000.

KEUSKAMP J. A. et al., Tea Bag Index: a novel approach to collect uniform decomposition data across ecosystems. Methods. **Ecology and Evololution**, London, v. 4, p. 1070-1075, 2013.

KOZOVITS, A. R. et al., Nutrient resorption and patterns of litter production and decomposition in a Neotropical Savanna. **Functional Ecology**, Londres, v. 21, p. 1034-1043, 2007.

LACLAU, J. P. et al., Biogeochemical cycles of nutrients in tropical Eucalyptus plantations Main features shown by intensive monitoring in Congo and Brazil. **Forest Ecology and Management**, Amsterdam, v. 259, p. 1771-1785, 2010.

LATHWELL, D. J.; GROVE, T. L. Soil-Plant Relationships in the Tropics. **Annual Review of Ecology and Systematics**, Palo alto, v. 17, p. 1-16, 1986.

LOIOLA, P. P.; SCHERER-LORENZEN, M.; BATALHA, M. A. The role of environmental filters and Functional traits in predicting the root biomass and productivity in savannas and tropical seasonal forests. **Forest Ecology and Management**, Amsterdam, v. 342, p. 49-55, 2015.

LOPES, J. F. B. et al., Deposição e decomposição de serapilheira em área da Caatinga. **Revista Agro@mbiente On-line**, Boa Vista, v. 3, n. 2, p. 72-79, 2009.

MIATTO, R. C.; BATALHA, M. A. Leaf chemistry of woody species in the Brazilian cerrado and seasonal forest: response to soil and taxonomy and effects on decomposition rates. **Plant Ecology**, Oxford, v. 217, p. 1467-1479, 2016.

NASCIMENTO, L. S., CERQUEIRA, R. M., HENDERSON, B. L. R. Produção de serapilheira em um fragmento adjacente a uma cava de mineração, Ribeirão Grande, SP. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 19, n. 9, p. 892-897, 2015.

OLIVEIRA, B. et al., Unraveling the ecosystem functions in the Amazonia–Cerrado transition: evidence of hyperdynamic nutrient cycling. **Plant Ecology**, Oxford, n. 218, p. 225-239, 2017.

PAIVA, A. O.; SILVA, L. C. R.; HARIDASAN, M. Productivity-efficiency tradeoffs in tropical gallery forestsavanna transitions: linking plant and soil processes through litter input and composition. **Plant Ecology**, Oxford, v. 216, p. 775-787, 2015.

PARRON, L. M.; BUSTAMANTE, M. M. C.; MARKEWITZ, D. Fluxes of nitrogen and phosphorus in a gallery forest in the Cerrado of central Brazil. **Biogeochemistry**, Heidelberg, v. 105, n. 1-3, p. 89-104, 2011.

PEGORARO, R. F. et al., Fenóis derivados da lignina, carboidratos e aminoaçúcares em serapilheira e solos cultivados com eucalipto e pastagem. **Revista Árvore**, Viçosa, MG, v. 35, n. 2, p. 359-370, 2011.

PICKERING, C. M.; BYRNE, J. The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early career researchers. **Higher Education Research and Development**, Londres, v. 33, p. 534-548, 2014.

POGGIANI, F. Estoques e transferências de nutrientes nos ecossistemas. In: MARTINS, S. V. **Ecologia de florestas tropicais do Brasil**. Viçosa, MG: Editora UFV, 2012. p. 175-242.

QUESADA, C. A. et al., Seasonal variations in soil water in two woodland savannas of central Brazil with different fire history. **Tree Physiology**, Oxford, v. 28, p. 405-415, 2008.

RIBEIRO, J. F.; WALTER, B. M. T. As principais fitofisionomias do Bioma Cerrado. In.: SANO, S. M.; ALMEIDA, S. P.; RIBEIRO, J. F. **Ecologia e flora**. Brasília: EMBRAPA, 2008. p. 152-212.

RUBIM, P.; NASCIMENTO, H. E. M.; MORELLATO, L. P. C. Variações interanuais na fenologia de uma comunidade arbórea de floresta semidecídua no sudeste do Brasil. **Acta Botânica Brasilica**, São Paulo, v. 24, n. 3, p. 756-762, 2010.

SANCHES, L. et al., Dinâmica sazonal da produção e decomposição de serrapilheira em floresta tropical de transição. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 13, n. 2, p. 183-189, 2009.

SANTANA, J. A. S. et al., Decomposição da biomassa foliar de cana-de açúcar em um neossolo na região de areia - PB. **Revista Caatinga**, Mossoró, v. 24, n. 3, p. 28-32, 2011.

SCORIZA, R. N. et al. Métodos para coleta e análise de serapilheira aplicados à ciclagem de nutrientes**. Floresta e Ambiente**, Seropédica, v. 2, n. 2, p. 01-18, 2012.

SETALA, H.; MARSHALL, V. G.; TROFYMOW, J. A. Influence of body size of soil fauna on litter decomposition and 15N uptake by poplar in a pot trial. **Soil Biology and Biochemistry,** Amsterdam, v. 28, n. 12, p. 1661-1675, 1996.

SILVA, C. J. et al. Contribuição de folhas na formação da serrapilheira e no retorno de nutrientes em floresta de transição no norte de Mato Grosso. **Acta amazônica**, Manaus, v. 39, n. 3, p. 591-600, 2009.

SILVA, C. J. et al., Produção de serrapilheira no Cerrado e Floresta de Transição Amazônia-Cerrado do Centro-Oeste Brasileiro. **Acta amazônica**, Manaus, v. 37, n.4, p. 543-548, 2007.

SILVA, P. H. M.; POGGIANI, F.; LACLAU, J. P. Applying sewage sludge to eucalyptus grandis plantations: effects on biomass production and nutrient cycling through litterfall. **Applied and Environmental Soil Science**, London, v. 2011, p. 1-11, 2011.

SOUTO, P. C. et al., Características químicas da serapilheira depositada em área de caatinga. **Revista Caatinga**, Mossoró, v. 22, n. 1, p. 264-272, 2009.

VALENTI, M. W.; CIANCIARUSO, M. V.; BATALHA, M. A. Seasonality of litterfall and leaf decomposition in a cerrado site. **Brazilian Journal of Biology**, São Carlos, v. 68, n. 3, p. 459-465, 2008.

VILLALOBOS-VEJA, R. *et al*. Leaf litter manipulations alter soil physicochemical properties and tree growth in a Neotropical savana. **Plant and Soil**, Heidelberg, v. 346, p. 385-397, 2011.

ZIMMERMAN, J. K. *et al*. Flowering and fruiting phenologies of seasonal and aseasonal neotropical forests: the role of annual changes in irradiance. **Journal of Tropical Ecology**, Cambridge, v. 23, p. 231-251, 2007.

WIEDER, R. K.; LANG, G. E. A critique of the analytical methods used examining decomposition data obtained from litter bags. **Ecology**, Washington, v. 63, p. 1636-1642, 1982.

WILCKE, W.; LILIENFEIN, J. Biogeochemical consequences of the transformation of native Cerrado into Pinus caribaea plantations in Brazil. **Plant and Soil**, Heidelberg, v. 238, p. 175-189, 2002.

3 CAPÍTULO II*

LINKING SOIL BIODIVERSITY AND ECOSYSTEM FUNCTION IN A NEOTROPICAL SAVANNA

ABSTRACT

Conserving the remaining savanna ecosystems in the Brazilian savanna (Cerrado) — a global biodiversity hotspot that stores carbon and provides water to a large portion of South America — requires understanding the ecological processes maintaining their function. Nutrient cycling supports savanna function via plant litter production and decomposition by soil fauna, releasing nutrients for plant and soil organism uptake. Little is known about how litter dynamics relate to soil biodiversity and biogeochemistry in Neotropical savannas under a changing climate. Here, we combined two years of rainfall seasonality, leaf and wood litter production and decomposition with soil epigeic fauna abundance — the number of ground-surface dwelling invertebrates collected through pitfall traps — taxa richness, Shannon's diversity and Pielou's evenness, and 16 soil biogeochemical variables measured in 12 plots of preserved savanna. Rainfall seasonality modulated the mean soil epigeic fauna diversity and evenness across all plots, which were greatest in the rainy season, in contrast to litterfall rates which peaked in the dry season. In the dry season (April to September), the Formicidae family was the most abundant with 50% of all individuals, while in the rainy season (October to March) the Isoptera order was the most abundant with ~39% of individuals. Wood litter decomposition strongly related with Hemiptera abundance and grouped with soil epigeic fauna diversity and evenness per plot, in opposed quadrants to soil fertility variables, while leaf decomposition co-varied with the total epigeic fauna abundance and soil pH. We speculate that the specific need to decompose wood litter may be associated with a greater need for diversity than an abundance of soil epigeic fauna. Our work highlights the role of rainfall seasonality on soil biodiversity and physicochemistry, which are also tightly linked with litter production and decomposition. This study advances our understanding of the mechanisms governing nutrient cycling in savanna ecosystems on nutrient-

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impoverished soils, with implications for achieving sustainable conservation and restoration goals.

Keywords: Biodiversity; Community ecology; Epigeic fauna; Nutrient cycling; Soil carbon; Soil ecology; Cerrado.

Highlights

- Rainfall seasonality modulates soil epigeic fauna composition in a Brazilian savanna.
- Wood and leaf litter decomposition rates are statistically similar and very low.
- Soil epigeic fauna diversity positively relates to wood litter decomposition.

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3.1 INTRODUCTION

The Brazilian savanna (Cerrado) is the second-largest biome in South America, covering nearly 21% (~1.8 million km²) of Brazil's territory. As one of the world's hotspots for biodiversity conservation, the Cerrado has high species endemism, heterogeneity of landscapes, and faces rampant human threat (Morandi et al., 2018; Myers et al., 2000; Strassburg et al., 2020); between 2008 and 2012, annual deforestation rates were twice as those in the Brazilian Amazon (Lambin et al., 2013). Also, less than half of the original land covered by Cerrado ecosystems is still conserved (Zuin, 2020), which jeopardizes their role in the water and carbon cycles (Arantes et al., 2016; Brasil, 2018). Reducing greenhouse gas emissions by avoiding deforestation can provide a monetary incentive through REDD+ initiatives in Cerrado areas (Gallo and Albrecht, 2019).

Conserving, sustainably managing, and actively restoring native Cerrado ecosystems depend on understanding the ecological processes that maintain their function and ecosystem service provision (Buisson et al., 2020; Morandi et al., 2018). A critical ecosystem process is litterfall, which is the main conduit for nutrient recycling in systems on highly-weathered, nutrient-poor soils covering 46% of the Cerrado (Djukic et al., 2018). For instance, litter production and its decomposition explain over 3.6 tons of carbon uptake per hectare in Cerrado savanna ecosystems (*e.g.*, cerrado *sensu stricto*)

(Park et al., 2020; Pompeo et al., 2016). Litterfall is highly seasonal in savanna ecosystems in the Cerrado, with the highest rates occurring at the end of the four-to-seven-month dry season (Bustamante et al., 2012). Nevertheless, several biotic and abiotic factors control litter dynamics, especially those related to ecosystem structure and composition, soil fertility, and climate variables such as rainfall, wind speed, and relative humidity (Ferreira and Uchiyama, 2015; Giweta, 2020). Thus, understanding the patterns of and controls on litterfall and its role in nutrient cycling in savanna ecosystems in the Cerrado is essential to restore and conserve those ecosystems in a changing climate.

Soil organisms are critical decomposers of senesced plant materials, converting litter nutrients into mineral nutrients incorporated into the soil solution and taken up by plants for growth and development (Garlet et al., 2019; Lavelle et al., 1993; Pritchett, 1979). The edaphic organisms are composed of individuals that remain at least part of their life cycle in the soil (Swift et al., 1973). However, some of these emerge after the larval phases and become exclusively epigeic. Therefore, soil organism classifications are important for the various ecological compartments and provision of essential ecosystem services such as organic matter decomposition.

In general, the soil fauna (meso and macrofauna) explains about 7% of litter decomposition through fragmentation (Wall et al., 2008), contributing to biological balance through microorganism consumption and food provision for other fauna groups. It is essential to investigate the ecological role of soil fauna diversity and abundance, which is also a useful environmental quality indicator (Rosa et al., 2015; Zagatto et al., 2017). Because so many processes are conducted and affected by these organisms — such as nutrient cycling, waste decomposition, soil aggregation, climate regulation, pathogen resistance — understanding these communities is essential for ecosystem conservation practices (Guerra et al., 2021). Still, little is known about soil epigeic fauna communities and their links with litter decomposition, and how climate drivers and soil properties can alter litter production and decomposition rates, in turn affecting those soil communities in savanna ecosystems.

Litter decomposition rates are generally empirically estimated through decomposition bags, where the leaf fraction is stored and left in the field to measure the decay rate (Olson, 1963). This method is limited by not considering the decomposition rate of all litter fractions separately. A recent systematic review on Cerrado litter decomposition (Inkotte et al., 2019) indicated a lack of studies quantifying wood decay rates in Cerrado ecosystems. However, fractions other than leaves, especially fine wood, can make up to 30–40% of the total plant material deposited on the soil (Correia and Andrade, 2008). This knowledge gap is concerning because quantifying fine wood decomposition rate is necessary to fully comprehend nutrient recycling patterns in Cerrado ecosystems on nutrient-poor soils.

Our main objective in this study was to investigate biodiversity-ecosystem function relationships in a Neotropical savanna ecosystem. We related soil epigeic fauna community metrics to litter production, leaf and wood litter decomposition, 16 soil biogeochemical variables, and their relationships with rainfall in central Brazil. Specifically, we aimed at answering the following questions: i) How are litterfall and soil epigeic fauna diversity, richness, abundance and evenness affected by rainfall seasonality?; ii) Do leaf and wood litter decomposition rates differ?; and iii) Do leaf and wood decay rates correlate with soil epigeic fauna metrics and biogeochemistry? We hypothesized that: (H_1) Litterfall and soil epigeic fauna diversity and abundance vary seasonally, increasing during the rainy season; (H_2) Wood decomposition is slower than leaf decomposition; and that (H_3) Leaf litter decomposition correlates positively with soil epigeic fauna abundance, diversity, and soil fertility.

3.2 METHODS

3.2.1 Study area

This study was conducted at the University of Brasilia's research station (Fazenda Água Limpa; 15°56 '–15°59' S and 47°55'–47°58' W), which covers over 4.3 thousand hectares of Brazilian savanna. Located within UNESCO’s Cerrado Biosphere Reserve, about 86% of the research station is preserved, and 45% is covered by native savanna vegetation (dense savanna woodland) known as cerrado *sensu stricto* (Felfili et al., 2000). The region's climate is classified as AW, according to Köppen’s classification, with well-defined dry (May to October) and rainy (October to March) seasons. The mean annual precipitation is 1552 mm, with monthly means ranging from 9 mm in June to 249 mm in December. Monthly mean temperatures range from 19ºC in June to 21.4ºC in December (Nimer, 1989). Soils at the research station are mainly deep Oxisols (Soil Survey Staff, 2010) or Red Latosols (EMBRAPA classification system - Santos et al., 2018) on flat terrain, characterized by high acidity and low nutrient (*e.g.*, phosphorus-P) availability (Haridasan, 2008).

Within ~1.929 ha of preserved cerrado *sensu stricto*, we randomly selected 12 20 m × 50 m plots following previously established protocols (Felfili et al., 2000), in a total of 1.2 hectares (Figure 1). In each plot, litterfall and soil samples were collected, soil epigeic fauna abundance, diversity, richness (number of taxa) and evenness were quantified, and litter decomposition rates were measured for two years between 2018 and 2020. On average, each plot contained a woody basal area of 13.11 m^2 ha^{-1}, ~156 woody individuals, and 36 woody species (Mota, 2017). To the best of our knowledge, only an accidental fire occurred in 2011 within the studied area, a typical disturbance in savanna ecosystems in the Cerrado.

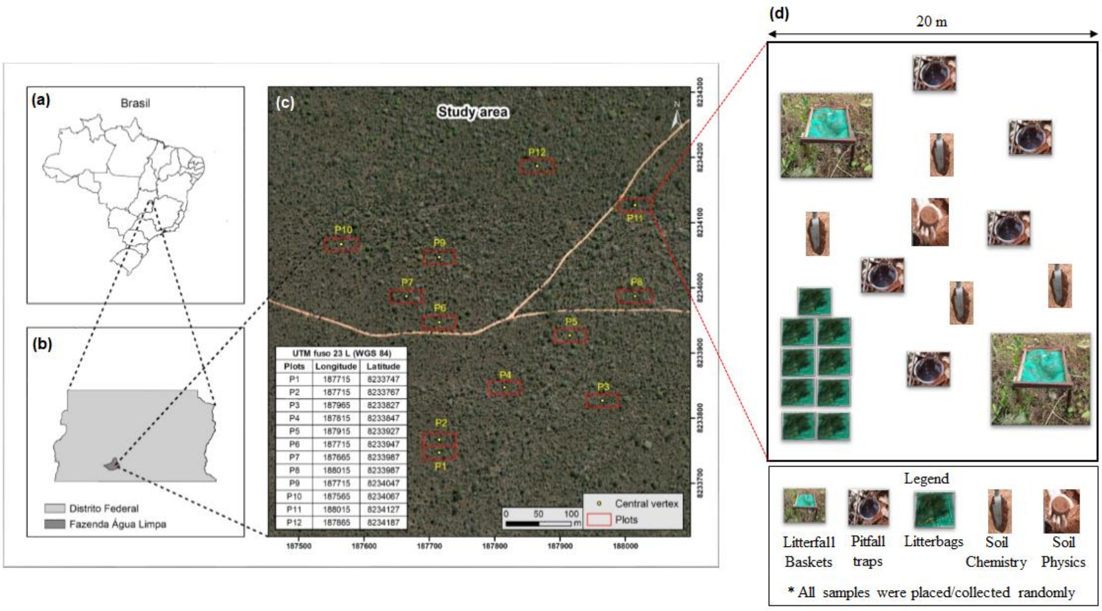

Figure 1, Study site location in Brazil's Federal District, and the 12 plots randomly distributed within an area of preserved native savanna (cerrado *sensu stricto*) at the University of Brasilia's research station.

3.2.2 Soil epigeic fauna sampling and biogeochemical measurements

We assessed soil epigeic fauna abundance and composition during the dry (September 2018) and rainy (January 2020) seasons. A total of sixty (five per plot) plastic pitfall traps containing ~ 200 ml of water and 10 ml of colorless neutral detergent — sensu Baretta et al. (2007) — were deployed near the decomposition bags (15-cm diameter; described in 2.4). All traps were left in the field for 48 hours, after which they were collected and taken to the laboratory for manual separation of organisms using a 0.125-mesh sieve. All organisms were transferred to flasks containing absolute ethyl alcohol for fixation. Soil epigeic fauna organisms were identified at the highest possible taxonomic level (genera, order, or family whenever possible) using a magnifying lens and taxonomic keys. Individuals in the larval phase were designated as ‘others’, as their identification was not possible. Our choice of collection method, similar to other studies (*e.g.*, Vanolli et al., 2021), was due to most epigeic fauna groups being found in the litter-soil interface.

To quantify key soil biogeochemical variables, we collected four soil samples at three depths (0–20, 20–40, and 40–60 cm) per plot and combined them in one sample per depth per plot. After the sampling, soils were air-dried in the shade and then analyzed according to (EMBRAPA, 1998): Exchangeable aluminum (Al^{3+}) and potential acidity (H + Al) by titration. Phosphorus (P_{av}) and potassium (K) by Mehlich-1 extractor, where remaining P (P_{rem}) was determined using molecular absorption spectrophotometer as well as calcium (Ca^{2+}) and magnesium (Mg^{2+}), and K by photometer of flame. Soil organic matter (SOM) was determined by Walkley and Black (1934). For all samples, we calculated the total cation exchange capacity (CECt), effective cation exchange capacity (CECe), the sum of bases (SB), base saturation (V), and aluminum saturation (m). The studied soils are the typical nutrient-poor Oxisols in central Brazil (Haridasan, 2008). The low levels of exchangeable cations, especially Ca^{2+} and Mg^{2+}, reflected the soil's acidic nature, which negatively affected SB, CEC, and V. See Appendix A for additional information.

3.2.3 Soil physical measurements and SOC stock calculation

We randomly selected three plots to sample soils every four months in randomly selected points where trenches of 40 cm × 40 cm × 100 cm (160 L) were opened. Soil samples were collected and measured following (EMBRAPA, 2011) at the 0-20 and 20-40 cm depths using a volumetric steel ring (88.60 cm^3). Then, samples were transported to the laboratory to determine their wet weight and were then oven-dried at 105ºC until constant weight. Volumetric moisture ($m^3\ m^{-3}$), soil density ($g\ cm^{-3}$), gravimetric moisture ($g\ cm^{-3}$) content, and total porosity ($kg\ dm^{-3}$)

Soil organic carbon (SOC) was calculated as soil organic matter concentration in $g\ kg^{-1}$ divided by 1.724 (Walkley and Black, 1934). Soil C stock was calculated in $Mg\ C\ ha^{-1}$ following Usuga et al. (2010): SOC stock = (SOC × BD × d)/10, where SOC is the concentration of soil organic carbon at a given soil depth in $g\ C\ kg^{-1}$, BD is bulk density in $g\ cm^{-3}$, and d is soil layer depth in cm (Table 1).

Table 1. Soil physical variables and carbon stocks measured in the studied savanna.

Depth (cm)	Bulk density (kg dm^{-3})	Gravimetric moisture (g cm^{-3})	Volumetric moisture (m^3 m^{-3})	Total porosity (kg dm^{-3})	SOC stock (Mg ha^{-1})	SOM (dag kg-1)
0–20	0.85	34.04	29.12	67.77	48.9	4,94
s.e.	0.01	1.97	2.30	1.50	1.33	0,73
20–40	0.96	32.36	30.93	63.67	39.36	3,18
s.e.	0.02	1.39	1.34	0.71	1.44	0,59

s.e. = Standard error

3.2.4 Litter decomposition rates

Leaf and wood decomposition rates were measured following Olson (1963). Briefly, 20 g of each freshly deposited leaf and fine wood (< 1 cm diameter) litter fraction were collected on the soil surface of each plot (IFN, 2015). Both leaf and wood litter were confined in 20 cm × 20 cm litter decomposition bags made with 2-mm mesh nylon. The collections were carried out with one litterbag per plot at 30, 60, 120, 240, 365 days after litter bags were randomly placed on the ground (between May 2018 and April 2019). As a result, a total of 120 litterbags (2 types × 5 sampling dates × 12 replicates) were used. After each litter bag collection, the remaining leaf and wood material was taken to the research station's laboratory. Then, roots and soil were removed from the litter materials using a brush, and litter mass was determined by weighing before and after oven drying at 65°C until reaching constant weight. Leaf and wood decomposition rates (k) were calculated by decay rates: Remaining mass (%) = (final mass - initial mass) × 100.

The decomposition rate *k* indicates the annual mass loss, while the half-life proposed by Olson (1963) indicates the time required for 50% of the initial mass stored in the bags to decay, as following: $X_t = X_0 \times e^{-kt}$, where X_t is the dry weight of the remaining litter after t days and X_0 is the dry weight of litter material at t = 0, and $T_{1/2} = \ln(2)/k$, where $T_{1/2}$ is the number of days needed to decay 50% of the initial mass, ln is the natural logarithm and *k* is the decomposition rate.

3.2.5 Monthly litterfall sampling and climate data compilation

Litterfall was collected monthly for two years (from May 2018 to April 2020) from two replicated baskets (50 cm × 50 cm) (Scoriza et al., 2012) randomly placed inside each of the 12 plots. All senesced plant material deposited monthly in each basket was carefully collected and placed in paper bags in a total of 576 samples (12 plots × 2 replications × 24 sampling dates). Litterfall samples were oven-dried at 65ºC until constant weight and immediately sorted into the following fractions: leaves, reproductive parts (*i.e.*, fruits, flower, and seeds), fine wood (diameter < 1cm), and miscellaneous (unidentifiable plant material). Each fraction was weighed, and the relative contribution to monthly total litterfall rates was estimated by extrapolating the results to Mg ha^{-1} $month^{-1}$.

Rainfall rates were obtained from manual and automatic stations controlled by Brazil's National Meteorological Institute (INMET, 2020) through daily observations. Because this variable may influence litter production and decomposition, and soil epigeic fauna composition, the data obtained were used as a predictive variable in this study.

3.2.8 Statistical Analysis

Calculations and graphical output were produced in R (version 3.6.2; R Core Team, 2019). We utilized package vegan to calculate: Shannon's diversity (h'; *biodiversity* function), taxa richness (S; the number of taxonomic groups using the *specnumber* function), Pielou's evenness index [J; J = h'/ log(S)], and total and relative abundances of soil epigeic fauna organisms per plot (ODUM, 1969) for both dry and rainy seasons. The seasonal plot means of these community variables were compared by t-tests. Pearson's correlation coefficients were calculated to verify the relationships between soil epigeic fauna community variables, monthly total litterfall and leaf fall, and mean monthly rainfall during the dry and rainy seasons. Soil chemical properties were compared by analysis of variance (one-way ANOVA) and Tukey's HSD test after assessing for normality using the Shapiro-Wilk's test. When normality was not achieved after transformations, a Kruskal-Wallis test was used. The remaining mass of leaf and wood litter in the decomposition bags was compared by t-test. A 95% confidence level was considered in all statistical tests.

A Mantel test for spatial autocorrelation (*mantel.rtest* function in package *ade4* with 999 permutations) was conducted on two distance matrices: One containing spatial distances among plots — latitude and longitude of each plot — and another containing distances among annual abundances of epigeic fauna — the sum of the dry and rainy season total abundances per plot. No spatial autocorrelation among plots was detected (r

= 0.08, p-value = 0.30). We then conducted non-metric multidimensional scaling (NMDS) ordinations (*metaMDS* function) based on Bray-Curtis dissimilarity (*vegdist* function) and standardized data (Legendre, 2008) to compare: i) the mean abundances of soil epigeic fauna groups per plot between seasons, and ii) the annual abundances of soil fauna groups among plots. Statistically significant differences in clustering by season were determined by permutational multivariate analysis of variance (PERMANOVA) calculated with the *adonis2* function (Dixon and Palmer, 2003). The soil epigeic fauna group vectors that were significant at the 95% confidence level (group scores obtained by the *envit* function with 999 permutations) were plotted as arrows on the seasonal and annual NMDS ordinations.

A Principal Component Analysis (PCA) was conducted to ordinate the plots regarding the main drivers of variation in soil physicochemistry, epigeic fauna community variables, and litter decomposition. We included leaf and wood k rates after 720 days of the experiment to match the soil collections during both years of this study. We averaged the mean soil diversity and evenness per plot of both dry and rainy seasons and calculated the total abundance per plot (sum of both seasons) to avoid non-integer numbers and to represent the number of organisms counted per plot. Preliminary soil PCAs were run using standardized data matrices to select the critical variables for the final PCA. In the preliminary PCA, low (< 1.0) eigenvalues (Peña-Claros et al., 2012) were found for all parameters except leaf and wood k, pH, available P, H+Al, SB, CECe, SOM, SOC stock, and mean diversity, evenness and annual total abundance per plot — which were included in the final PCA. Finally, we plotted the final soil variables that were significant at the 95% confidence level (group scores from function *envit* with 999 permutations) as arrows into the annual NMDS ordination to verify the relationships (annual scale) among soil epigeic fauna groups with soil chemistry and litter decomposition rates.

3.3 RESULTS

3.3.1 Seasonal variation in soil epigeic fauna abundance and diversity

We found marked seasonal differences in the mean epigeic fauna Shannon's diversity and Pielou's evenness per plot ($p < 0.05$), but not in total abundance or taxonomic group richness (Figure 2). Across all 12 plots, Shannon's diversity was highest in the rainy season, with values ranging from 0.78 to 1.753 and a plot average of 1.41, representing 15 taxonomic groups across all plots. Taxa richness per plot ranged from 7 to 11, with a mean value of 9 taxa per plot. Pielou's evenness, indicating the uniformity of soil epigeic fauna, ranged from 0.84 to 0.34 with a plot average of 0.66. In the dry season, diversity ranged from 0.37 to 2.12, with a plot average of 1.01, representing a total of 23 orders and classes. Taxa richness per plot ranged from 5 to 17, with an average of 10 taxa per plot. Pielou's evenness ranged from 0.17 to 0.75 with a plot average of 0.44.

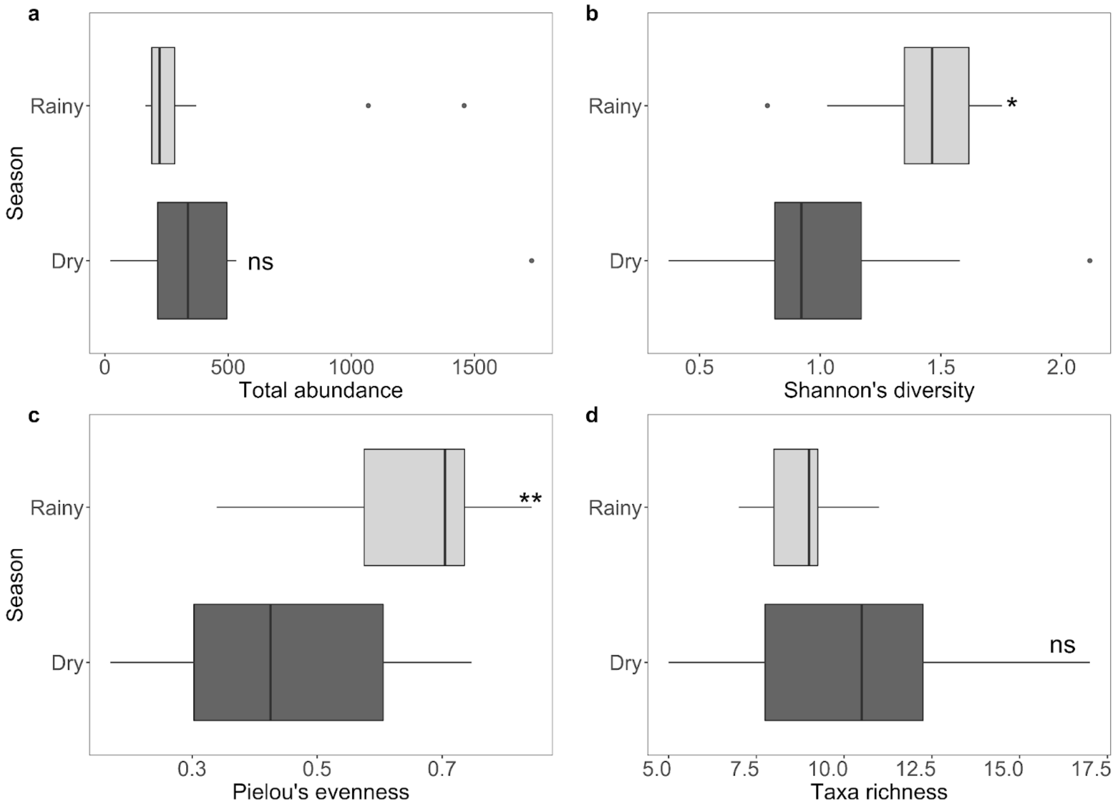

Figure 2. Seasonal variation in the soil epigeic fauna community in 12 plots of typical Brazilian savanna (cerrado sensu stricto) in central Brazil. **(a)** Total soil epigeic fauna abundance (total number of individuals per plot). **(b)** Shannon's diversity and **(c)** Pielou's evenness means per plot. **(d)** Total number of taxonomic groups. In each box, the middle band is the median value of 12 plots, and the top and bottom of the box are the first and third quartiles, respectively. Whiskers indicate the maximum and minimum values. Points outside the whiskers range are outliers. One asterisk denotes significant difference between seasons at the 95% confidence level, two asterisks indicate difference at the 99% confidence level, and 'ns' denotes no significant difference by t-tests.

In the rainy season, we counted 5,140 individuals of soil epigeic fauna in all 12 plots, averaging 428 per plot. Isoptera was the most abundant order with 2,021 individuals, followed by Collembola and the Formicidae family, with 995 and 819 individuals, respectively (Figure 3a). We counted a total of 4,763 soil epigeic fauna individuals during the dry season, averaging 397 per plot. Overall, the Formicidae family was the most abundant taxonomic group in our study, with 2,377 individuals, followed by Isoptera (1907) and Araneidae (363) (Figure 3b).

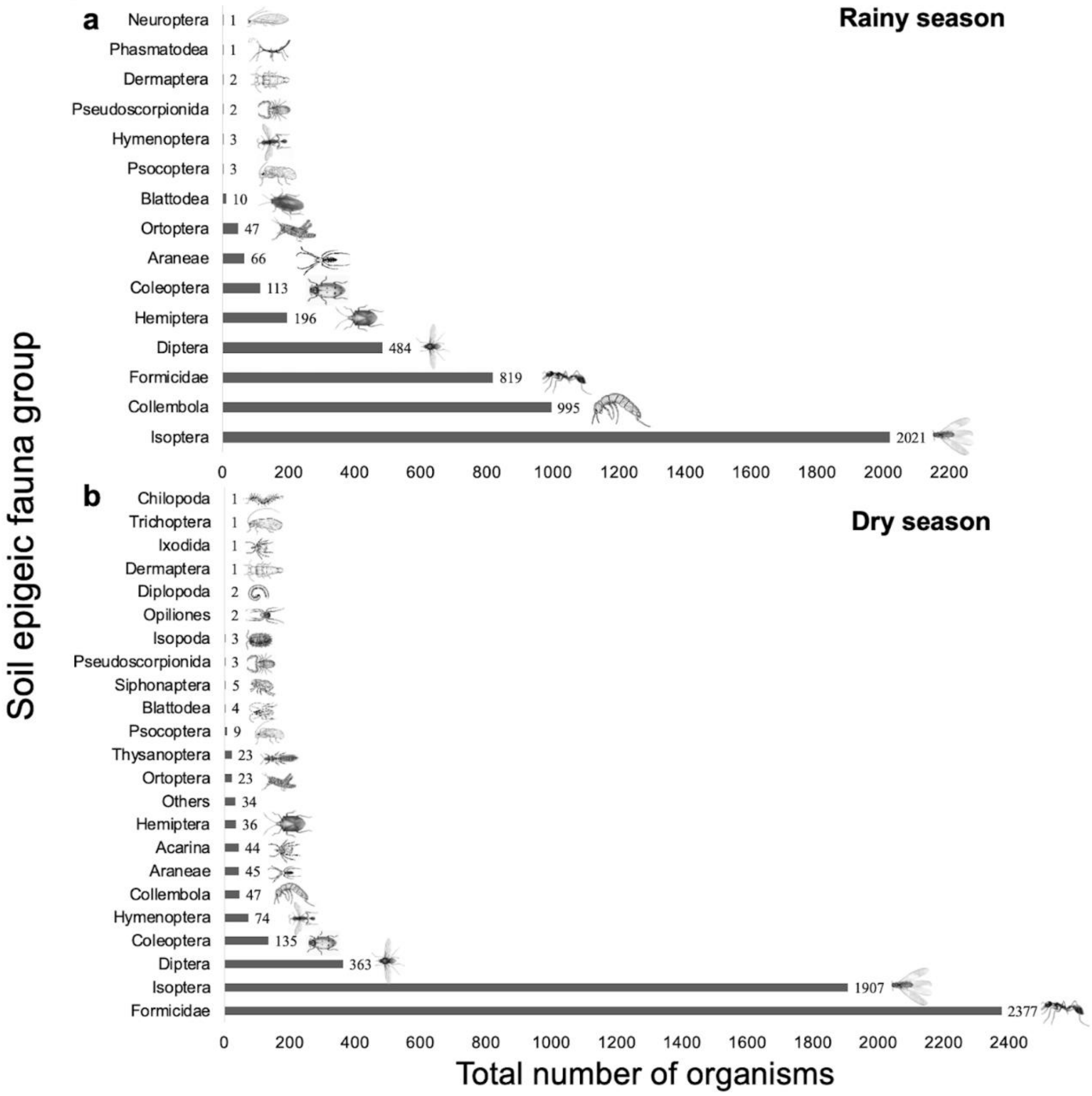

Figure 3. Soil epigeic fauna abundance (x axes) per taxonomic group (y axes) in **(a)** the rainy and **(b)** dry seasons in a typical savanna ecosystem in central Brazil. ‘Others’ indicate individuals in the larval phase, as their identification was not possible.

3.3.2 Correlations among rainfall, soil epigeic fauna and litterfall

Mean monthly rainfall correlated ($p < 0.05$) positively with Shannon’s diversity ($r = 0.47$) and Pielou’s evenness ($r = 0.55$; Figure 4). Rainfall correlated ($p < 0.05$) negatively with mean monthly leaf fall ($r = -0.88$) and total litterfall rates ($r = -0.84$).

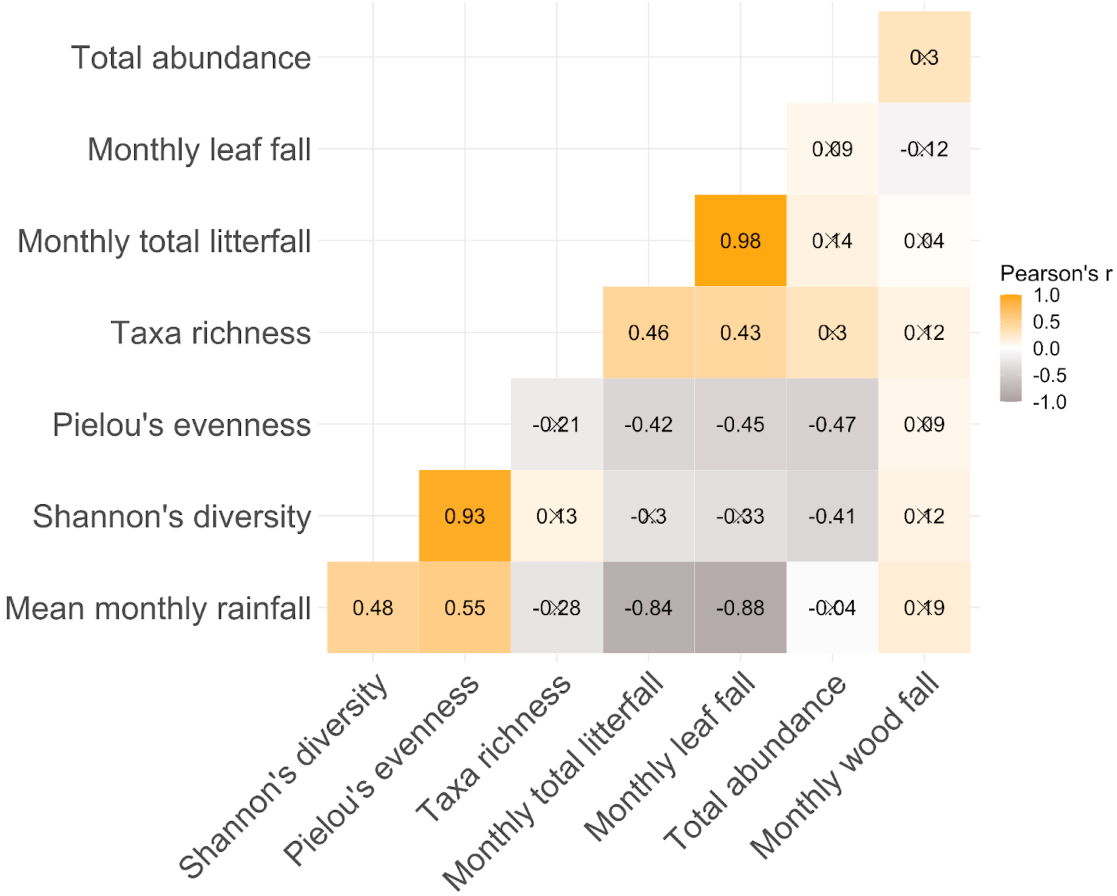

Figure 4. Pearson's correlation coefficients among rainfall, litter production and decomposition rates, and soil epigeic fauna community variables measured in a typical savanna ecosystem in central Brazil. Crossed squares indicate non-significance at the 95% confidence level.

Total annual litterfall in the first year (2018-2019) was 2.72 Mg ha^{-1}, where 81.5% were composed of leaves, 7.1% fine wood, 9.4% reproductive material, and 1.4% miscellaneous (*i.e.*, non-identifiable plant material). In the second sampling year (2019-2020), the total annual litterfall was 3.09 Mg ha^{-1}, where 83.9% were leaves, 9% fine wood, 6.1% reproductive parts, and 0.9% miscellaneous (Figure 5).

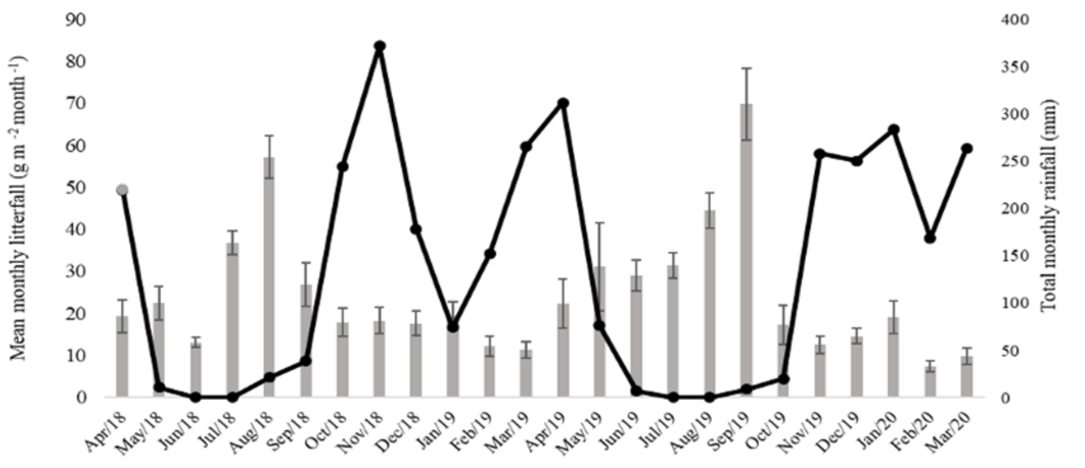

Figure 5. Mean monthly total litterfall (bars) and total monthly rainfall (line) from April 2018 to March 2020. Error bars indicate standard erros.

3.3.3 Leaf and wood decomposition rates

Leaf and fine wood litter decomposition rates (*k*) were statistically similar, with mean annual *k* rates of 0.006 for all plots for both fractions (Figure 6). Regarding litter half-life, leaf litter would lose 50% of the initial mass after 531 days and wood litter after 495 days of exposure. Comparing the remaining mass of both litter fractions during the whole study (five samplings), we did not find a significant difference between leaf and fine wood *k* rates ($p = 0.15$).

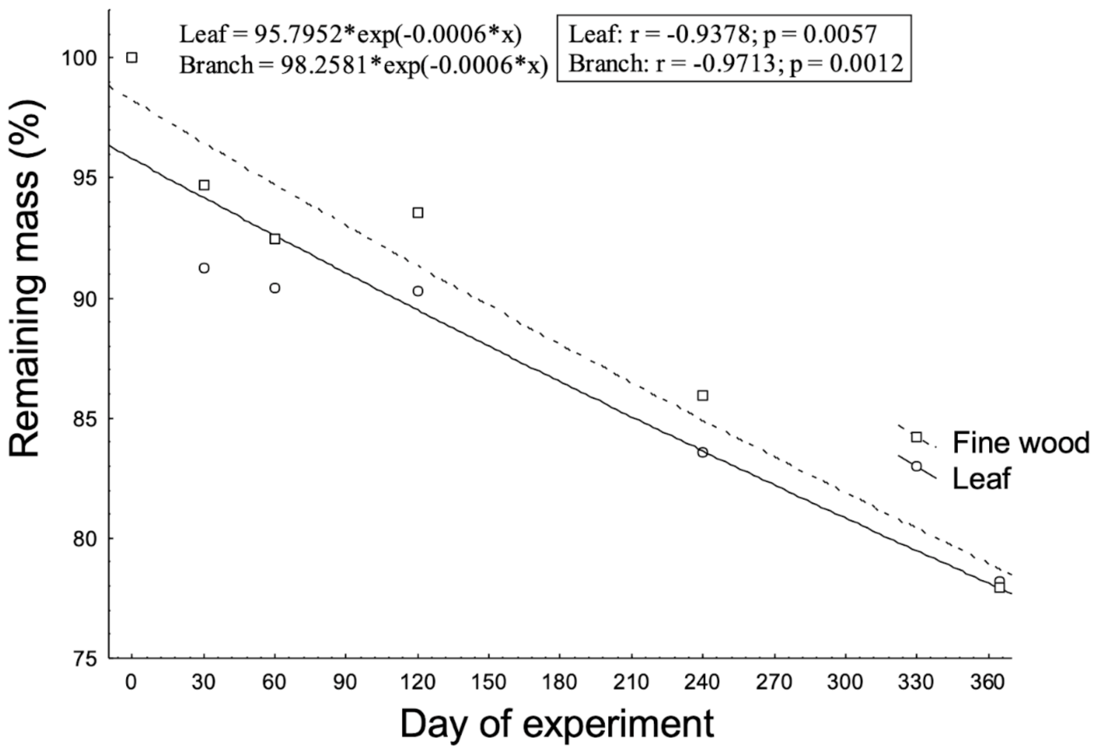

Figure 6. Leaf and fine wood decomposition rates during 365 days of the experiment in the studied savanna in Central Brazil.

However, we observed different temporal patterns in leaf and wood decomposition. Leaf decomposition was highest after 30 days of exposure, when 8.7% of the initial mass had decayed (~1.74g). In contrast, wood litter presented the highest decomposition after 120 days, decomposing ~1.51 and 1.60g on 240 and 365 days, respectively. During the dry season (from May to August – 30 to 120 days exposure), leaf and wood litter decomposition remained almost inactive, decomposing only 0.97% and 2.2%, respectively.

3.3.4 NMDS and PCA of litter decomposition, soil epigeic fauna and physicochemistry

The NMDS of plot-level soil epigeic fauna abundances showed a significant distinction among the dry and rainy seasons (Figure 7a), where season significantly explained 33% of the variance in epigeic fauna abundance (PERMANOVA p = 0.001; Appendix B). We noted that Hemiptera and Collembola groups, as well as epigeic fauna evenness and diversity strongly associated with rainy season collections (Figure 7b). By contrast, Formicidae, total litterfall and leaf fall were more associated with dry season sampling, and Isoptera was closely associated with the total abundance of epigeic fauna per plot.

A PCA of litter decomposition and soil epigeic fauna and physicochemical variables explained 66.4% of the variance on the first two principal components (Figure 7c; Appendix B). PC1 explained 47.4% and PC2 explained 19% of the variation. PC1 included soil fertility variables co-varying in the opposite direction relative to fine wood decomposition and Shannon's diversity and Pielou's evenness. PC2 included the highest rates of leaf litter decomposition positively associated with soil pH and epigeic fauna abundance. Out of these soil and litter variables included in the PCA, wood decomposition was strongly associated with Hemiptera, while Isoptera, the most abundant group in the rainy season, was associated with epigeic fauna abundance (Figure 7d).

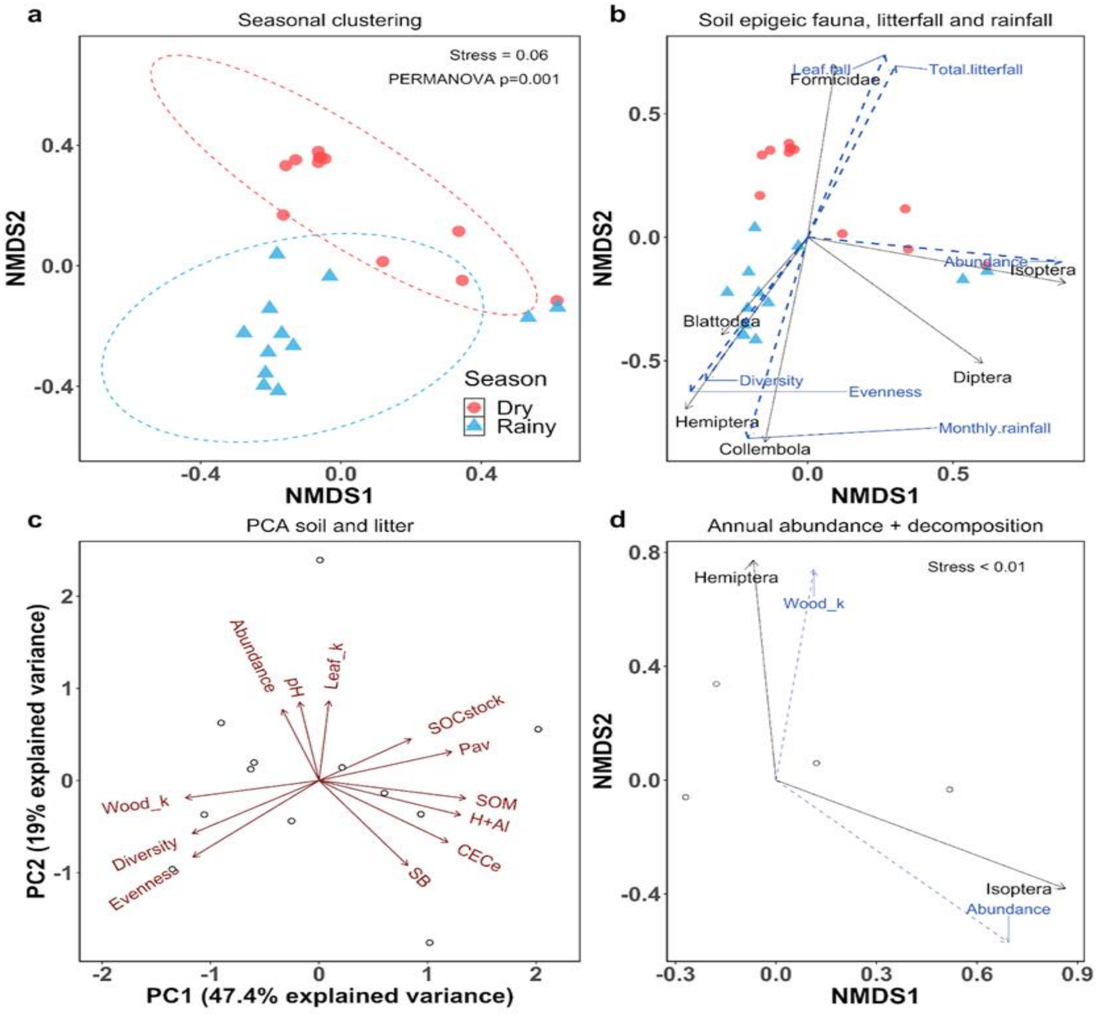

Figure 7. (a) Seasonal NMDS clustering of soil epigeic fauna communities. The stress value of the ordination is indicated. Ellipses indicate the 95% confidence interval of the group centroids. Each point indicates a plot, in a total of 12 for each season. **(b)** Seasonal NMDS including the soil epigeic fauna taxa and community metrics, litterfall and rainfall

vectors that were significant at the 95% confidence level. **(c)** Principal component analysis (PCA) of annual soil epigeic fauna abundance, Shannon's diversity and Pielou's evenness, leaf and wood decomposition rates (k at 720 days), soil organic matter (SOM in dag kg^{-1}), sum of bases (SB in cmolc dm^{-3}), effective cation exchange (CECe in cmolc dm^{-3}), potential acidity (H+Al in cmolc dm^{-3}), available phosphorus (P_{av} in mg dm^{-3}) and pH. Each point represents the plot averages of these variables, in a total of 12 plots. PC1 (x-axis) explained 47.4%, and PC2 (y-axis) explained 19% of the total variance in the soil and litter data. **(d)** Annual NMDS including soil epigeic fauna taxa (total abundance per plot) and the variables from (c) that were significant at the 95% confidence level. The stress value of the ordination is indicated. The statistical results of the NMDS's and PCA are listed in Appendix B.

3.4 DISCUSSION

3.4.1 Seasonal variation in soil epigeic fauna diversity and abundance

Our results suggest that soil epigeic fauna diversity and evenness, but not abundance and taxa richness, in the studied savanna ecosystem are positively influenced by rainfall and soil water content. We expected rainfall seasonality to influence soil epigeic fauna diversity and abundance because these are generally related to soil type, climate, and vegetation (Lavelle and Pashanasi, 1989; Pinheiro et al., 2002; Sobreira et al., 2020), although studies in the Cerrado are scarce. Soil fauna is also regulated by soil temperature — not measured in our study — and moisture, determining its spatial and temporal patterns (Lavelle and Spain, 2001). Our results make sense because while heavy rainfall events can cause physical damage during flight, reduce foraging efficiency, and increase migration, dry periods can lead to the desiccation of invertebrates that live at the soil-litter interface and decrease egg and larvae viability and survival (Torode et al., 2016).

Although our dry season collections presented a non-significantly higher number of soil epigeic fauna taxa, the mean Shannon's diversity and Pielou's evenness across all plots were highest during the rainy season. This may be explained by the fact that Shannon's diversity index takes into account richness and the degree of evenness in species abundances, assigning equal weights to rare and abundant species. Still, season significantly explained 33% of the variance in epigeic fauna composition.

Differences in soil epigeic fauna diversity and evenness among dry and rainy seasons make sense, given certain groups, like Collembola, significantly increase in abundance during the rainy season due to sensitivity to low soil water content (Holmstrup, 2019). We noted that Hemiptera followed this same trend. Although comparisons with other studies in natural savanna ecosystems was not possible, Cajaiba and Silva (2017) reported that the family Cydnidae (Insecta: Hemiptera: Heteroptera) was more abundant during rainy seasons in agricultural, native forest and cattle pasture land-use types in northern Brazil.

Formicidae, Isoptera, Araneidae, and Collembola were the most abundant soil epigeic fauna groups in the studied savanna. This finding corroborates Benito and others (2004) in a similar savanna ecosystem but using a different methodology; in their study, soil samples were removed, and all macroinvertebrates were collected. By contrast, Pinhero et al., (2002) found that Coleoptera, Hymenoptera, Diptera and Isoptera were the most abundant groups in a similar savanna in the Cerrado. These authors used a combined trap method (i.e. pitfall, malaise tent, and window trap), which could explain the differences.

Formicidae is generally reported as the most abundant group in soil fauna studies (Lima et al., 2020; Nunes et al., 2021) due to its crucial role in litter fragmentation and organic material incorporation into the soil (Tavares et al., 2020). Nunes et al. (2021) related the Formicidae dominance in the dry season due to its high mobility. Besides, soil ants become unsheltered in long rainy periods, and an increase in soil water favors the development of some fungi species that eat formicidae eggs, putting all ants offspring at risk (Martins et al., 2020).

Studies on soil fauna in the Cerrado are still scarce, especially in natural ecosystems. The few existing studies were mainly conducted in silvopasture and pasture systems (Vendrame et al., 2009; Marchão et al., 2009; Portilho et al., 2011; Silveira et al., 2016). Given soil fauna embrace one-quarter of all species on Earth and provide a wide variety of functions (e.g., nutrient cycling, waste decomposition, climate regulation, pathogen resistance), it regulates aboveground diversity and functioning. Because soil fauna influence extends to human well-being, soil biodiversity and its ecosystem functions thus require explicit consideration when establishing nature protection priorities and policies to design new conservation areas (Guerra et al., 2021). The scarcity of studies in the Cerrado represents a major gap in soil biodiversity knowledge and reinforces the need for future studies surveying soil fauna, especially in areas covered by native savanna vegetation undergoing chronic environmental alterations.

3.4.2 Relationships between litterfall and soil epigeic fauna

We found an association between leaf fall and the Formicidae group, both being high in the dry season. We believe that this relates to Formicidae's high mobility and to the fact several species in this family are found in the leaf litter layer complex (Fernandes et al., 2020; Nunes et al., 2021). Also, these authors found that most ant species live in the leaf litter, and only a small part of the species lives in the twigs litter.

Our findings corroborate the notion that litterfall patterns in savannas are strongly influenced by climate variables (Giweta, 2020), especially those linked to water (Ferreira and Uchiyama, 2015). Regarding the implications of water availability to plant phenology and litter production, Giweta (2020) found that plant water consumption is related to air temperature and relative humidity, affecting plant growth, development, and health status. Consequently, plant water availability strongly influences fine litter production by savanna plant species.

The Cerrado ecoregion is characterized by well-defined dry and rainy seasons, reflecting the observed well-defined seasonal litterfall peaks. Fine litter production was highest during drier months (May to September) when plants are water-stressed. This litter deposition pattern in Cerrado ecosystems can be a strategy to consume less water in dry seasons and maintain soil water content, as litter deposited on soil decreases plant transpiration surface (Moraes and Prado 1998). Considering litterfall plays such an essential role in nutrient cycling by providing a means of supplying nutrients to the soil and serving as a niche and food for soil fauna (Giweta, 2020), global climatic changes can alter nutrient cycles in Brazilian Cerrado ecosystems.

3.4.3 Litter decay relates to soil epigeic fauna and chemistry

We expected leaf and wood decay rates to differ because of their contrasting chemical compositions, especially lignin content (Hall et al., 2020). By contrast, leaf and wood litter decay rates were statistically similar and very low ($k = 0.006$); fast decomposition rates usually fall between 1.0 and 4.0 (Olson, 1963). It took over a year to decompose 50% of the initial leaf and wood litter mass (*i.e.*, 531 and 495 days for leaf and wood, respectively). Miatto and Batalha (2016) found similar results in a savanna ecosystem in southeastern Brazil, where k ranged from 0.004 to 0.043. These authors reported that litter chemistry reflected an extreme leaf economic spectrum, showing a conservative strategy with low nutrient concentrations; this could explain the similar leaf and wood litter decomposition rates, as lignin-to-nitrogen ratios highly influence decomposition. Litter decomposition rates in Cerrado soils are generally considered slow, with a half-life time greater than one year, which corroborates our findings (Bustamante et al., 2012).

While litter decomposition is a multi-factorial, cascade process that is not usually continuous (Lavelle et al., 1993), the observed low decomposition rates can generally relate to the typical rainfall seasonality and soil acidity in typical savanna ecosystems in the Cerrado. Litter decomposition correlates strongly with temperature and humidity (Lavelle et al., 1993; Wall et al., 2008) as both climate variables control soil fauna activity and, consequently, decomposition rates. We observed that litter decomposition presented a strong seasonal trend, occurring more intensively in the rainy season. This pattern is supported by studies reporting that litter decay can be three to seven times faster in rainy than in dry seasons (Peña-Peña and Irmler, 2016; Ribeiro et al., 2018).

Regarding litter decomposition association with soil epigeic fauna groups, we noted a strong association between wood litter decay and Hemiptera order abundance. This trend could be explained by the phytophagous habits of some species in this order that feed from litter (Capinheira, 2008). According to Goldman et al. (2020), there are several tropical Hemipterans commonly found in litter, which corroborates our findings.

The PCA indicated that wood litter decay rate grouped with soil epigeic fauna diversity and evenness per plot, in opposed quadrants to soil fertility variables like SOM, SOC stock, and P availability (Figure 5). On the other hand, leaf litter decay rate co-varied with epigeic fauna abundance and soil pH. These results may be explained by the specific nutrition requirements of each soil fauna ecological guild (Primavesi, 1981), and the generally higher levels of lignin and recalcitrant compounds in fine wood compared to leaf litter. Lignin, the hardest organic compound to decompose, is broken down by a few specific organisms (Tan et al., 2020). Therefore, we speculate that the specific need to decompose wood litter may be associated with a greater need for diversity than an abundance of soil epigeic fauna, even though both epigeic fauna diversity and Hemiptera abundance increased with rainfall in our study.

In the studied savanna, soil pH related strongly with leaf decomposition and epigeic fauna abundance. Soil pH is known to affect soil fauna activity, showing a negative correlation with the abundance of Cerrado macrofauna groups (Franco et al., 2016). This pattern can be associated with the soil epigeic fauna spatial distribution

(Giweta, 2020) that leads to a slow litter decay, which in turn promotes an increase in soil organic matter and C stocks (Primavesi, 1981). Leaf litter decay is an important nutrient cycling process linked with soil solution P in highly-weathered soils — such as those in the studied savanna — due to strong P adsorption on soil mineral colloids (Novais et al., 2007). Savanna ecosystems in the Cerrado present low shade, soil moisture content, and available P concentration in the topsoil (Jacobson and Bustamante, 2014). Our findings indicate that key soil physicochemical variables, as well as soil epigeic fauna diversity and abundance, were strongly related to litter decomposition in the studied savanna ecosystem in the Cerrado. Therefore, the soil-plant-atmosphere interactions that promote function and ecosystem service provision in savanna ecosystems may be threatened by conversion to agriculture and mining, and climate change.

3.5 CONCLUSIONS

In studying soil biodiversity-ecosystem function relationships in a preserved savanna ecosystem in the Cerrado, we found that rainfall seasonality modulated the mean soil epigeic fauna diversity and evenness across all savanna plots, which were greatest in the rainy season (October to March), in contrast to litterfall rates which peaked in the dry season (May to October). Hemiptera and Collembola were more related to the rainy season collections, while Formicidae was more associated with the dry season collections; this trend is linked to each group's needs related to soil humidity. In addition, based on our findings, we speculate that the specific needs to decompose wood litter may be associated with a greater need for diversity than an abundance of soil epigeic fauna. Taken together, our findings suggest that future climatic changes, including longer dry season lengths, can directly affect those ecosystem processes and nutrient cycling in savanna ecosystems.

Our study was a pioneer in quantifying fine wood litter decomposition rates in savannas in the Cerrado and relating it to soil epigeic fauna composition and diversity. Surprisingly, leaf and wood litter decomposition rates were very similar. These findings highlight the close links between soils and vegetation, which are key ecosystem components influenced by climatic conditions. Additional studies in tropical savanna ecosystems are encouraged to further our understanding of decay patterns of litter fractions other than leaves and fine wood, and the role of species composition on litter decomposition and nutrient cycling in tropical savannas. We especially encourage long-term studies linking soil epigeic fauna and topsoil parameters in the Cerrado, which is a conservation hotspot due to high ecological importance and rampant human threat.

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3.7 REFERENCES

ARANTES, A. E. et al., The seasonal carbon and water balances of the Cerrado environment of Brazil: Past, present, and future influences of land cover and land use. **ISPRS Journal of Photogrammetry and Remote Sensing,** v.117, p. 66–78. 2016. https://doi.org/10.1016/j.isprsjprs.2016.02.008

BARETTA, D. et al., Trap and soil monolith sampled edaphic spiders (arachnida: araneae) in Araucaria angustifolia. **Forest. Sci. agric.** v. 64, p. 375–383, 2007. https://doi.org/10.1590/S0103-90162007000400008

BENITO, N. P. et al., Transformations of soil macroinvertebrate populations after native vegetation conversion to pasture cultivation (Brazilian Cerrado). **European Journal of Soil Biology**, v.40, p.147–154, 2004. https://doi.org/10.1016/j.ejsobi.2005.02.002

BRASIL, Ministério do Meio Ambiente, **Plano de Ação para Prevenção e Controle do Desmatamento e das queimadas no Cerrado** (PPCerrado). Brasília-DF, 2018, 173p.

BUISSON, E. et al., A research agenda for the restoration of tropical and subtropical grasslands and savannas. **Restoration Ecology**, v.29, e13292, 2020. https://doi.org/10.1111/rec.13292

BUSTAMANTE, M. et al., Potential impacts of climate change on biogeochemical functioning of Cerrado ecosystems. **Braz. J. Biol.** 72, 655–671, 2012. https://doi.org/10.1590/S1519-69842012000400005

CAJAÍBA, R. L., SILVA, W. B. da., Diversidade e sazonalidade de Cydnidae (Insecta: Hemiptera: Heteroptera) em diferentes habitats no estado do Pará, norte do Brasil. **Revista brasileira de Biociências**, v.15, p. 32-37, 2017.

CORREIA, M. E. F., ANDRADE, A. G., Formação de serapilheira e ciclagem de nutrientes. In: **Fundamentos Da Matéria Orgânica Do Solo: Ecossistemas Tropicais & Subtropicais**. Metrópole, Porto alegre, 2008, pp. 137–157.

CAPINERA, J. L., **Encyclopedia of entomology**. 2nd ed., v. 1-4. Springer, Dordrecht, The Netherlands. 2008, 4346p.

FRANCO, A. L. C. et al., Loss of soil (macro)fauna due to the expansion of Brazilian sugarcane acreage. **Science of the Total Environment**, v.563–564, p.160–168. 2016. https://doi.org/10.1016/j.scitotenv.2016.04.116.

DJUKIC, I. et al., Early stage litter decomposition across biomes**. Science of The Total Environment**, v.628–629, p.1369–1394, 2018. https://doi.org/10.1016/j.scitotenv.2018.01.012

Empresa Brasileira de Pesquisa Agropecuária EMBRAPA. **Manual de métodos de análises do solo**. 2.ed. Rio de Janeiro: Ministério da Agricultura e do Abastecimento, 2011. 230 p.

Empresa Brasileira de Pesquisa Agropecuária (Embrapa); **Manual de Métodos de Análises Químicas para Avaliação da Fertilidade do Solo**; da Silva, F. C.; da Eira, P. A.; Barreto, W. O.; Pérez, D. V.; Silva, C. A., eds.; EMBRAPA-CNPS: Rio de Janeiro, 1998, 56 p.

FELFILI, J. M., et al., Changes in the floristic composition of cerrado *sensu stricto* in Brazil over a nine-year period. **J. Trop. Ecol**. V. 16, p. 579–590, 2000. https://doi.org/10.1017/S0266467400001589

FERREIRA, M. L., UCHIYAMA, E. A., 2015. Litterfall assessment in a fragment of secondary tropical forest, Ibiúna, SP, Southeastern Brazil. **Rev. Árvore**, v. 39, p. 791–799, 2015.
https://doi.org/10.1590/0100-67622015000500002

GALLO, P., ALBRECHT, E. Brazil and the Paris Agreement: REDD+ as an instrument of Brazil's Nationally Determined Contribution compliance. International Environmental Agreements: **Politics, Law and Economics**, v.19, p.123–144, 2019. https://doi.org/10.1007/s10784-018-9426-9

GARLET, C. et al., Ciclagem de nutrientes em povoamento de Eucalyptus dunnii Maiden: produção de serapilheira e devolução de macronutrientes no bioma Pampa. **Ecol. Nutr. Flor.**, v.7, e.05. 2019. https://doi.org/10.5902/2316980X37057

GIWETA, M., 2020. Role of litter production and its decomposition, and factors affecting the processes in a tropical forest ecosystem: a review. **J. Ecology Environ.**, v. 44, e.11, 2020.

https://doi.org/10.1186/s41610-020-0151-2

GOLDMAN, A. E. et al., Drought and presence of ants can influence hemiptera in tropical leaf litter. **Biotropica**, v. 52, 0.221-229, 2020. https://doi.org.10.1111/btp.12762.

GUERRA, C. A. et al., Tracking, targeting, and conserving soil biodiversity. **Science**, v. 371, p. 239–241, 2021. https://doi.org/10.1126/science.abd7926

HALL, S. J. et al., Lignin lags, leads, or limits the decomposition of litter and soil organic carbon. **Ecology**, v. 101, e03113, 2020. https://doi.org/10.1002/ecy.3113

HARIDASAN, M., Nutritional adaptations of native plants of the cerrado biome in acid soils. **Braz. J. Plant Physiol**. v. 20, p. 183–195, 2008. https://doi.org/10.1590/S1677-04202008000300003

HOLMSTRUP, M., 2019. Water relations and drought sensitivity of Folsomia candida eggs (Collembola: Isotomidae). **Eur. J. Entomol.**, v. 116, p. 229–234, 2019. https://doi.org/10.14411/eje.2019.025

Inventário Florestal Nacional - IFN. **Manual de campo: Procedimentos de coleta de dados biofísicos e Socioambientais**, Serviço Florestal Brasileiro. – Brasília: SFB, 2015, 67 p.

INKOTTE, J. et al. Métodos de avaliação da ciclagem de nutrientes no bioma Cerrado: uma revisão sistemática. **Ciência Florestal**, v. 29, n. 2, p. 988, 30 jun. 2019. https://doi.org/10.5902/1980509827982

INMET. **Instituto Nacional de Meteorologia**. Instituto Nacional de Meteorologia, [s.d.]. Disponível em: <https://portal.inmet.gov.br/dadoshistoricos>. Acesso em: 03/08/2020.

JACOBSON, T. K. B.; BUSTAMANTE, M. M. C. Leaf Litter Decomposition and Nutrient Release Under Nitrogen, Phosphorus and Nitrogen Plus Phosphorus Additions in a Savanna in Central Brazil. In: SUTTON, M. A. et al. (Eds.). . **Nitrogen Deposition, Critical Loads and Biodiversity**. Dordrecht: Springer Netherlands, 2014. p. 155–163. https://doi.org/10.1007/978-94-007-7939-6_17

KOUKOURA, Z.; MAMOLOS, A. P.; KALBURTJI, K. L. Decomposition of dominant plant species litter in a semi-arid grassland. **Applied Soil Ecology**, v. 23, n. 1, p. 13–23, maio 2003. https://doi.org/10.1016/S0929-1393(03)00006-4

LAMBIN, E. F. et al. Estimating the world's potentially available cropland using a bottom-up approach. **Global Environmental Change**, v. 23, n. 5, p. 892–901, out. 2013.
LAUBER, C. L. et al. Pyrosequencing-Based Assessment of Soil pH as a Predictor of Soil Bacterial Community Structure at the Continental Scale. **Applied and Environmental Microbiology**, v. 75, n. 15, p. 5111–5120, 1 ago. 2009.

LAVELLE, P.; PASHANASI, B. **Soil macrofauna and land management in peruvian amazonia (Yurimaguas. Loreto)**. [s.l.] Pedobiologia, 1989. v. 33

LAVELLE, P.; SPAIN, A. **Soil ecology**. Dordrecht: Kluwer Academic Publishers, 2001.

LIMA, C. de S. et al., Composição funcional e sazonalidade da macrofauna edáfica em diferentes usos do solo, Bioma Cerrado, Brasil. R**evista Ibero-Americana de Ciências Ambientais**, v. 11, p. 33–48, 2020.
https://doi.org/10.6008/cbpc2179-6858.2020.006.0004

MARCHÃO, R. L.et al., Macrofauna edáfica em sistemas de integração lavoura-pecuária num Latossolo Vermelho do Cerrado. **Pesquisa Agropecuaria Brasileira**, v.44, 1011–1020, 2009.
https://doi.org/10.1590/S0100-204X2009000800033

MARTINS, M. F. O. et al., Accessing the subterranean ant fauna (Hymenoptera: Formicidae) in native and modified subtropical landscapes in the Neotropics. **Biota Neotropica**, v. 20, e20190782, 2020.
http://dx.doi.org/10.1590/1676-0611-BN-2019-0782

MIATTO, R.C., BATALHA, M.A., Leaf chemistry of woody species in the Brazilian cerrado and seasonal forest: response to soil and taxonomy and effects on decomposition rates. **Plant Ecol**, v. 217, p. 1467–1479. 2016.
https://doi.org/10.1007/s11258-016-0658-x

MIRANDA, C. do C., et al., Caracterização da matéria orgânica do solo em fragmentos de mata atlântica e em plantios abandonados de eucalipto. **Rev. Bras. Ciênc. Solo**, v. 31, p. 905–91, 2007.
https://doi.org/10.1590/S0100-06832007000500008

MORAES, J.A.P.V., PRADO, C.H.B.A., 1998. Photosynthesis and water relations in cerrado vegetation. In: **Ecophysiological Strategies of Xerophytic and Amphibious Plants in the Neotrópicos**. UFRJ, Rio de Janeiro, 1998, pp. 45–63.

MORANDI, P. S. et al. Tree diversity and above-ground biomass in the South America Cerrado biome and their conservation implications. **Biodiversity and Conservation**, v. 29, n. 5, p. 1519–1536, 2018.
https://doi.org/10.1007/s10531-018-1589-8

MOTA, F. C. M. **Biomassa, fluxos de carbono e energia em área de Cerrado sentido restrito e plantio de eucalipto no Distrito Federal**. Brasília, DF: Universidade de Brasília, 2017.

MYERS, N. et al., Biodiversity hotspots for conservation priorities. **Nature**, v.403, p. 853–858, 2000.
https://doi.org/10.1038/35002501

NIMER, E., **Climatologia do Brasil**, 2nd ed. IBGE, Rio de Janeiro, 1989.

NOVAIS, R. F. et al., **Fertilidade do Solo**. Viçosa: Sociedade Brasileira de Ciência do Solo, v.1, 2007, 1017 p.

NUNES, L. A. P. L. et al., Characterization of edaphic fauna in different monocultures in Savanna of Piauí. **Braz. J. Biol.**, v. 81, p. 657-664, 2021. https://doi.org/10.1590/1519-6984.228799

ODUM, E. P. **Ecologia**. São Paulo: Pioneira, 1969.

OLSON, J. S. Energy Storage and the Balance of Producers and Decomposers in Ecological Systems. **Ecology**, v. 44, n. 2, 1963, p. 322–331. https://doi.org/10.2307/1932179

PARK, B. B., et al., Carbon and Nutrient Inputs by Litterfall in Evergreen and Deciduous Forests in Korea. **Forests**, v. 11, e.143, 2020. https://doi.org/10.3390/f11020143

PEÑA-CLAROS, M. et al., Soil Effects on Forest Structure and Diversity in a Moist and a Dry Tropical Forest: Tropical Forest Characteristics Influenced by Soil. **Biotropica**, v. 44, p. 276–283, 2012. https://doi.org/10.1111/j.1744-7429.2011.00813.x

PEÑA-PEÑA, K.; IRMLER, U. Moisture seasonality, soil fauna, litter quality and land use as drivers of decomposition in Cerrado soils in SE-Mato Grosso, Brazil. **Applied Soil Ecology**, v. 107, p. 124–133, 2016. https://doi.org/10.1016/j.apsoil.2016.05.007

POMPEO, P. N. et al. Fauna e sua relação com atributos edáficos em Lages, Santa Catarina - brasil. **Scientia Agraria**, v. 17, n. 1, 13 out. 2016. https://doi.org/10.5380/rsa.v17i1.46535

PINHEIRO, F. et al., Seasonal pattern of insect abundance in the Brazilian cerrado. **Austral Ecology**, v. 27, p. 132–136, 2002. https://doi.org/10.1046/j.1442-9993.2002.01165.x.

PORTILHO, I. I. R. et al. Fauna invertebrada e atributos físicos e químicos do solo em sistemas de integração lavoura-pecuária. **Pesquisa Agropecuária Brasileira**, v. 46, n. 10, p. 1310–1320, out. 2011. https://doi.org/10.1590/S0100-204X2011001000027

PRIMAVESI, A. M. **O manejo ecológico do solo: a agricultura em regiões tropicais**. São Paulo: Nobel, 1981.

PRITCHETT, W. **Properties and management of forest soils.** 2. ed. New York: John Wiley, 1979.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, 2009. Disponível em: https://www.R-project.org/.

RIBEIRO, F. P. et al. Litter Dynamics in Eucalyptus and Native Forest in the Brazilian Cerrado. **Journal of Agricultural Science**, v. 10, n. 11, p. 29, 15 out. 2018. https://doi.org/10.5539/jas.v10n11p29

ROSA, M. G. et al., Macrofauna Edáfica e Atributos Físicos e Químicos em Sistemas de Uso do Solo no Planalto Catarinense. **Revista Brasileira de Ciência do Solo**, v. 39, n.6, p. 1544-1553, 2015.
https://doi.org/10.1590/01000683rbcs20150033

SANTOS, H. G. DOS et al. **Sistema Brasileiro de Classificação de Solos**. 5. ed. Brasília, DF: Embrapa Solos, 2018.

SCORIZA, R. N. et al. Métodos para coleta e análise de serrapilheira aplicados à ciclagem de nutrientes. **Floresta e Ambiente**, p. 19, 2012.

SILVEIRA, E. R. et al. Diversidade e papel funcional da macrofauna do solo na integração lavoura-pecuária. Rev. **Téc, Cient. CREA-PR**, n. 4, p. 1–16, 2016.
SOIL SURVEY STAFF, Keys to Soil Taxonomy, Eleventh Edition, 2010.

SILVA JUNIOR, S. et al., Soil macrofauna associated with cover crops in an Oxisol from the southwest of Piauí state, Brazil. **Arquivos do Instituto Biológico**, v. 87, 2010. https://doi.org/10.1590/1808-1657000822018

STRASSBURG, B.B.N., Iribarrem, A., Beyer, H.L., Cordeiro, C.L., Crouzeilles, R., Jakovac, C.C., et al., Global priority areas for ecosystem restoration. **Nature**, v. 586, p. 724–729, 2020.
https://doi.org/10.1038/s41586-020-2784-9

SWIFT, M. J. et al., Decomposition in terrestrial ecosystems. Oxford: Blackwell, 1979, 372p.

TAVARES, P. D., SILVA, C. F., PEREIRA, M. G., SILVA, E. M. R. da, Composition of the soil fauna community and leaf litter stock in agro-forestry systems and secondary forestry. **Bioscience Journal**. v.36, 2020.
https://doi.org/10.14393/BJ-v36n4a2020-42715

TORODE, M. D. et al. Altered Precipitation Impacts on Above- and Below-Ground Grassland Invertebrates: Summer Drought Leads to Outbreaks in Spring. **Frontiers in Plant Science**, v. 7, 6 out. 2016.
https://doi.org/10.3389/fpls.2016.01468

USUGA, J. C. L. et al. Estimation of biomass and carbon stocks in plants, soil and forest floor in different tropical forests. **Forest Ecology and Management**, v. 260, n. 10, p. 1906–1913, 15 out. 2010.
https://doi.org/10.1016/j.foreco.2010.08.040

VANOLLI, B. S., et al., Epigeic fauna (with emphasis on ant community) response to land-use change for sugarcane expansion in Brazil. Acta Oecol., v.110, e.103702, 2021. https://doi.org/10.1016/j.actao.2021.103702

VENDRAME, P. R. S. et al. Relationship between macrofauna, mineralogy and exchangeable calcium and magnesium in Cerrado Oxisols under pasture. **Pesquisa Agropecuária Brasileira**, v. 44, n. 8, p. 996–1001, ago. 2009. https://doi.org/10.1590/S0100-204X2009000800031

WALL, D.H., et al., Soil Invertebrates in Different Land Use Systems: How Integrated Production Systems and Seasonality Affect Soil Mesofauna Communities v. 7, p. 158–169, 2017. https://doi.org/10.17265/2161-6264/2017.03.003

WALKLEY, A.; BLACK, I. A., An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. **Soil Sci.**, v. 37, p. 29-38, 1934.

ZUIN, V.G., What Can Be Learnt from the Brazilian Cerrado? In: **Biomass Burning in Sub-Saharan Africa**. pp. 143–160, 2020.

Appendix A. Mean soil physicochemical properties of the studied savanna ecosystem in central Brazil.

Soil depth (cm)	pH (H_2O)	P_{av}	K	Ca^{2+}	Mg^{2+}	Al^{3+}	H + Al	SB	CECe	CECt	v	m	SOM	P_{rem}
0-20	4.96	0.42	29.67	0.08	0.06	0.62	7.38	0.22	0.84	7.59	2.79	74.22	4.94	10.88
S.e.	0.05	0.06	1.55	0.02	0.00	0.04	0.21	0.02	0.05	0.23	0.20	1.65	0.21	0.29
20-40	5.20	0.23	16.92	0.06	0.04	0.29	5.38	0.14	0.43	5.53	2.54	66.92	3.54	9.18
S.e.	0.05	0.03	0.69	0.01	0.00	0.02	0.16	0.02	0.03	0.17	0.24	2.37	0.14	0.21
40-60	5.24	0.13	9.08	0.06	0.02	0.09	4.03	0.10	0.19	4.13	2.34	28.49	2.81	7.21
S.e.	0.04	0.02	0.81	0.01	0.00	0.03	0.14	0.01	0.04	0.15	0.32	10.44	0.13	0.20

Note: S.e. = Standard error; SB = Sum of bases; CECe = Effective cation exchange capacity; CECt = total cation exchange capacity; V = base saturation and m = Aluminum saturation. P_{av} and K are in mg/dm3; Ca^{2+}, Mg^{2+}, Al^{3+}, H+Al, SB, and CEC in cmolc/dm3; V and m in %; OM in dag/kg, and P_{rem} in mg/L.

Appendix B. Statistical results of the plot-level seasonal and annual NMDS ordinations including the soil, epigeic fauna, and litter vectors fit with function *envfit*, and the PCA components and scores.

Output of the PERMANOVA testing the effect of season on soil epigeic fauna abundance in 12 savanna plots.

	Df	**Sum of Squares**	**R^2**	**F**	**p-value**
Season	1	1.21	0.33	10.94	0.001
Residual	22	2.44	0.67		
Total	23	3.66	1.00		

Output of the seasonal (plot-level) NMDS vectors, including individual scores, coefficient of determination, and p-value. Only the significant vectors at the 95% confidence level were plotted in Figure 5b.

	NMDS1	**NMDS2**	**R^2**	**p-value**
Abundance	0.8742883	-0.0984154	0.77	***
Monthly total litterfall	0.3013857	0.6933225	0.57	***
Monthly leaf fall	0.2650479	0.7380813	0.62	***
Monthly wood fall	0.2146909	-0.1475337	0.07	0.48
Monthly rainfall	-0.2053798	-0.8144315	0.71	***
Diversity	-0.3506321	-0.5796577	0.46	**
Richness	0.2305279	0.1397634	0.07	0.42
Evenness	-0.4030874	-0.6252132	0.55	***

Significance level codes: 0 '***' 0.001 '**' 0.01

	NMDS1	**NMDS2**	**R^2**	**p-value**
Formicidae	0.095	0.695	0.49	***
Collembola	-0.147	-0.830	0.71	***
Hemiptera	-0.420	-0.696	0.66	***
Araneae	-0.030	-0.254	0.07	0.49
Diptera	0.601	-0.510	0.62	***
Psocoptera	-0.049	0.228	0.05	0.59
Hymenoptera	0.188	0.403	0.20	0.06
Blattodea	-0.295	-0.395	0.24	*
Isoptera	0.887	-0.185	0.82	***
Coleoptera	0.455	0.083	0.21	0.05
Diplopoda	0.092	0.011	0.01	0.96

Isopoda	0.092	0.011	0.01	0.96
Opiliones	0.030	0.222	0.05	0.59
Ortoptera	-0.064	-0.283	0.08	0.40
Dermaptera	0.491	-0.102	0.25	0.06
Ixodida	0.092	0.011	0.01	0.96
Siphonaptera	0.394	0.083	0.16	0.12
Trichoptera	-0.035	0.277	0.08	0.49
Pseudoscorpionida	-0.169	0.199	0.07	0.55
Chilopoda	0.476	-0.091	0.23	0.08
Acarina	0.476	-0.091	0.23	0.08
Thysanoptera	0.031	0.136	0.02	0.88
Others	0.175	0.245	0.09	0.37
Phasmatodea	-0.141	0.030	0.02	0.92
Neuroptera	-0.137	-0.323	0.12	0.21

Significance level codes: '***' 0.001 '**' 0.01 '*' 0.05

Output of the PCA of annual (plot-level) soil and litter variables (Figure 5c).

Importance of components:

	PC1	PC2	PC3	PC4
Standard deviation	2.3844	1.5110	1.1515	1.0188
Proportion of Variance	0.4738	0.1903	0.1105	0.0865
Cumulative Proportion	**0.47**	**0.66**	**0.78**	**0.86**

Variable eigenvectors:

	PC1	PC2	PC3	PC4
Leaf_k	0.026	0.3903	0.4125	-0.3802
Wood_k	-0.3526	0.0850	0.2513	0.0963
pH	-0.0514	0.3847	-0.5567	0.3236
Available P	0.3499	0.1412	0.2474	0.1128
H+Al	0.3734	-0.1695	-0.2311	-0.1274
SB	0.2338	-0.4165	-0.2383	-0.2143
CECe	0.3397	-0.3027	0.1837	-0.1492
SOM	0.3865	-0.0875	-0.2200	0.1636
SOC stock	0.2425	0.2041	0.1732	0.5941
Diversity	-0.3345	-0.2599	-0.16	0.1366
Abundance	-0.0968	0.3477	-0.3835	0.4817
Evenness_	-0.3327	-0.375	0.0162	0.1168

Output of the annual (plot-level) NMDS vectors. Only the significant vectors at the 95% confidence level were plotted in Figure 5b.

	NMDS1	NMDS2	R^2	p-value
Leaf_k	0.0555	-0.2169	0.05	0.78
Wood_k	0.1137	0.7397	0.56	*
pH	0.2547	0.2145	0.11	0.57
Pav	-0.2181	-0.4415	0.24	0.31
H+Al	-0.1175	-0.5867	0.36	0.13
SB	-0.0867	-0.3143	0.11	0.55
CECe	-0.1907	-0.5526	0.34	0.14
SOM	-0.1321	-0.5597	0.33	0.18
SOCstock	-0.1751	-0.1594	0.06	0.75
Diversity	0.1185	0.6229	0.40	0.11
Abundance	0.6943	-0.5708	0.81	**
Evenness	0.0262	0.5655	0.32	0.19

Significance level codes: '**' 0.01 '*' 0.05

	NMDS1	NMDS2	R^2	p-value
Formicidae	-0.168	-0.576	0.36	0.15
Collembola	-0.066	0.023	0.00	0.98
Hemiptera	-0.068	0.773	0.60	**
Araneae	0.110	0.186	0.05	0.78
Diptera	0.638	0.222	0.46	0.09
Psocoptera	0.018	-0.257	0.07	0.73
Hymenoptera	0.060	-0.341	0.12	0.56
Blattodea	0.042	0.580	0.34	0.16
Isoptera	0.864	-0.381	0.89	***
Coleoptera	0.618	-0.128	0.40	0.10
Diplopoda	0.420	-0.238	0.23	0.35
Isopoda	0.420	-0.238	0.23	0.35

Opiliones	0.073	-0.242	0.06	0.67
Ortoptera	0.024	-0.094	0.01	0.97
Dermaptera	0.282	-0.411	0.25	0.33
Ixodida	0.420	-0.238	0.23	0.35
Siphonaptera	0.403	-0.382	0.31	0.12
Trichoptera	-0.134	-0.264	0.09	0.55
Pseudo scorpionida	0.357	-0.223	0.18	0.33
Chilopoda	0.420	-0.238	0.23	0.18
Acarina	0.420	-0.238	0.23	0.18
Thysanoptera	0.088	0.671	0.46	0.10
Others	0.713	-0.123	0.52	0.08
Phasmatodea	-0.134	-0.264	0.09	0.65
Neuroptera	-0.134	-0.264	0.09	0.49

Significance level codes: '***' 0.001 '**' 0.01 '*' 0.05

4 CAPÍTULO III*

IMPACTS OF LITTER LAYER REMOVAL ON EUCALYPTUS STAND FUNCTION AND SOIL BIODIVERSITY

ABSTRACT

Litter layer on the forest floor is a source of primary nutrients for plant uptake, and buffers changes in soil water content and temperature, prevents soil erosion and nutrient leaching, and provides habitat and substrate to soil fauna. Because litter layer affects so many soil processes, it is necessary to quantify the consequences of changes in litter dynamics on Eucalyptus plantation function. Yet, we still fall short in understanding how aboveground litter production, soil epigeic fauna, and soil physicochemistry interact on Eucalyptus plantations in the Brazilian Cerrado. To understand and link these variables and processes that influence Eucalyptus plantation function, this study quantified the effects of litter manipulation on litterfall, litter decomposition, soil biogeochemistry and soil epigeic fauna community in two Eucalyptus stands in the Cerrado. Litter layer removal management reduced the leaf litter decomposition rates and also reduced the abundance of Hemiptera, Diptera, and Diplopoda soil epigeic fauna groups, suggesting a breakdown on the edaphic food chain and promoting impacts on nutrient cycling process that can spoil the whole ecosystem functioning, also Shannon's diversity index was highly correlated to control plots, as remaining P, wood decay and soil moisture when compared to litter removal plots. Individual tree diameter increment was affected by litter layer removal only in the Juvenile stand, which can be a consequence of slower growth in Mature stands compared to Juvenile ones, which have not yet reached the peak growth stabilization. We believe that litter layer removal impacted edaphic conditions that can spoil the hole nutrient cycling processes, since in two years of study several soil parameters were affected by litter removal management.

Keywords: nutrient cycling, litter layer, forest management, soil epigeic fauna

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4.1 INTRODUCTION

Eucalyptus is one of the most widely planted tree genera in tropical and subtropical regions worldwide. This is largely related to its excellent adaptation to various environmental conditions in addition to short highly productive cycles (CASTRO et al., 2016; BOENO, et al., 2020). In Brazil, Eucalyptus stands cover 6.97 million hectares, which corresponds to nearly 77% of all forest planted area in the country, and account for most of the domestic and international market demands for wood products, such as paper and cellulose (IBA, 2020). However, the increasing demand for forest products from Eucalyptus plantations exerts pressure to convert land covered by native vegetation into monoculture systems. Combined with land-use changes for agricultural purposes in recent decades, such pressures have led to the degradation of the Brazilian savanna, also known as Cerrado.

The Cerrado is the second-largest biome of South America, and one of the world's hotspots for biodiversity conservation due to high species endemism and heterogeneity of landscapes (MYERS et al, 2000; MORANDI et al., 2018). Approximately, 40% of the original Cerrado area has been deforested and 40% has been degraded, while only 19% is covered by preserved native vegetation (ZUIN, 2020). Thus, establishing commercial tree plantations in degraded areas in the Cerrado can be a key mechanism to compromise forest product demand and preservation of native forests and savannas in the Cerrado (BOULMANE, et al., 2017). The reforestation of degraded areas through tree plantations has been widely used and shown significant results in restoring soil productivity, promoting nutrient mineralization, and increase of water holding capacity (PAULUCIO et al., 2017; SENA et al., 2017) being a good start point for soil recovery, to be consequently managed to be replaced by ecological restoration practices. However, the introduction of exotic species as monoculture stands remains controversial, especially because of the negative impacts on soil biodiversity (SOUZA et al., 2016; BALIEIRO et al., 2020; CORREA et al., 2020).

The conversion of savanna to Eucalyptus plantation alters nutrient cycles due to modifications above - and below-ground. Because of the change in vegetation composition, nutrient inputs and outputs are altered, which in turn leads to shifts in soil fauna composition and diversity (PENÃ-PENÃ; IRMLER, 2016). This impact on soil biodiversity results from the alteration of a high diversity of substrates (i.e. litter from various plant species) to a single type of substrate, favoring certain groups of edaphic organisms and causing a biological imbalance (BARETTA et al., 2003). However, studies suggest that Eucalyptus plantations, compared to other monocropping systems, are less impactful to soil fauna communities (ROSA et al., 2015; SOUZA et al., 2016). For instance, soil biological quality has been partially restored eight years after bare soil conversion to Eucalyptus plantation (BOENO et al., 2020).

In forested systems, litterfall is a key ecosystem process that acts as a natural nutrient conduit, with a special role in the maintenance of self-sustaining forests (i.e., unfertilized) in low nutrients soils like the Oxisols (Latosols) that cover nearly 40% of the Cerrado (HARIDASAN, 1994). In commercial Eucalyptus stands, fertilization is necessarily conducted within the first two years after the seedlings are planted. Then, the nutrient cycling naturally takes place via litterfall throughout stand development (SCHUMACHER; VIEIRA, 2015). The senesced plant materials deposited on the soil surface are decomposed by soil organisms that convert their nutrient content into mineral forms that are incorporated into the soil solution, which can then be absorbed and used by the Eucalyptus trees for their full development (PRITCHETT, 1979; GARLET et al., 2019).

Litter deposited on the forest floor provides the primary nutrients for plant uptake, buffers changes in soil water content and temperature, prevents soil erosion and nutrient leaching, and provides habitat and substrate to soil fauna (GIWETA, 2020). Because litter affects so many soil processes, it is necessary to quantify the consequences of changes in litter dynamics on Eucalyptus plantation function. For example, litter layer manipulation is a direct way of studying the effects of litterfall mass and nutrient fluxes on ecosystem processes (CHEN, et al., 2014). Also, managing excess litter from adjacent Eucalyptus stands can be an alternative to breakdown uncontrolled fire, a typical disturbance in the Cerrado (GOMES et al., 2018; ALVARADO et al., 2017), by decreasing combustible material. The removed litter can also be used in nucleation restoration practices for bare soil cover (REIS et al., 2014), promoting the improvement of several soil properties and provide niche for terrestrial fauna as mammals and reptiles that contribute to the restoration processes. Yet, we still fall short in understanding how litter production, soil epigeic fauna, and soil physicochemistry interact on Eucalyptus plantations, especially on tropical forests planted or not (SAYER, 2020).

To understand and link the variables and processes that influence Eucalyptus plantation functionining, this study quantified the effects of litter manipulation on litterfall, litter decomposition, soil biogeochemistry and epigeic fauna community in two

Eucalyptus stands in the Cerrado. Specifically, we aimed at answering the following questions: i) Does litter removal affect litter production and decomposition rates?; If so, do effects vary between different Eucalyptus stands?; ii) Does litter removal affect soil bulk density, water content, and fertility?; iii) Does soil epigeic fauna respond to litter layer removal?; and iv) Is tree diameter increment affected by litter manipulation? In view of the issues raised, we hypothesized that: i) Litter removal impacts litterfall and litter decomposition in Eucalyptus stands; ii) Soil bulk density, water content and fertility are affected by litter removal; iii) Litter removal impacts on soil epigeic fauna communities; and iv) Tree growth is negatively influenced by litter removal.

4.2 METHODS

4.2.1 Study site description

This study was conducted at the University of Brasilia's experimental research station (Fazenda Água Limpa; 15°56 '- 15°59 'S and 47°55' - 47°58' W). The property covers over 4,300 hectares, wherein approximately 153.5 hectares are used for silviculture, mainly Eucalyptus plantations. The region's climate is classified as AW according to Köppen's classification, with an annual average rainfall of 1552 mm and well-defined dry and rainy seasons; monthly mean rainfall ranges from 9 mm in June to 249 mm in December (NIMER, 1989). Oxisol (USDA classification system) or Red Latosol (EMBRAPA classification system) is the main soil order in the study site, with a small area of Yellow Latosol (EMBRAPA classification system). The soils are highly acidic and have low nutrient (e.g., phosphorus) availability (HARIDASAN, 2000).

We selected two adjacent Eucalyptus stands less than 1 km apart for this study. The stands differ in three years in age: The Mature stand (3.3 ha) was established in January 2010 and was eight years old when we started this experiment. *Eucalyptus urophylla* ST Blake *x Eucalyptus grandis* Hill ex-Maiden is the clone planted in the Mature stand, arranged in 3 m x 2 m spacing with soil tillage plowing down to 40 cm depth and fertilizer application along the planting line with 100 g of super simple phosphate in addition to 100 g of NPK (4-30-16) (Figure a). The Juvenile stand (23 ha) was planted in 2013 with a hybrid clonal planting: *Eucalyptus grandis* × *Eucalyptus urophylla* (GG 100), with 3 m × 3m spacing. Before planting, subsoiling was performed up to 70 cm in depth and 600 kg ha^{-1} of super simple phosphate was applied. Fertilization was carried out in pits with 200 g per well of NPK (20-05-20) applied 15 cm away from the seedling with applications at fifteen days, two months, one year, and two years after planting (Figure b).

4.2.2 Experimental design

Twelve 10 m × 10 m (100 m²) plots were established in each studied stand, wherein half (6 plots each) were our litter removal plots. Those plots were kept uncovered and the litter layer was removed every other month from March 2018 to April 2020. The other half of the control plots maintained the natural litter layer on the soil surface. For the better knowledge, only in the Mature stand, the litter removal plots were maintained for one year between November 2016 to October 2017 (i.e., the entire litter layer within the plot was removed), after which all plots remained without any manipulation for five months before the beginning of the present study (Figure).

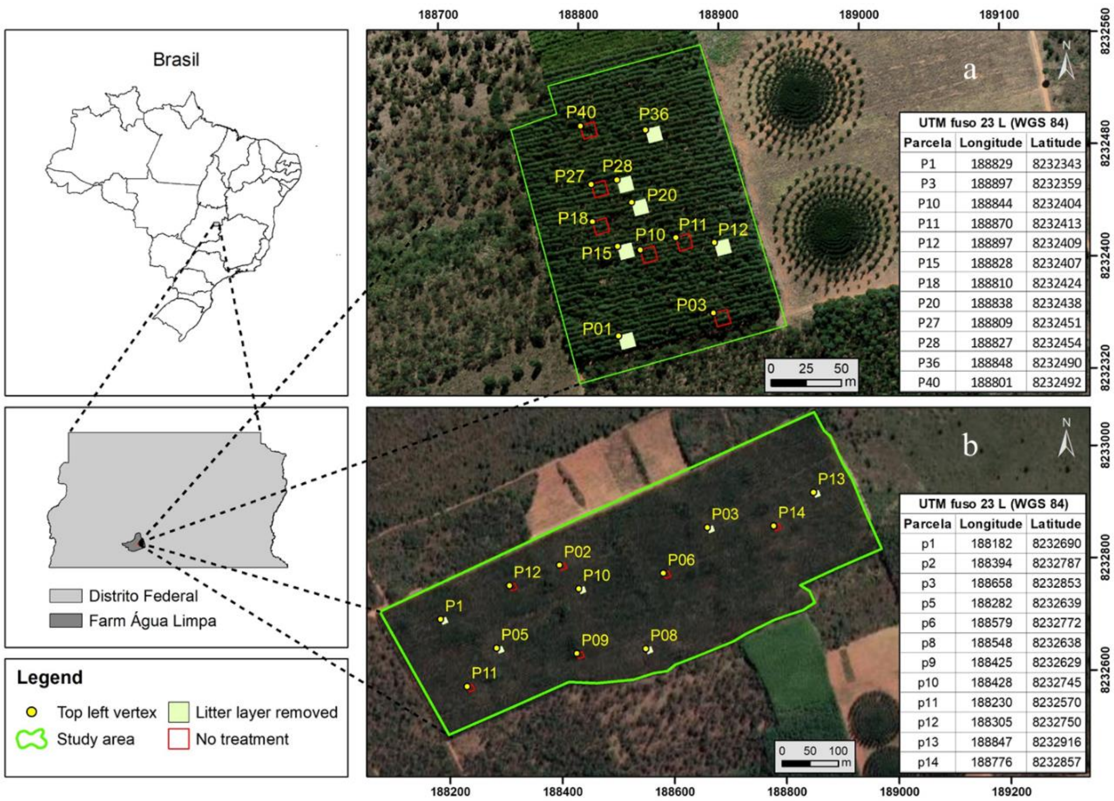

Figure 1. Studied Eucalyptus stands in Central Brazil: **(a)** Mature stand, and **(b)** Juvenile stand. Twelve plots were randomly distributed within each stand, where the red lines indicate the litter removal plots and the white lines indicate the control plots (no litter removal).

4.2.3 Litterfall sampling

Litterfall was collected monthly between May 2018 and April 2020 (two years of monthly collections). One 50 × 50 cm (0.25 m²) collector (SCORIZA et al., 2012) was installed in each of the 12 plots established in both stands (Figure). All plant material deposited monthly was carefully collected and placed in paper bags. Then, the samples were taken to the University of Brasilia's Animal Nutrition Laboratory and oven-dried at 65 ºC until reaching constant weight. The oven-dried samples were then sorted into the following fractions: leaves, reproductive parts (i.e., fruits, flower, and seeds), branches (smaller than 1cm diameter), and miscellaneous (i.e., unidentifiable plant material). Each litterfall fraction was weighed and their relative contribution to monthly total litterfall rates was estimated by extrapolating the dry mass per area to Mg ha^{-1}.

4.2.4 Litter decomposition

Decomposition rates of leaf and fine wood litter fractions were measured following the methodology proposed by Olson (1963). Briefly, the plant material was confined in 20 cm × 20 cm decomposition bags (i.e., litter bags) made with 2-mm mesh nylon and filled with 20 g of each freshly deposited leaf and fine wood material (i.e., branches <1 cm in diameter) collected on the soil surface of each stand (INF, 2015). The collections were carried out with one litterbag per plot in each stand, for each treatment at 30, 60, 120, 240, and 365 days of exposure between May 2018 and April 2019. After each litterbag collection, the remaining leaf and wood material was taken to LNA, where, after the impurities (roots and soil) were removed using a brush, it was weighed to determine the fresh weight. Then, the materials were oven-dried at 65ºC and re-weighed to determine the dry weight after reaching a constant weight. Decomposition rates were calculated as the ratio of the initial mass to the remaining mass after the exposure period, using the following equation:

$$\text{Remaining litter mass (\%)} = (\text{final litter mass}/\text{initial litter mass}) \times 100$$

The decomposition rate constant *k*, which indicates the annual mass loss, and the half-life proposed by Olson (1963), which indicates the time required for decomposition of 50% of the initial mass stored in the bags, were calculated as following, respectively:

$$X_t = X_0 * e^{-kt},$$

Where: X_t = dry weight of litter material remaining after t days and X_0 = dry weight of litter material at t = 0.

$$T_{1/2} = \ln(2) / k,$$

Where: $T_{1/2}$ = Estimated days needed to decompose 50% of the initial mass, ln = natural logarithm, and k = decomposition constant.

4.2.5 Soil chemical analysis

To quantify soil biogeochemical variables of control and litter removal plots in both stands, soil samples were collected in May 2018 and March 2020, by four random simple samples forming one composite sample per plot at two depths: 0–20 and 20–40cm, and then air-dried in the shade. The shade-dried soil samples were analyzed according to EMBRAPA (1998) by the following methods: Exchangeable aluminum (Al^{3+}), potential acidity (H + Al) by titration; phosphorus (P) and potassium (K) by Mehlich-1 extractor, where remaining P (P_{rem}) was determined using molecular absorption spectrophotometer as well as calcium (Ca^{2+}) and magnesium (Mg^{2+}); K by photometer of flame and organic matter (OM) by extraction and titration. For all samples, we calculated the total cation exchange capacity (CECt), effective cation exchange capacity (CECe), the sum of bases (SB), base saturation (V), and aluminum saturation (m).

An initial soil chemical analysis was performed in all plots in both stands to compare soil parameters before the litter manipulations, and it was not observed significant differences ($p > 0.05$) between litter removal and control plots on both depths, indicating that the plots presented similar fertility and chemical parameters before we started removing the litter layer (Appendix A).

4.2.6 Soil physical analyses

Soil volumetric and gravimetric moisture were measured following EMBRAPA (2011); three randomly selected plots from control and litter layer removal plots of each area were sampled every four months (three collections from dry and rainy seasons) from randomly selected points where trenches of 40 cm × 40 cm × 100 cm (160 L) were opened. Using a volumetric steel ring (88.60 cm^3), undisturbed soil samples were collected at the 0–20 and 20–40 cm depths. The collected samples were transported to the laboratory to determine their wet weight and were then oven-dried at 105ºC until a constant weight was reached. Volumetric moisture, soil density, gravimetric moisture, and total porosity were obtained using the following expressions:

$$VM = \left(\frac{a-b}{c}\right),$$

Where: VM = volumetric moisture (m^3 m^{-3}); a = wet sample mass (kg); b = dry sample mass (kg); c = sample volume (dm^3).

$$Bulk\ density\ (g\ /\ cm3)\ =\ a\ /\ b,$$

Where: Bulk density = g cm^{-3}; a = weight of the sample dried at 105ºC (g); and b = volume of the ring or cylinder (cm^3).

$$GM\ =\ (1)\ x\ d,$$

Where: GM = gravimetric moisture; (1) = gravimetric density and d = soil density (g cm^{-3}).

$$Tp = \left[\frac{Pd-Ds}{Pd}\right],$$

Where: Tp = Total porosity (m^3 m^{-3}), Ds = density of solid soil particles (kg dm^{-3}), and Ds = soil density (kg dm^{-3}).

4.2.7 Soil epigeic fauna

Soil epigeic fauna was sampled during the dry (September 2018) and rainy (January 2020) seasons. Five plastic fall traps (15-cm diameter) per plot containing ~200 ml of water and 10 ml of colorless neutral detergent were used as described by Baretta et al., (2007) and left in the field for 48 hours. After that, the traps were collected and taken to the FAL laboratory, manually separated with the aid of 0.125 mesh sieves, transferred to flasks containing absolute ethyl alcohol for fixation, and subsequently identified at the highest possible taxonomic level (genus, order, or family) using a magnifying lens and taxonomic keys (Appendix B).

4.2.8 Tree diameter increment

Tree diameter increment was measured biannually with a diametric tape at the breast height (DBH ~1.30 m) in all individuals with a stem diameter equal or greater than 15 cm in all plots during the two years of this study (April and October in 2018, April and October in 2019 and April 2020). Tree diameter and basal area (g) were by the following expressions:

$$d = c/\pi$$

Where: d = diameter (cm) and c = circumference (cm).

$$g = \pi\ d^2/40000$$

Where: g = basal area (cm) and d = diameter (cm).

The measurements taken at 6, 12, 18, and 24 months into the experiment were compared to the initial data (April 2018) to calculate the diameter increment of individual trees. Tree diameter increment was compared among control and litter removal plots to analyze the influence of litter removal. Also, by the sum of all individual increments in each plot, we obtained the increase in basal area in 10 m^2 and then extrapolated to m^2 per hectare, to compared this increment on control and litter removal plots. The average number of trees measured in each plot in the Mature and Juvenile stands was 14.58 and 15.25, respectively.

4.2.9 Statistical analysis

We compared monthly litterfall rates, leaf and fine wood litter decomposition, soil biogeochemical variables — including volumetric moisture, soil density, gravimetric moisture, total porosity, Al^{3+}, H + Al, P, K, Prem, Ca^{2+}, Mg^{2+}, OM, CEC_t, CEC_e, SB, V and m) — and soil epigeic fauna abundance between control and litter removal plots using t-tests. When a normal distribution was not achieved, we used the non-parametric Mann Whitney (u) test. To test the effect of litter removal on basal area gain during two years we used a three-way ANOVA, also testing increment on diameter at breast height by individual trees at the control and litter removal plots, a t-test was performed. We considered a 95% confidence level for all statistical tests.

Soil epigeic fauna abundance in control and litter removal plots was compared using a Non-metric Multidimensional Scaling (NMDS) with the Bray–Curtis dissimilarity index (BRAY; CURTIS, 1957). We applied the *envfit* function in order to fit environmental vectors, like litterfall, litter decomposition, tree grown, four soil physical parameters and fourteen chemical parameters at 0-20 and 20-40 cm depth onto the ordination to verify correlations between them and only the significant vector were plotted.

4.3. RESULTS

4.3.1 Effects of litter removal on litterfall and litter decomposition between stands

There was no significant effect ($p > 0.05$) of litter removal on monthly litterfall rates for all fractions during both study years in the Juvenile stand. The total annual litterfall in the first year (2018-2019) was 4.07 Mg ha^{-1} $year^{-1}$ in litter removal plots (82.5% of leaves, 16% branches, 0.8% reproductive material, and 0.5 % miscellaneous), and 3.89 Mg ha^{-1} in the control plots (84.1% leaves, 15.4% branches, 0.10% reproductive material and 0.67% miscellaneous (Figure 2). In the following year (2019-2020), total litterfall in litter removal plots was 4.14 Mg ha^{-1} $year^{-1}$ (78.7% leaves, 22.4% branches, and 0.2% of reproductive material and 0.77% miscellaneous), slightly lower than 4.94 Mg ha^{-1} $year^{-1}$ in the control plots (77.1% leaves, 21.9% branches, 0.17% reproductive material and 0.76% miscellaneous).

There was also no significant effect ($p > 0.05$) of litter removal on monthly litterfall rates for all fractions during both study years in the Mature stand. The annual litterfall between 2018 and 2019 was 4.41 Mg ha^{-1} $year^{-1}$ in litter removal plots (63.7% leaves, 28.2% branches, 6.6% reproductive materials and 1,4% miscellaneous). In control plots, the annual litter deposition was 4.77 Mg ha^{-1} $year^{-1}$ (63% leaves, 29.7% branches, 5.5% reproductive parts and 1.8% miscellaneous). In the second year (2019-2020), litter removal plots presented an annual litterfall of 4.90 Mg ha^{-1}, composed of 56.8% of leaves and 36.8% of branches (**Erro! Fonte de referência não encontrada.**). The control plots had 4.53 Mg ha^{-1} of annual litterfall, where 66.4% were leaves and 27.4% branches.

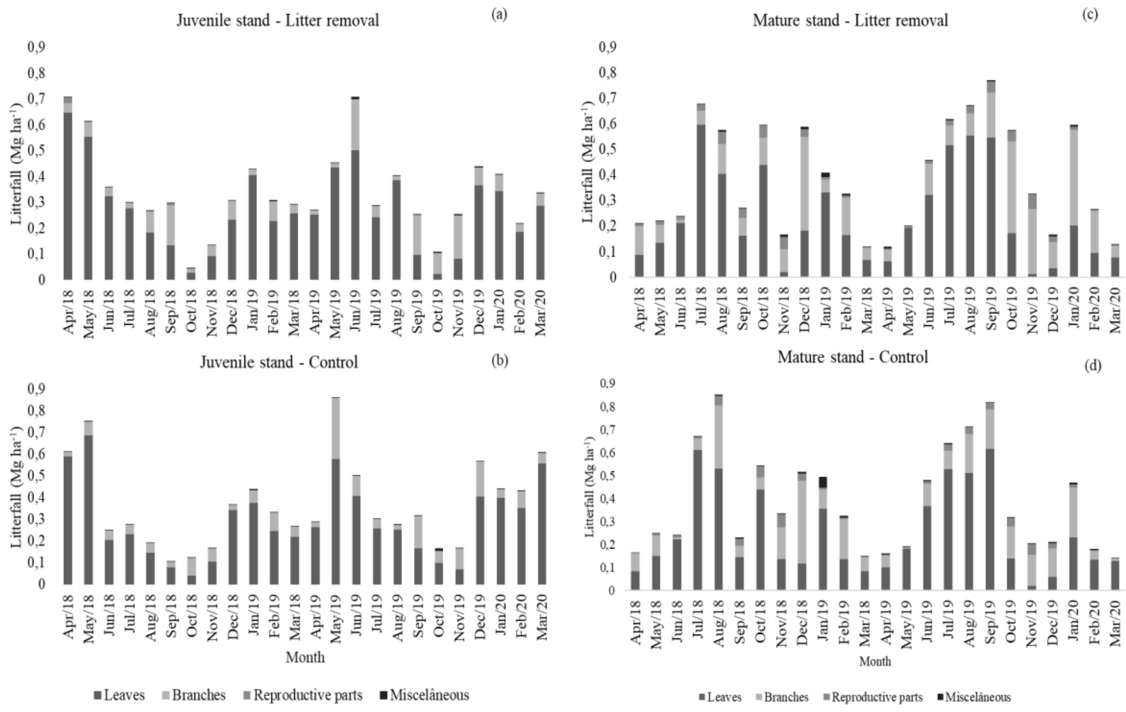

Figure 2. Monthly litterfall (Mg ha^{-1} $month^{-1}$) from April 2018 to March 2020 in: **(a)** Litter removal plots and **(b)** Control plots in Juvenile stand; **(c)** Litter removal plots and **(d)** Control plots in the Mature stand in central Brazil.

In the Juvenile stand, leaf and fine wood litter decomposition rates (Figure 3**Erro! Fonte de referência não encontrada.**a and b) were lower in litter removal plots (k leaf = 0.0009; k wood = 0.0001) relative to the control plots (k leaf = 0.001; k wood = 0.0003). These k rates in control plots led to a half-life of 301 and 1003 days for leaves and wood, respectively. In the litter removal plots, leaf litter half-life was 334 days and wood litter is 3010 days. Although, even with different k rates and half-life time, comparing the remaining mass trough the collections times, there was no significant difference between both litter removal treatments ($p > 0.05$).

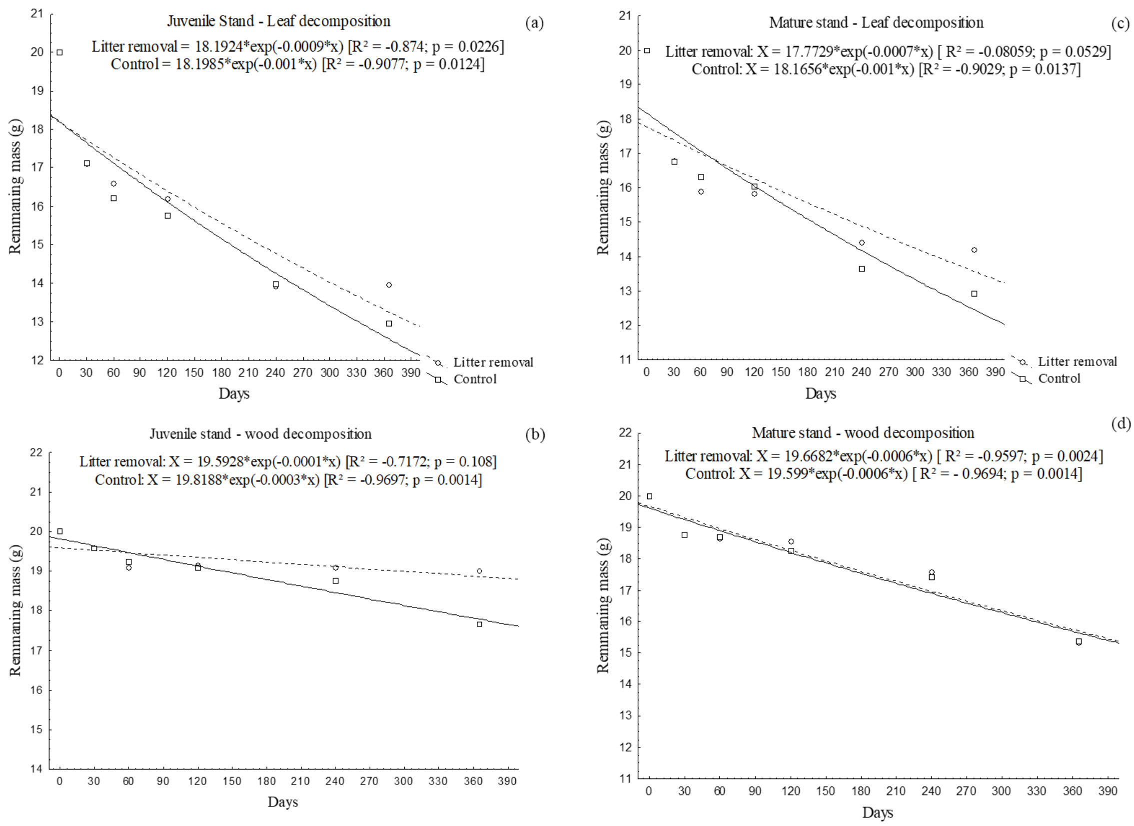

Figure 3. Exponential regression of litter biomass decay (g) during one year in litter removal and control plots. **(a)** Leaf decomposition in the Juvenile stand; **(b)** Fine wood decomposition in the Juvenile stand; **(c)** Leaf decomposition in the Mature stand; **(d)** Fine wood decomposition in the Mature stand.

In the Mature stand, leaf decomposition rate was lower in litter removal plots ($k = 0.0007$) compared to control plots ($k = 0.001$), indicating that litter removing reduced litter decomposition (Figure 3c). However, fine wood decomposition rates did not differ between control and litter removal plots ($k = 0.0006$) (Figure 3d). Leaf half-life in control plots was 301 days and 430 days for litter removal plots, resulting in more than four months of difference. Branch half-life was 502 days, indicating a faster decomposition for leaves than for wood. Although, even with different k rates and half-life time, there was no significant effect of litter removal on the remaining mass of litter throughout the experiment ($p > 0.05$).

4.3.2 Chemical and physical soil parameters

After two years of litter removal in the Juvenile stand, we did not observe differences in topsoil (0–20 cm depth) biogeochemical parameters. However, soil available P concentration at the 20–40 cm depth was higher in the litter removal plots ($p < 0.05$). All other parameters did not differ between treatments (Appendix C). In the Mature stand, only total cation exchange capacity (CECt) at the 0–20cm depth was higher in the control plots ($p < 0.05$) relative to the litter removal plots (**Erro! Fonte de referência não encontrada.**4).

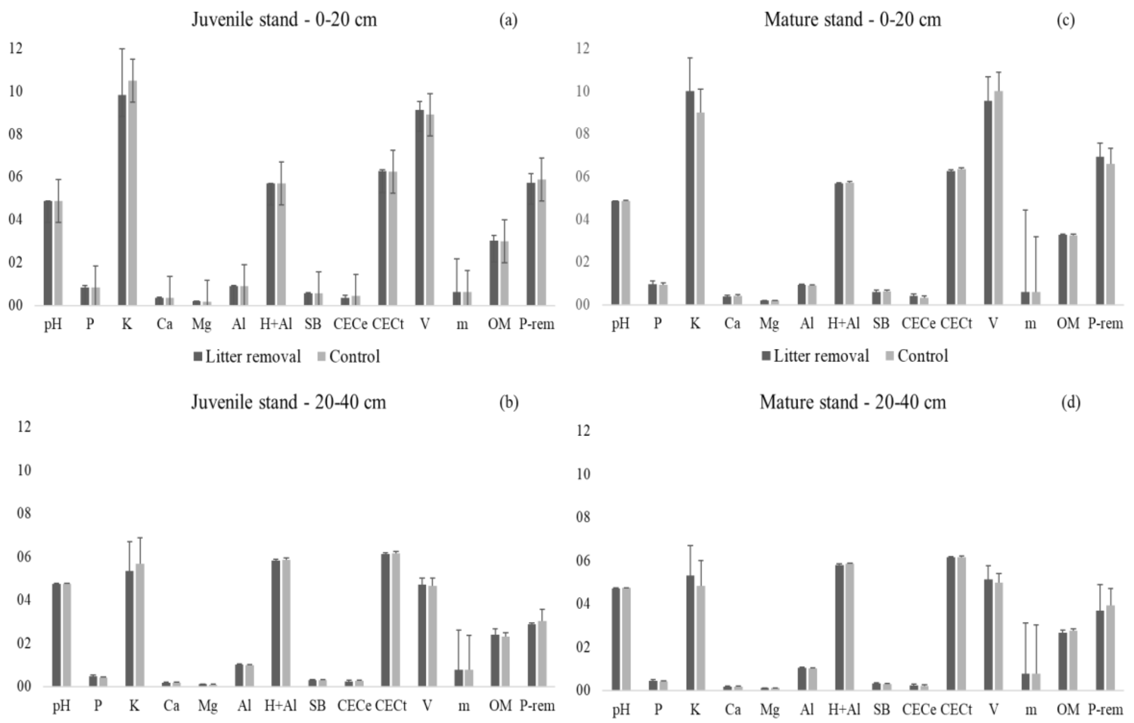

Figure 4. Soil chemical parameters in control and litter removal plots in the Juvenile and Mature Eucalyptus stands after two years of the experiment. **(a)** Juvenile stand in 0-20 cm depth; **(b)** Juvenile stand in 20-40 cm depth; **(c)** Mature stand in 0-20 cm depth; **(d)** Mature stand in 20-40 cm depth in central Brazil.

Where: SB = Sum of bases; CECe(t) = Cation exchange capacity (effective); CECt (T) = Cation exchange capacity (total); V = base saturation and m = Aluminum saturation. P and K = mg dm^{-3}; Ca^{2+}, Mg^{2+}, Al^{3+}, H+Al, SB, t and T = cmolc dm^{-3}; V and m = %; OM = dag/kg e P-Rem = mg L^{-1}.

Regarding soil physical parameters, in the Juvenile stand we did not observe differences ($p > 0.05$) between control and litter removal plots in both periods (Appendix D). However, during the dry period, in the Mature stand soil gravimetric moisture (GM) at 20-40cm depth was lower in litter removal compared to control plots ($p < 0.05$), and the same parameter at 0-20cm depth was affected (0.05), where also the litter removal plots presented lower soil moisture (Figure 5).

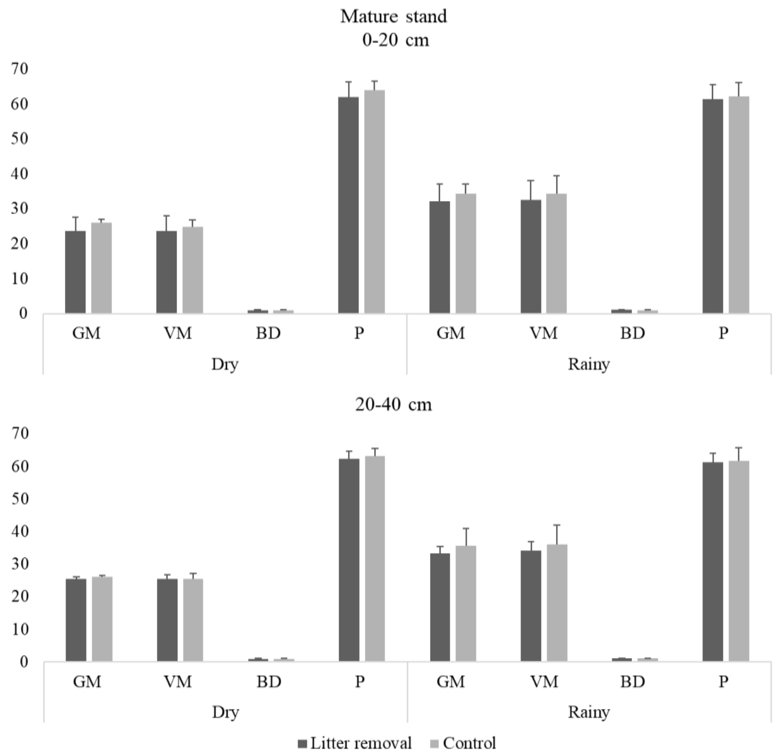

Figure 5. Soil physical variables in control and litter removal plots in Mature stand during dry and rainy seasons over two years in central Brazil.

Where: GM = Geometric moisture (m^3 m^{-3}); VM = Volumetric moisture (g cm^{-3}); BD = Bulk density (g cm^{-3}); P = Soil porosity (m^3 m^{-3}).

4.3.3 Tree diameter increment

Tree basal area increment in both stands did not differ ($p > 0.05$) between litter removal and control plots. In the Juvenile stand, basal area increments in the litter removal plots presented a semiannual average increase of 0.026 m^2 ha^{-1}, which was lower than the 0.029 m^2 ha^{-1} measured in the control plots. After two years of evaluation, this change would represent a loss of 0.42 m^2 per hectare in increment basal area due to litter removal (Appendix E).

Litter removal negatively affected the individual tree diameter increment in the Juvenile stand ($p < 0.05$), representing a 19.5% reduction after 2 years of experiment. However, the effect of litter removal on diameter increment was not noted in the Mature stand (**Erro! Fonte de referência não encontrada.**6).

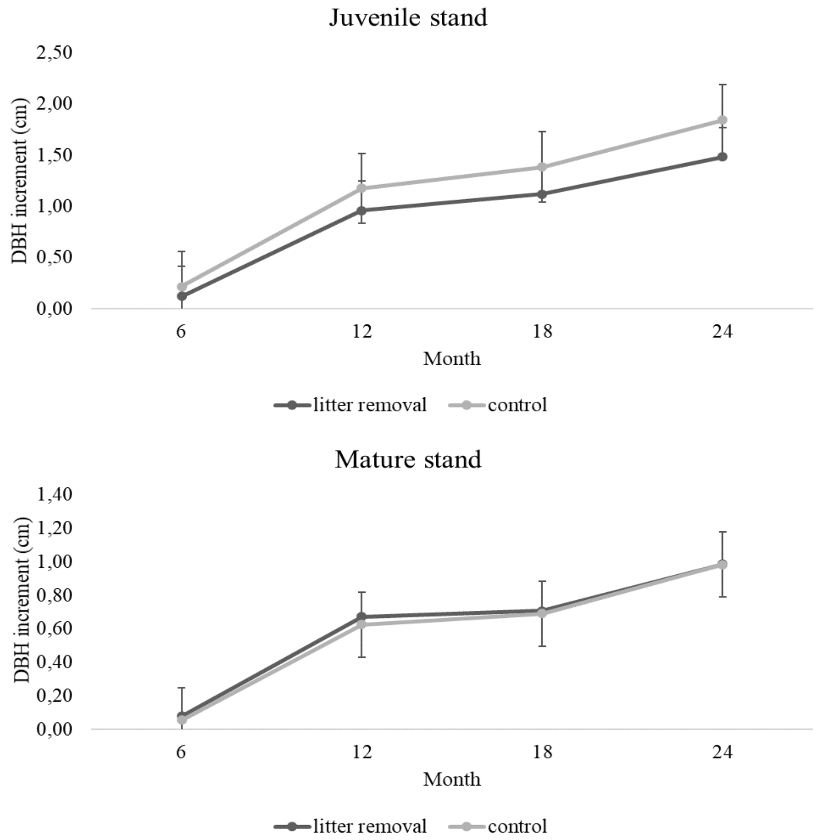

Figure 6. Two years of tree diameter at breast height (cm) accumulative increment in litter removal and control plots in Juvenile and Mature Eucalyptus stands in central Brazil.

4.3.4 Soil epigeic fauna abundance and diversity

Regardless of season, we found that in the Juvenile stand, litter removal had a significant negative effect on Hemiptera and Diptera abundances ($p < 0.05$), while all other epigeic fauna groups did not change (Appendix B). In the Mature stand, only Diplopoda and Collembola presented differences in abundance between treatments: Diplopoda was most abundant in control plots and Collembola was most abundant in litter removal plots ($p < 0.05$). The abundance of Diptera organisms in the Mature stand was negatively affected ($p = 0.05$) by litter removal.

The NMDS presented at a low-stress level (0.09), indicating a good fit of observed and actual dissimilarities (Figure 7). Regarding the distribution of litter removal and control plots, we could observe a higher homogeneity of soil epigeic fauna communities in litter layer removal plots, while in the control plots, we can notice a more heterogeneity trend between plots, indicating a reduction of beta biodiversity by litter removal management. Also, Shannon's diversity vector ($p < 0.05$) correlated positively with control plots rather than litter removal plots, indicating that litter removal also reduced the soil epigeic fauna diversity.

The other significant vectors ($p < 0.05$) were: soil moisture at 0-20 and 20-40cm depth, remaining P also on these two depths, wood decomposition k rates and available P. Soil moisture in both sample depths are correlated to control plots, indicating relation between soil epigeic fauna and humidity. The same trend observed for the remaining P that represents buffer power P soil. Also, wood decay was correlated to control plots epigeic fauna diversity, while only the available P was more correlated to the litter removal plots (Appendix F). All other environmental parameters tested presented no significant effects ($p > 0,05$).

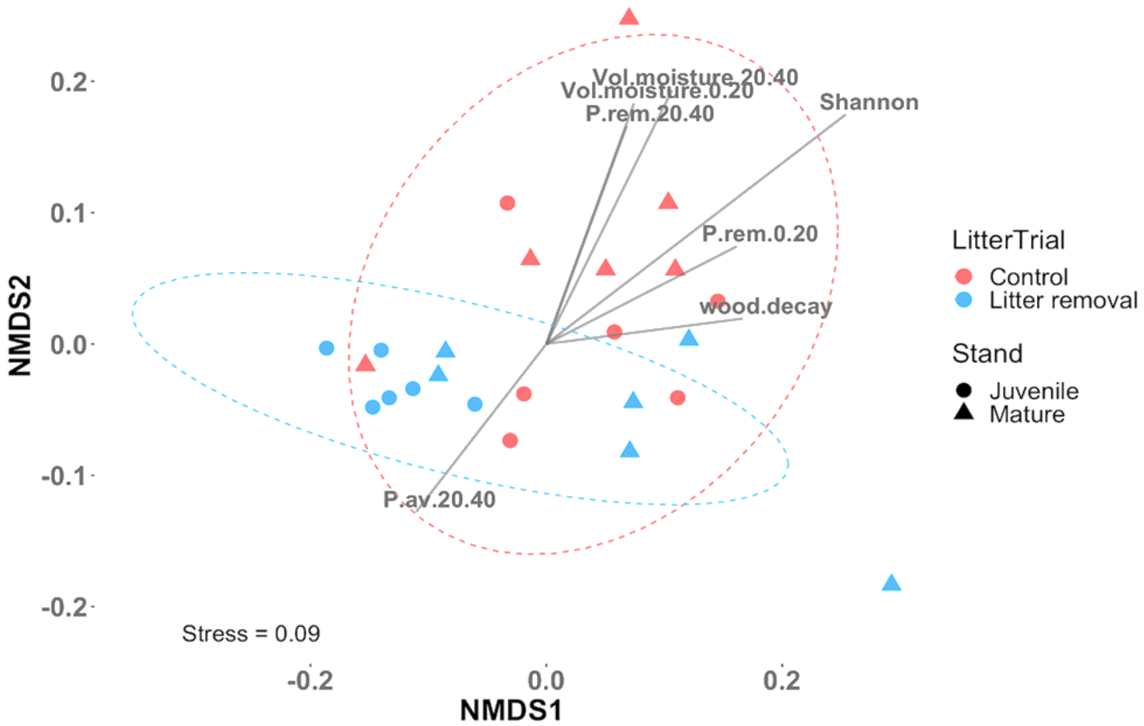

Figure 7. Non-metric multidimensional scaling (NMDS) plot of soil epigeic fauna including the environmental vectors in juvenile and mature Eucalyptus stands in central Brazil.

Where: P. av. = Avaliable P (mg dm^{-3}); P. rem. = Remaining P (mg L^{-1}); Vol. moisture = Volumetric moisture (g cm^{-3}); Shannon = Shannon's diversity Index (h') and Wood decay = Wood decomposition (k) rates.

4.4 DISCUSSION

4.4.1 Litter removal affects Eucalyptus litter decomposition rates, but not litterfall

Contrary to our predictions, litterfall was not affected by litter removal in both Eucalyptus stands. We expected litter removal to negatively impact litterfall because litter dominates the intra-annual nutrient cycling representing a major pathway for the transfer of mineral nutrients and organic matter from vegetation to soil, in such that soil nutrient availability is known to influence litter production (SAYER, 2020). But litter production is also affected by numerous aspects such as climate and evapotranspiration (GIWETA, 2020). We expeculate that if our litter removal experiment had continued for over two years, litterfall would be affected by this type of management practice. as seen by other studies as Nzila et al., (2002).

Our results and analysis indicated that litter decomposition (leaf and wood) was negatively affected by litter removal regardless of Eucalyptus stand age. Given that the litter layer strongly influences soil moisture and temperature, and soil biogeochemical variables, litter removal may have generally decreased decomposer activity. For instance, microbial communities that decompose plant litter are commonly negatively affected by changes in microclimate (GIWETA, 2020). In another study in tropical China, litter removal decreased litter decomposition in three successional forests by up to 27% (CHEN et al., 2014). Litter removal in Pine plantations in northern Argentina also showed a decrease in litter decomposition rates as early as after one month of exposure (TRENTINI et al., 2018). Those authors also reported that litter removal had a strong impact on soil fauna communities that lives in litter layer and not the soil, what could be observed at the NMDS analyses in the most heterogeneity distribution of soil epigeic communities in non-litter removal plots (**Erro! Fonte de referência não encontrada.**)

However, microbial decomposer activity is not always affected by short-term litter manipulation (FAHEY; BATTLES; WILSON, 1998). This may explain our observed null effect of litter removal on wood decomposition rates in the Mature stand. Similarly, Wang et al. (2019) found no differences in litter decomposition rates due to litter removal in a Eucalyptus-dominated forest of southeast Queensland, Australia. Also, in older stands, litter decomposition tends to be slower (VALADÃO et al., 2019), and the effects of litter removal are less detectable in short-term experiments (< 5 years). This could explain the null effect of litter removal on wood decomposition rates in the Mature stand.

4.4.2 Litter removal reduced water content and remaining P but increased available P content

Litter removal in Mature stand significantly reduced gravimetric moisture during the dry period, while all other physical parameters did not change. By contrast, litter removal in the Juvenile stand did not affect soil physical parameters. Contrary to our findings, Versini et al. (2013) found that soil water content decreased with litter removal in a young Eucalyptus stand with a higher spacing of 3.3 x 3.7 m. This may be explained by the canopy structure of our Juvenile and Mature stands because there is less direct solar radiation on the soil surface when the canopy is closed (LEI et al., 2018). Also, the litter layer acts as a natural buffer for soil water content (GIWETA et al., 2020) especially during the dry season, which corroborates the observed decrease in soil moisture content by litter removal during this period. This might have influenced the lower litter decomposition rates found in the litter removal plots, since soil moisture directly influences soil fauna activity and, consequently, litter decomposition (PETRAGLIA et al., 2019).

In terms of soil chemistry, total cation exchange capacity at 0-20 cm depth was the only variable that decreased with litter removal in the Mature stand. This trend may be explained by the reduction of organic residues that could be starting to affect soil organic matter (SOM) contents in litter removal plots, given SOM is highly correlated to total cation exchange capacity in tropical regions (NOVAIS, 2007). Yet, no significant difference in SOM content was found in control and litter removal plots in both stands.

In the Juvenile stand, subsurface soil P availability increased with litter removal. This may be related to the characteristics of this macronutrient and its buffering power that tends to equalize labile and non-labile soil pools (NOVAIS, 2007). With litter removal and the consequent reduction of P from litter, soil P becomes more present in the soil solution; however, this presence may not represent greater availability to plants due to a low mobility in the soil. Because of the predominance of positive charges in the highly weathered soils in the Cerrado, soil P adsorption in Fe/Al oxyhydroxides is favored. Also, the correlations between soil fauna diversity and the remaining P in control plots supports this assumption. According to Sayer et al. (2020), soil P concentrations after litter removal presents significant interannual fluctuations, which may also be other explanation for the increased soil P concentration in our litter removal plots after two years of experiment.

The non-impact on most part of the chemical parameters matches with Wang et al., (2019) study in Eucalyptus-dominated forests in Australia which found no significant differences in soil chemistry due to short-term litter manipulation, suggesting that the Australian studied stands were resistant to 15 months of litter removal. On the other hand, several studies reported significant impacts of litter removal on soil organic carbon (CAO et al., 2020), total carbon, pH and P, (TANNER; SHELDRAKE; TURNER, 2016), K, Ca and Mg (VERSINI et al., 2014; WANG et al., 2019). Given litter decomposition rates were affected by litter removal, we speculate that soil fertility can be impacted over the following years in the litter removal plots. This is based on the fact that the decomposition of litter is essential for plant nutrition in eucalyptus stands after two years after planting, where, then, the cycling of nutrients occurs naturally through the fall of litter along the development of the stand and become the main source of nutrients for the plants (SCHUMACHER; VIEIRA, 2015).

4.4.3 Tree diameter increment influenced by litter manipulation

Litter removal negatively affected the tree diameter increments in the Juvenile, but not in the Mature stand. This finding is supported by other studies showing that the effect of organic residue removal on Eucalyptus tree growth in Congo and Brazil also reduced the mean tree growth (Laclau et al., 2010 a, 2010 b). Versini et al. (2013) found that litter removal decreased above-ground biomass by 33 to 38%. Rocha et al., (2016) found that wood productivity after removal or burning of forest residues were 6% lower than in the control plots. However, Wood et al. (2009), studying litter removal effects on old-growth tropical wet forests, found that litter removal had no significant effect on woody growth, similar to our findings in the Mature stand.

The differences in tree growth response to litter removal between the Juvenile and Mature stands can be explained by the slower tree growth in older stands, which have already reached their growth stabilization peak. Also, in Mature stands, litter decomposition tends to be slower (VALADÃO et al., 2019) in such that the effects of litter removal management in tree grown trends are less perceptive in short-term experiment (< 5 years).

4.4.4 Litter removal negatively impacted soil epigeic fauna abundance and diversity

We found that the soil epigeic fauna organisms belonging to Hemiptera, Diptera, and Diplopoda orders were affected by litter removal in both Eucalyptus stands (Appendix B). The observed reduction of Hemiptera individuals in the Juvenile stand could have important consequences for ecosystem function, like break food chain (GOLDMAN et al., 2020). Because this order is commonly found in Eucalyptus stands (Reference), a reduction due to litter removal could lead serious consequences on the edaphic food chain. The Diptera order — which decreased by over 50% relative to the control values in the Juvenile stand — is one of the most important insect groups in soils; this order is only temporarily present in soils because of a remarkable litter-decaying activity (ASSAD, 1997). Other studies also reported that Diptera was severely impacted by litter manipulation in *Corymbia citriodora* plantations in southeastern Brazil (CAMARA et al., 2019). Because the Diptera order is one of the most abundant soil fauna group in Eucalyptus plantations (MARTINS et al., 2017; TACCA; KLEIN; PREUSS, 2017), the impact of litter removal on their abundance represents a major ecological concern to Eucalyptus stand function.

Litter removal in the Mature stand led to a reduction of Diplopoda organisms. According to Nsabimana (2013), Diplopoda is one of the most frequent found edaphic group across several types of Eucalyptus stands, and is extremely dependent on litter for habitat and food (ASSAD, 1997). Diplopoda also contributes to the transformation of plant residues to SOM, thus their disappearance can spoil nutrient cycling and disturb the soil food chain. Overall, our findings corroborate Trentini et al., (2018), who reported that litter removal in an exotic Pinus plantation in Argentina reduced the abundance of some soil epigeic fauna groups.

Regardless of stand, the litter removal homogenized the soil epigeic fauna abundance. Shannon's diversity index was highly correlated to the control plots indicating a reduction of the soil epigeic fauna abundance and diversity by litter removal management. In this context, in a 15 years experiment in old growth lowland tropical forest, Sayer et al., (2020) found that litter removal reduced the soil arthropod abundance, and this process explained at least partly of the reduction of litter decomposition rates, what can impact on the hole nutrient cycling processes.

The correlation between soil moisture and soil epigeic fauna found in control plots represented a major concern in litter removal management since soil humidity influences the epigeic fauna diversity because every organism of soil had an optimal humidity point to survive (WASIS; WINATA; MARPAUNG, 2018). Since that litter removal practices reduced the soil moisture, especially in dry seasons, soil epigeic fauna can be directly affected and consequently spoil the hole nutrient cycling process.

Soil organisms are partially dependent on litter deposition as most epigeic fauna species and populations use litter as niche more than the soil (TRENTINI et al., 2018). Consequently, they are a key component in nutrient cycling in both managed and unmanaged systems (ASHFORD et al., 2013).

4.5 CONCLUSIONS

We evaluated the impacts of litter removal management practices in Eucalyptus stands, highlighting the impacts of litter layer removal on litter-soil-plant interactions. Our two-year study showed that in both stands, leaf litter decomposition was slower in litter removal plots. This suggests that the litter removal impacted litter decomposition, which can in turn affect nutrient cycling in Eucalyptus plantations. Individual tree diameter increment was only affected by litter removal in the Juvenile stand, which can be a consequence of a slower growth in Mature stands compared to Juvenile ones, due to the fact that juvenile stands have not yet reached the peak growth stabilization.

We found that litter removal affected certain soil faunal groups in such that the abundance of Hemiptera, Diptera and Diplopoda groups decreased with litter removal. Soil remaining P and moisture, wood decay rate, and Shannon's diversity were correlated to control plots, suggesting that litter removal can promote a breakdown on the edaphic food chain impacting nutrient cycling processes that can spoil the whole ecosystem functioning.

Although litterfall was not affected by litter removal, in the long term, we believe this could be the case in the long term due to changes in nutrient cycling processes promoted by litter layer removal. Additional long-term ecological studies in Eucalyptus stands in the seasonal tropics are encouraged to better understand the impacts of litter removal practices on litter-soil-plant interactions in order to support management decisions and prescriptions.

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4.7 REFERENCES

ALVARADO, S. T. et al., Drivers of fire occurrence in a mountainous Brazilian cerrado savanna: Tracking long-term fire regimes using remote sensing. **Ecological Indicators**, v. 78, p. 270–281, 2017.

ASSAD, M. L. L. Fauna do solo. In: VARGAS, M. A. T.; HUNGRIA, M., (Eds) **Biologia dos solos dos cerrados**. 1. Ed. Planaltina: EMBRAPA, 1977. p. 363-443.

ASHFORD, O. S. et al., Litter manipulation and the soil arthropod community in a lowland tropical rainforest, **Soil Biology & Biochemistry**, v. 62, p. 5–12, 2013.

BALIEIRO F. C. et al., Ecosystem Services in Eucalyptus Planted Forests and Mixed and Multifunctional Planted Forests. In: Cardoso B. N. E., Gonçalves J., Balieiro F., Franco A. (eds) **Mixed Plantations of Eucalyptus and Leguminous Trees**. Springer, Cham. pp. 193-219, 2020.

BARETTA, D. et al., Fauna edáfica avaliada por armadilha e por catação manual afetada pelo manejo do solo na região Oeste Catarinense. **Revista de Ciências Agroveterinárias**, v. 2, n. 2, p. 97-106, 2003.

BARETTA, D. et al., Trap and soil monolith sampled edaphic spiders (arachnida: araneae) in Araucaria angustifolia forest. **Scientia Agricola**, v. 64, n.4, p. 375-383, 2007

BOENO, D. et al., Influence of eucalyptus development under soil fauna. **Brazilian Journal of Biology**, v. 80, n. 2, p. 345-353, 2020.

BOULMANE, M. et al., The potential of Eucalyptus plantations to restore degraded soils in semi-arid Morocco (NW Africa). **Annals of Forest Science**, v. 74, n. 57, p. 1-10, 2017.

BRAY, J. R., CURTIS, J. T., An ordination of the upland forest communities of southern Wisconsin. **Ecological Monographs**, v. 27, p.325–349, 1957.

CAMARA, R. et al., Impacto da remoção de serapilheira sobre a comunidade de artrópodes edáficos em plantios abandonados de Corymbia citriodora, **Ciência Florestal**, v. 29, n. 1, p. 14-26, 2019.

CAO, J. et al., Leaf litter contributes more to soil organic carbon than fine roots in two 10-year-old subtropical plantations. **Science of Total Environment**, n. 704, p. 135–341, 2020.

CASTRO, C. A. O. et al., Brief history of Eucalyptus breeding in Brazil under perspective of biometric advances. **Ciência Rural**, v. 46, n. 9, p. 1585-1593, 2016.

CHEN, H. et al., Effects of Litter Manipulation on Litter Decomposition in a Successional Gradients of Tropical Forests in Southern China. **PLoS ONE**, v.9, n.6 e99018, 2014. doi:10.1371/journal.pone.0099018

CORREA C. M. A. et al., Exotic pastureland is better than Eucalyptus monoculture: β-diversity responses of flower chafer beetles to Brazilian Atlantic Forest conversion. **International Journal of Tropical Insect Science**, v.1, p. 1-8, 2020. Doi:<https//:10.1007/s42690-020-00186-9>.

Empresa Brasileira de Pesquisa Agropecuária EMBRAPA. **Manual de métodos de análises do solo**. 2.ed. Rio de Janeiro: Ministério da Agricultura e do Abastecimento, 2011. 230 p.

Empresa Brasileira de Pesquisa Agropecuária (Embrapa); **Manual de Métodos de Análises Químicas para Avaliação da Fertilidade do Solo**; da Silva, F. C.; da Eira, P. A.; Barreto, W. O.; Pérez, D. V.; Silva, C. A., eds.; EMBRAPA-CNPS: Rio de Janeiro, 1998, 56 p.

FAHEY T. J., BATTLES, J. J., WILSON, G. F. Responses of early successional northern hardwood forests to changes in nutrient availability. **Ecological Monographs**, v. 68, p. 183–212, 1998.

GARLET, C. et al., Ciclagem de nutrientes em povoamento de Eucalyptus dunnii Maiden: produção de serapilheira e devolução de macronutrientes no bioma Pampa. **Ecologia e Nutrição Florestal/Ecology and Forest Nutrition**, v.7, n.5, p. 1-9, 2019.

GIWETA, M. Role of litter production and its decomposition, and factors affecting the processes in a tropical forest ecosystem: a review. **Journal of Ecology and Environment**, v.44, n. 1, p. 1-9, 2020. < https://doi.org/10.1186/s41610-020-0151-2>.

GOLDMAN, A. E. et al., Drought and presence of ants can influence hemiptera in tropical leaf litter. **Biotropica**, n. 52, p. 221– 229, 2020. <https://doi.org/10.1111/btp.12762>.

GOMES, L. et al., How can we advance the knowledge on the behavior and effects of fire in the Cerrado biome? **Forest Ecology and Management**, v. 417, p. 281–290, 2018.

HARIDASAN, M. Solos do Distrito Federal. In: PINTO, N. M. (ed), **Cerrado: Caracterização, ocupação e perspectivas - O caso do Distrito Federal**. Editora Universidade de Brasília/SEMATEC, Brasília, 1994, p.322-334.

HARIDASAN, M. Nutrição mineral de plantas nativas do cerrado. **Revista Brasileira de Fisiologia Vegetal**, Londrina, v. 12, n. 1, p. 54-64, 2000.

Inventário Florestal Nacional - IFN. **Manual de campo: Procedimentos de coleta de dados biofísicos e Socioambientais**, Serviço Florestal Brasileiro. – Brasília: SFB, 2015, 67 p.

INDÚSTRIA BRASILEIRA DE ÁRVORES – IBÁ, 2020**. Anuário estatístico IBÁ 2020 ano base 2019**. Brasília: IBÁ.

LACLAU, J. P. et al., Organic residue mass at planting is an excellent predictor of tree growth in Eucalyptus plantations established on a sandy tropical soil. **Forest Ecology and Management**. v. 260, p. 2148–2159, 2010a.

LACLAU, J. P. et al., Biogeochemical cycles of nutrients in tropical Eucalyptus plantations: main features shown by intensive monitoring in Congo and Brazil. **Forest Ecology and Management**, v. 259, p. 1771–1785, 2010b.

LEI, L. et al., Thinning but not understory removal increased heterotrophic respiration and total soil respiration in Pinus massoniana stands. **Science Total Environmental**, n. 621, p. 1360-1369, 2018.

MARTINS, L. F. et al., Composição da macrofauna do solo sob diferentes usos da terra (cana-de-açúcar, eucalipto e mata nativa) em Jacutinga (MG). **Revista Agrogeoambiental**, v. 9, n. 1, 2017.

MORANDI, P. S. et al., Tree diversity and above-ground biomass in the South America Cerrado biome and their conservation implications. **Biodiversity and Conservation**, v. Online, p. 1–18, 2018.

MYERS N., et al., Biodiversity hotspots for conservation priorities. **Nature**, v.403, p.853–858, 2000.

NIMER, E. **Climatologia do Brasil**. 2ª ed, Rio de Janeiro: IBGE, Departamento de Recursos Naturais e Estudos Ambientais, 1989, 421 p.

NOVAIS, R. F. et al., **Fertilidade do Solo**. Viçosa: Sociedade Brasileira de Ciência do Solo, v.1, 2007, 1017 p.

NSABIMANA, D. Seasonal variation of litter arthropods in some Eucalyptus plantations at the Arboretum of Ruhande in Rwanda. **Journal of Biology, Agriculture and Healthcare**, n. 3, p. 49-56, 2013.

NZILA, J. D. et al., The effects of slash management on nutrient cycling and tree growth in Eucalyptus plantations in the Congo. **Forest Ecology and Management**, v. 171, n. 1–2, p. 209-221, 2002.

OLSON, J. S. Energy storage and the balance of producers and decomposers in ecological systems. **Ecology**, Hoboken, v. 44, n. 2, p. 322-331, 1963. https://doi.org/10.2307/1932179

PAULUCIO, V. O. et al., Reforestation of a degraded area with eucalyptus and sesbania: microbial activity and chemical soil properties. **Revista Brasileira de Ciência do Solo**; v. 41, e0160239, 2017.

PENÃ-PENÃ, K.; IRMLER, U. Moisture seasonality, soil fauna, litter quality and land use as drivers of decomposition in Cerrado soils in SE-Mato Grosso, Brazil. **Applied Soil Ecology**, v. 107, p. 124–133, 2016.

PETRAGLIA, A. et al., Litter decomposition: effects of temperature driven by soil moisture and vegetation type. **Plant Soil**, v. 435, p.187–200, 2019.

PRITCHETT, W. **Properties and management of forest soils**. 2nd ed. New York, John Wiley, 1979, 494 p.

REIS, A. et al., Nucleação: concepção biocêntrica para a restauração ecológica. Ciência Florestal, v. 24, n.2, p. 509-519, 2014.

ROCHA, J. H. T. et al., Forest residue maintenance increased the wood productivity of a Eucalyptus plantation over two short rotations. **Forest Ecology and Management**, v. 379, p. 1–10, 2016.

ROSA, M. G. et al., Macrofauna Edáfica e Atributos Físicos e Químicos em Sistemas de Uso do Solo no Planalto Catarinense. **Revista Brasileira de Ciência do Solo**, v. 39, n.6, p. 1544-1553, 2015.

SAYER, E. J. Using experimental manipulation to assess the roles of leaf litter in the functioning of forest ecosystems. **Biological Reviews**, v.81, p.1–31, 2006.

SAYER, E. J. et al., Revisiting nutrient cycling by litterfall—Insights from 15 years of litter manipulation in oldgrowth lowland tropical forest. In: **Advances in Ecological Research**. [s.l.] Elsevier, v. 62, p. 173–223, 2020.

SCHUMACHER, M. V.; VIERA, M. Ciclagem de nutrientes em plantações de eucalipto. In: SCHUMACHER, M. V.; VIERA, M. (Org.). **Silvicultura do Eucalipto no Brasil**. Santa Maria: UFSM, 2015, p. 273-307.

SCORIZA, R. N. et al., Métodos para coleta e análise de serapilheira aplicados à ciclagem de nutrientes. **Floresta e Ambiente**, v. 2, n. 2, p. 01-18, 2012.

SENA, K. N. et al., Organic carbon and physical properties in sandy soil after conversion from degraded pasture to eucalyptus in the brazilian cerrado. **Revista Brasileira de Ciência do Solo**, v. 41, e0150505, 2017.

SOUZA, S. T. de. et al., Abundance and Diversity of Soil Macrofauna in Native Forest, Eucalyptus Plantations, Perennial Pasture, Integrated Crop-Livestock, and No-Tillage Cropping. **Revista Brasileira de Ciência do Solo**, v. 40, n. 1, p. 1-14, 2016.

TACCA, D.; KLEIN, C.; PREUSS, J. F. Artropodofauna do solo em um bosque de eucalipto e um remanescente de mata nativa no sul do Brasil. **Ciências Biológicas**, v. 14, n.2, p. 249-261, 2017.

TANNER, E. V. J.; SHELDRAKE, M. W. A.; TURNER, B. L. Changes in soil carbon and nutrients following 6 years of litter removal and addition in a tropical semi-evergreen rain forest. **Biogeosciences**, n. 13, p. 6183– 6190, 2016.

TRENTINI, C. P. et al., Effect of nitrogen addition and litter removal on understory vegetation, soil mesofauna, and litter decomposition in loblolly pine plantations in subtropical Argentina. **Forest Ecology and Management**, v. 429, p. 133–142, 2018.

VALADÃO, M. B. X. et al., Litterfall, litter layer and leaf decomposition in Eucalyptus stands on Cerrado soils. **Scientia Forestalis**, v. 47, n. 122, p. 256-264, 2019.

VERSINI, A. et al., The manipulation of organic residues affects tree growth and heterotrophic CO2 efflux in a tropical Eucalyptus plantation. **Forest Ecology and Management**, n.301, p. 79–88, 2013.

VERSINI, A. et al., Effects of litter manipulation in a tropical Eucalyptus plantation on leaching of mineral nutrients dissolved organic nitrogen and dissolved organic carbon. **Geoderma**, n. 232, p. 426-436, 2014.

ZUIN, V.G. What Can Be Learnt from the Brazilian Cerrado? In: Mammino L. (eds) **Biomass Burning in Sub-Saharan Africa**. Springer, Dordrecht, 2020, p.143-160.

WANG, Y. et al., Effects of changed litter inputs on soil labile carbon and nitrogen pools in a eucalyptus-dominated forest of southeast Queensland, Australia. **Journal of Soils and Sediments**, n. 19, p. 1661–167, 2019.

WOOD, T. E. et al., Rain forest nutrient cycling and productivity in response to large-scale litter manipulation. **Ecology**, v. 90, n.1, p. 109–121, 2009.

WASIS, B.; WINATA, B.; MARPAUNG, D. R. Impact of land and forest fire on soil fauna diversity in several land cover in Jambi Province, Indonesia. **Biodiversitas**, V. 19, n. 2, p. 740-746, 2018.

Appendix A. Initial chemical soil parameters in Juvenile and Mature Eucalyptus stands, on control and litter removal plots (May 2018 – dry season), analyzed by t-test and Mann-Whitney test at 95% confidence.

Juvenile stand										
Depth	0-20 cm					20-40 cm				
	Litter removal	S.d.	Control	S.d.	Test	Litter removal	S.d.	Control	S.d.	Test
pH	5.21	0.12	5.06	0.25	p > 0,05	5.22	0.17	5.28	0.18	p > 0,05
P	0.42	0.13	0.43	0.22	p > 0,05	0.32	0.17	0.25	0.08	p > 0,05
K	16.00	5.55	17.83	5.12	p > 0,05	9.83	2.64	8.33	3.98	p > 0,05
Ca	0.08	0.02	0.10	0.05	p > 0,05	0.09	0.04	0.09	0.03	p > 0,05
Mg	0.03	0.01	0.05	0.02	p > 0,05	0.03	0.01	0.03	0.01	p > 0,05
Al	0.26	0.05	0.32	0.16	p > 0,05	0.00	0.00	0.03	0.08	p > 0,05
H+Al	6.07	0.38	6.30	0.83	p > 0,05	4.27	0.45	4.28	0.42	p > 0,05
SB	0.16	0.02	0.19	0.05	p > 0,05	0.14	0.04	0.14	0.04	p > 0,05
CECe	0.41	0.05	0.51	0.15	p > 0,05	0.14	0.04	0.18	0.11	p > 0,05
CECt	6.22	0.38	6.49	0.83	p > 0,05	4.41	0.44	4.43	0.44	p > 0,05
V	2.52	0.43	2.93	0.92	p > 0,05	3.23	1.22	3.22	0.82	p > 0,05
m	61.68	7.14	59.97	17.24	p > 0,05	0.00	0.00	8.33	20.41	p > 0,05
OM	3.88	0.43	4.28	0.56	p > 0,05	3.08	0.24	3.02	0.36	p > 0,05
P-rem	7.97	1.23	7.87	1.74	p > 0,05	5.52	0.96	6.33	1.12	p > 0,05
Mature stand										
Depth	0-20 cm					20-40 cm				
	Litter removal	S.d.	Control	S.d.	Test	Litter removal	S.d.	Control	S.d.	Test
pH	4.75	0.18	4.87	0.11	p > 0,05	4.97	0.11	5.09	0.12	p > 0,05
P	0.45	0.12	0.50	0.34	p > 0,05	0.17	0.08	0.17	0.12	p > 0,05
K	5.67	6.06	10.83	9.06	p > 0,05	2.33	5.72	4.83	5.56	p > 0,05
Ca	0.16	0.05	0.21	0.18	p > 0,05	0.10	0.02	0.15	0.06	p > 0,05
Mg	0.09	0.08	0.15	0.24	p > 0,05	0.04	0.03	0.05	0.05	p > 0,05
Al	0.42	0.08	0.40	0.11	p > 0,05	0.02	0.04	0.03	0.05	p > 0,05
H+Al	6.90	0.55	6.83	1.15	p > 0,05	4.67	0.38	4.67	0.50	p > 0,05
SB	0.26	0.15	0.38	0.43	p > 0,05	0.15	0.05	0.21	0.10	p > 0,05
CECe	0.68	0.15	0.78	0.52	p > 0,05	0.17	0.10	0.25	0.13	p > 0,05
CECt	7.16	0.51	7.21	1.57	p > 0,05	4.82	0.43	4.88	0.57	p > 0,05
V	3.70	2.13	4.62	3.74	p > 0,05	3.05	0.82	4.27	1.50	p > 0,05
m	62.75	11.91	58.33	14.89	p > 0,05	4.63	11.35	10.42	17.44	p > 0,05
OM	4.19	0.25	4.37	0.82	p > 0,05	3.04	0.28	2.99	0.32	p > 0,05
P-rem	5.77	2.76	7.72	3.72	p > 0,05	2.10	2.86	4.27	3.27	p > 0,05

Where: S.d. = Standard deviation; SB = Sum of bases; CECe(t) = Cation exchange capacity (effective); CECt (T) = Cation exchange capacity (total); V = base saturation and m = Aluminum saturation. P and K = mg dm^{-3}; Ca^{2+}. Mg^{2+}. Al^{3+}. H+Al. SB. t and T = cmolc dm^{-3}; V and m = %; OM = dag/kg e P-Rem = mg/L.

Appendix B. Soil epigeic fauna in Juvenile and Mature Eucalyptus stands. on control and litter removal plots. analyzed by t-test and Mann-Whitney test at 95% confidence.

Juvenile Eucalyptus					
	Litter removal (mean)	**S.d.**	**Control (mean)**	**S.d.**	**p**
Formicidae	1544.83	3143.26	198.83	81.84	$p > 0.05$
Collembola	8.33	7.87	23.83	18.27	$p > 0.05$
Hemiptera	1.33	0.82	5.67	2.34	$p < 0.05$
Araneae	3.83	3.71	25.67	47.70	$p > 0.05$
Diptera	11.00	7.40	23.50	10.21	$p < 0.05$
Hymenoptera	2.83	1.94	2.17	2.04	$p > 0.05$
Blapoda	0.17	0.41	0.50	0.55	$p > 0.05$
Isoptera	0.67	0.82	4.50	4.23	$p > 0.05$
Coleoptera	3.33	3.50	9.67	8.87	$p > 0.05$
Isopoda	0.00	0.00	0.33	0.82	$p > 0.05$
Opiliones	0.33	0.82	0.00	0.00	$p > 0.05$
Ortoptera	1.00	0.63	1.50	1.05	$p > 0.05$
Neuroptera	0.17	0.41	0.67	0.82	$p > 0.05$
Protura	0.17	0.41	0.00	0.00	$p > 0.05$
Ixodida	0.17	0.41	0.00	0.00	$p > 0.05$
Siphonaptera	0.00	0.00	0.50	1.22	$p > 0.05$
Acarina	0.00	0.00	0.33	0.82	$p > 0.05$
Oligochaeta	0.17	0.41	0.00	0.00	$p > 0.05$
Molusca	0.00	0.00	0.33	0.82	$p > 0.05$
Diplopoda	1.50	2.07	0.83	0.75	$p > 0.05$
Embioptera	0.17	0.41	0.00	0.00	$p > 0.05$
Symphyla	0.00	0.00	0.17	0.41	$p > 0.05$
Others	1.33	1.37	1.83	0.75	$p > 0.05$

Mature Eucalyptus					
	Litter removal (mean)	**S.d.**	**Control (mean)**	**S.d.**	**p**
Formicidae	169.50	126.90	135.83	119.71	$p > 0.05$
Collembola	32.83	10.83	9.50	4.97	$p < 0.05$
Hemiptera	5.17	1.94	5.83	3.31	$p > 0.05$
Araneae	9.50	3.73	12.83	6.11	$p > 0.05$
Diptera	15.33	4.46	20.83	4.40	$p > 0.05$
Hymenoptera	4.00	3.03	4.50	3.27	$p > 0.05$
Blapoda	0.67	0.52	0.50	0.84	$p > 0.05$
Isoptera	1.17	1.17	1.83	2.32	$p > 0.05$
Coleoptera	1.33	1.21	2.17	1.83	$p > 0.05$
Diplopoda	12.67	8.45	57.00	35.93	$p < 0.05$
Scorpiones	0.17	0.41	0.00	0.00	$p > 0.05$
Ortoptera	1.00	0.63	2.00	2.28	$p > 0.05$
Phasmatodea	0.17	0.41	0.17	0.41	$p > 0.05$
Neuroptera	1.83	2.23	3.33	1.97	$p > 0.05$
Acarina	0.00	0.00	0.17	0.41	$p > 0.05$
Ixodida	0.00	0.00	0.33	0.52	$p > 0.05$
Lepidoptera	0.17	0.41	0.17	0.41	$p > 0.05$
Zoraptera	0.17	0.41	0.00	0.00	$p > 0.05$
Others	0.33	0.52	0.33	0.82	$p > 0.05$

Where: s.d. = Standard deviation.

Appendix C. Soil chemical parameters (0–20 and 20–40 cm depth) in litter removal and control plots in the Juvenile and Mature Eucalyptus stands post-removal sampling (March 2020 - rainy season) after two years of experiment in central Brazil.

Juvenile stand										
Depth	0-20					20-40				
	Litter removal	S.d.	Control	S.d.	Test	Litter removal	S.d.	Control	S.d.	Test
pH	4.87	0.02	4.87	0.02	p > 0,05	4.76	0.01	4.75	0.01	p > 0,05
P	0.84	0.09	0.83	0.06	p > 0,05	0.48	0.05	0.42	0.03	p < 0,05
K	9.83	2.14	10.50	1.76	p > 0,05	5.33	1.37	5.67	1.21	p > 0,05
Ca	0.36	0.01	0.35	0.02	p > 0,05	0.18	0.02	0.18	0.02	p > 0,05
Mg	0.19	0.01	0.18	0.01	p > 0,05	0.10	0.01	0.10	0.01	p > 0,05
Al	0.91	0.03	0.91	0.02	p > 0,05	1.00	0.04	0.99	0.02	p > 0,05
H+Al	5.70	0.00	5.70	0.06	p > 0,05	5.83	0.05	5.87	0.08	p > 0,05
SB	0.57	0.03	0.56	0.04	p > 0,05	0.29	0.02	0.29	0.02	p > 0,05
CECe	0.37	0.10	0.43	0.10	p > 0,05	0.23	0.05	0.25	0.05	p > 0,05
CECt	6.27	0.05	6.25	0.08	p > 0,05	6.13	0.05	6.17	0.08	p > 0,05
V	9.13	0.37	8.90	0.54	p > 0,05	4.70	0.32	4.65	0.36	p > 0,05
m	61.38	1.55	62.13	1.58	p > 0,05	77.65	1.83	77.53	1.58	p > 0,05
OM	3.02	0.25	3.00	0.18	p > 0,05	2.40	0.28	2.30	0.18	p > 0,05
P-rem	5.73	0.41	5.87	0.48	p > 0,05	2.87	0.08	3.03	0.53	p > 0,05
Mature stand										
	0-20					20-40				
	Litter removal	S.d.	Control	S.d.	Test	Litter removal	S.d.	Control	S.d.	Test
pH	4.86	0.0	4.86	0.02	p > 0,05	4.73	0.01	4.74	0.02	p > 0,05
P	0.96	0.2	0.92	0.09	p > 0,05	0.46	0.06	0.43	0.03	p > 0,05
K	10.00	1.5	9.00	1.10	p > 0,05	5.33	1.37	4.83	1.17	p > 0,05
Ca	0.38	0.1	0.42	0.05	p > 0,05	0.19	0.03	0.19	0.02	p > 0,05
Mg	0.19	0.0	0.20	0.01	p > 0,05	0.11	0.01	0.11	0.01	p > 0,05
Al	0.93	0.0	0.91	0.03	p > 0,05	1.04	0.04	1.01	0.06	p > 0,05
H+Al	5.68	0.0	5.72	0.04	p > 0,05	5.82	0.04	5.85	0.05	p > 0,05
SB	0.60	0.1	0.64	0.06	p > 0,05	0.32	0.04	0.31	0.03	p > 0,05
CECe	0.40	0.1	0.33	0.08	p > 0,05	0.25	0.05	0.22	0.04	p > 0,05
CECt	6.25	0.1	6.35	0.05	p < 0,05	6.15	0.05	6.17	0.05	p > 0,05
V	9.53	1.1	10.00	0.87	p > 0,05	5.13	0.64	4.98	0.42	p > 0,05
m	61.00	3.8	58.85	2.59	p > 0,05	76.82	2.35	76.53	2.28	p > 0,05
OM	3.27	0.1	3.25	0.05	p > 0,05	2.67	0.12	2.77	0.10	p > 0,05
P-rem	6.92	0.7	6.60	0.73	p > 0,05	3.70	1.19	3.93	0.79	p > 0,05

Where: S.d. = Standard deviation; SB = Sum of bases; CECe(t) = Cation exchange capacity (effective); CECt (T) = Cation exchange capacity (total); V = base saturation and m = Aluminum saturation. P and K = mg dm^{-3}; Ca^{2+}. Mg^{2+}. Al3+. H+Al. SB. t and T = cmolc dm^{-3}; V and m = %; OM = dag/kg e P-Rem = mg/L.

Appendix D. Soil physical variables in control and litter removal plots in Juvenile and Mature stands during dry and rainy seasons over two years.

Juvenile Eucalyptus							
Depth (cm)	**Seasons**	**Parameter**	**Litter removal**	**S.d.**	**Control**	**S.d.**	**p**
0-20	Dry	GM	23.12	3.3	22.41	3.7	p > 0.05
		VM	23.12	2.7	23.76	2.7	p > 0.05
		BD	1.01	0.1	1.07	0.1	p > 0.05
		P	61.96	3.5	59.53	3.9	p > 0.05
	Rainy	GM	29.27	5.6	28.73	5.5	p > 0.05
		VM	29.70	6.2	29.71	6.2	p > 0.05
		BD	1.02	0.1	1.04	0.1	p > 0.05
		P	61.51	4.6	60.76	5.3	p > 0.05
20-40	Dry	GM	23.13	2.7	23.40	4.0	p > 0.05
		VH	22.77	2.7	24.88	3.7	p > 0.05
		BD	0.99	0.1	1.07	0.1	p > 0.05
		P	62.75	2.8	59.48	4.7	p > 0.05
	Rainy	GM	31.91	4.3	30.95	4.9	p > 0.05
		VM	33.32	5.5	33.32	5.5	p > 0.05
		BD	1.05	0.1	1.08	0.1	p > 0.05
		P	60.54	4.0	59.24	4.0	p > 0.05

Mature Eucalyptus							
Depth (cm)	**Seasons**	**Parameter**	**Litter removal**	**S.e.**	**Control**	**S.e.**	**p**
0-20	Dry	GM	23.64	4.0	26.1	0.9	0.053
		VM	23.67	4.4	24.8	1.9	p > 0.05
		BD	1.01	0.1	1.0	0.1	p > 0.05
		P	61.97	4.4	64.0	2.5	p > 0.05
	Rainy	GM	32.18	5.0	34.4	2.7	p > 0.05
		VM	32.63	5.5	34.4	5.1	p > 0.05
		BD	1.02	0.1	1.0	0.1	p > 0.05
		P	61.54	4.1	62.3	3.9	p > 0.05
20-40	Dry	GM	25.45	0.7	26.0	0.5	P < 0.05
		VM	25.41	1.4	25.4	1.7	p > 0.05
		BD	1.00	0.1	1.0	0.1	p > 0.05
		P	62.29	2.4	63.2	2.4	p > 0.05
	Rainy	GM	33.41	2.1	35.6	5.3	p > 0.05
		VM	34.19	2.7	36.1	6.0	p > 0.05
		BD	1.02	0.1	1.0	0.1	p > 0.05
		P	61.33	2.7	61.6	4.1	p > 0.05

Where: S.d. = Standard deviation; GM = Geometric moisture ($m^3\ m^{-3}$); VM = Volumetric moisture ($g\ cm^{-3}$); BD = Bulk density ($g\ cm^{-3}$); P = Soil total porosity ($m^3\ m^{-3}$).

Appendix E. Two years of basal area increment per plot ($m^2 ha^{-1}$) and tree diameter at breast height (cm) in litter removal and control plots in Juvenile and Mature Eucalyptus stands.

Basal area increment ($m^2 ha^{-1}$)				
Juvenile Eucalyptus				
Time (months)	Litter removal	S.d.	Control	S.d.
0-6	0.003	0.001	0.005	0.002
0-12	0.028	0.005	0.029	0.006
0-18	0.032	0.006	0.035	0.008
0-24	0.044	0.007	0.048	0.011
Mature Eucalyptus				
Time (months)	Litter removal	S.d.	Control	S.d.
0-6	0.003	0.004	0.002	0.002
0-12	0.028	0.004	0.025	0.004
0-18	0.029	0.005	0.027	0.004
0-24	0.042	0.006	0.039	0.005

Tree individual increment (cm)					
Juvenile Eucalyptus					
Time (months)	Litter removal	S.d	Control	S.d	p
0-6	0.12	0.10	0.22	0.14	< 0.01
0-12	0.96	0.27	1.18	0.31	< 0.01
0-18	1.12	0.35	1.38	0.37	< 0.01
0-24	1.48	0.40	1.84	0.50	< 0.01
Mature Eucalyptus					
Time (months)	Litter removal	S.d	Control (cm)	S.d	p
0-6	0.08	0.35	0.06	0.08	> 0.05
0-12	0.67	0.39	0.63	0.29	> 0.05
0-18	0.71	0.41	0.69	0.32	> 0.05
0-24	0.99	0.56	0.98	0.49	> 0.05

Where: S.d. = Standard deviation

Appendix F. Non-metric multidimensional scaling (NMDS) plot of soil epigeic fauna and a envfit with environmental vectors in juvenile and mature Eucalyptus stands in central Brazil.

	NMDS 1	NMDS 2	r2	Pr(<r)
Vectors				
Wood decay	0.992	0.11542	0.2533	0.045 *
Vol. moisture (0-20)	0.37579	0.9267	0.3529	0.012 *
Vol. moisture (20-40)	0.48306	0.87559	0.4406	0.004 **
P. Rem. (0-20)	0.90837	0.41816	0.285	0.037 *
P. Rem. (20-40)	0.37993	0.92502	0.2904	0.030 *
Shannon	0.82372	0.567	0.8566	0.001 ***
P av. (20-40)	-0.65336	-0.75704	0.2568	0.044 *
Centroids				
Stand Juvenile	-0.0457	-0.015		
Stand Mature	0.0457	0.015		
Litter trial Control	0.0332	0.0428		
Litter trial Litter removal	-0.0332	-0.0428		
Goodnes of fit				
Stand			0.1144	0.060 .
Litter trial			0.1452	0.038 *
Number of permutations: 999				
Significance codes: 0 ‘*’ 0.001 ‘**’ 0.01 ‘*’ 0.05 '.' 0.1**				

5 CAPÍTULO IV*

IMPACTS OF SAVANNA TO EUCALYPTUS CONVERSION ON SOIL FAUNA COMMUNITIES IN BRAZILIAN SAVANNA

ABSTRACT

Soil organisms account for one-quarter of all species on Earth and play crucial roles in many ecosystem functions and services. However, soil communities are facing threats related to human activities especially in conservation hotspots like Brazil's Cerrado ecoregion. Uncertainty exists on whether widespread conversion of savanna ecosystems to Eucalypts plantations in the Cerrado impacts soil organisms and their role in ecosystem function. Here, to support decision making regarding public policies for forest management and land use strategies, we sampled soil epigeic fauna communities in a native savanna ecosystem and in two adjacent commercial Eucalyptus stands to test whether land-use change impacts soil epigeic fauna abundance and diversity during dry and rainy seasons. We also assessed correlations between soil chemical parameters and soil epigeic fauna groups. Pitfall traps were installed in each of the 12 plots per land-use type to collect soil faunal organisms in the dry and rainy seasons. We conducted one soil chemical analyses at 0-20 and 20-40 cm depths per plot in May 2018. We found that Collembola, Isoptera, and Diptera (dry season), and Formicidae, Isoptera, and Diptera (rainy season) were more abundant in the native cerrado, representing ~85% of de dissimilarities between both land use types. We also found that soil organic matter, potassium, calcium, and phosphorus contents and pH can be used as soil epigeic fauna indicators in the cerrado and Eucalyptus areas due to significant correlations with soil epigeic fauna. These results indicate that establishing Eucalyptus plantations can reduce the abundance of key soil faunal groups, with implications for nutrient cycling and, possibly, soil biodiversity loss. Therefore, further studies are encouraged to evaluate the best management practices for Eucalyptus stands that seek to improve soil biodiversity.

Key words: Soil epigeic fauna, Cerrado, Eucalyptus, Soil chemistry

* *Este capítulo foi redigido, em língua inglesa, no formato de artigo científico.*

5.1 INTRODUCTION

Soil organisms contain one-quarter of all species on Earth, and these organisms play crucial roles in many ecosystem functions and services, however, these communities are facing threats related to anthropic activities (BEAUMELLE et al., 2021). In this context of land-use changes, the Brazilian savanna (*i.e.*, Cerrado biome), which is the world's most biodiversity tropical savanna and the second-largest biome in South America (MYERS et al., 2000; MORANDI et al., 2018), is facing rampant threat due to agriculture and mianing expansion. Over 20,400 km^2 of native Cerrado were suppressed between 2017 and 2019 (ASSIS et al., 2019), and less than half of the original land covered by Cerrado ecosystems is still conserved (ZUIN,2020), reinforcing it as one of the most threatened biomes on the planet.

Among common types of land-use change in the Cerrado, the conversion of the savanna ecosystems into Eucalyptus plantations is concerting due to alterations of nutrient cycles related to to modifications above- and below-ground. The changes in vegetation composition, nutrient inputs, and outputs lead to alterations in the composition and diversity of soil fauna (BOENO et al., 2020; YANG et al., 2021). Therefore, Eucalyptus monocultures have long been questioned due to effects on soil biodiversity. Specifically, the diversity and distribution of soil fauna species can be impacted due to the reduction of variation in litter composition and quality, strongly influencing soil fauna communities and endemic organisms most vulnerable to ecosystem disturbances (BARETTA et al., 2003; RIEFF et al., 2016). Also, soil management directly affects soil fauna by the use of heavy soil tillage machinery (SILVA et al., 2011; GONÇALVES et al., 2020;). Still, studies suggest that commercial Eucalyptus stands, compared to other monoculture systems, cause less impact for soil fauna communities (ROSA et al., 2015; SOUZA et al., 2016).

Because of rampant land-use changes it is necessary to have a better understanding of the soil fauna communities' composition and ecology. This is particularly necessary because those organisms are responsible for several ecosystem services such as the formation of biogenic structures, improving aggregate stability, hydraulic conductivity, and total porosity. Also, the soil fauna promotes the incorporation of soil organic matter by litter decomposition, an essential nutrient cycling process in self-sustaining ecosystems (ARDGETT; VAN DER PUTTEN, 2014; GUERRA et al., 2021).

Little is known about the conservation status of most soil organisms globally (GUERRA et al., 2021). Studies on edaphic fauna in natural ecosystems in the Cerrado ecoregion are still scarce, given the few existing studies occurred in silvopastoral and pasture systems (VENDRAME et al., 2009; PORTILHO et al., 2011; SILVEIRA et al., 2016), and, more recently, in a regenerating patch of cerrado (FARIA et al., 2021). Since that the Cerrado biome is strongly related by the natural long dry season (April to September) and heavy rain periods (October to March) and the soil fauna activity is regulated by soil humidity, this different seasons could regulate the soil fauna distribution and composition among the seasons (NIMER, 1989; ROSA et al., 2015).

Soil fauna diversity is considered a key aspect for maintaining the structure and fertility of tropical soils, especially in nutrient-poor soil as the major part of cerrado that is covered by Latossolos (Oxisoils), presenting apparently faster response than other soil attributes, therefore serving as biological indicators sensitive to ecological changes in agrosystems (BARETTA et al., 2011; HARIDASSAN, 2008; FARIA et al., 2021). This study addresses this knowledge gap, providing information on the impacts of Cerrado-to-Eucalyptus conversion on soil epigeic fauna composition, structure and diversity. This knowledge can ultimately support the establishment of nature protection priorities and policies and when designing new conservation areas due to the numerous process that are conducted by these organisms (GUERRA et al., 2021).

This study aims to quantify the impact of land-use change on soil epigeic fauna by comparing soil fauna communities in a preserved cerrado with adjacent Eucalyptus plantations, and assessing their correlations with soil chemistry parameters. We aimed to respond to the following questions: i) Do cerrado and eucalyptus ecosystems differ in the diversity and abundance of epigeic fauna species? If so, does this difference change through rainy and dry seasons? ; and ii) Is there a relationship between soil chemistry and the soil epigeic fauna in the cerrado and Eucalyptus stands? We hypothesized that: i) The diversity and abundance of soil epigeic fauna are lower in Eucalyptus when compared to native cerrado and present changes trough dry and rainy seasons. iii) Specific groups of soil epigeic fauna correlate to soil chemistry parameters.

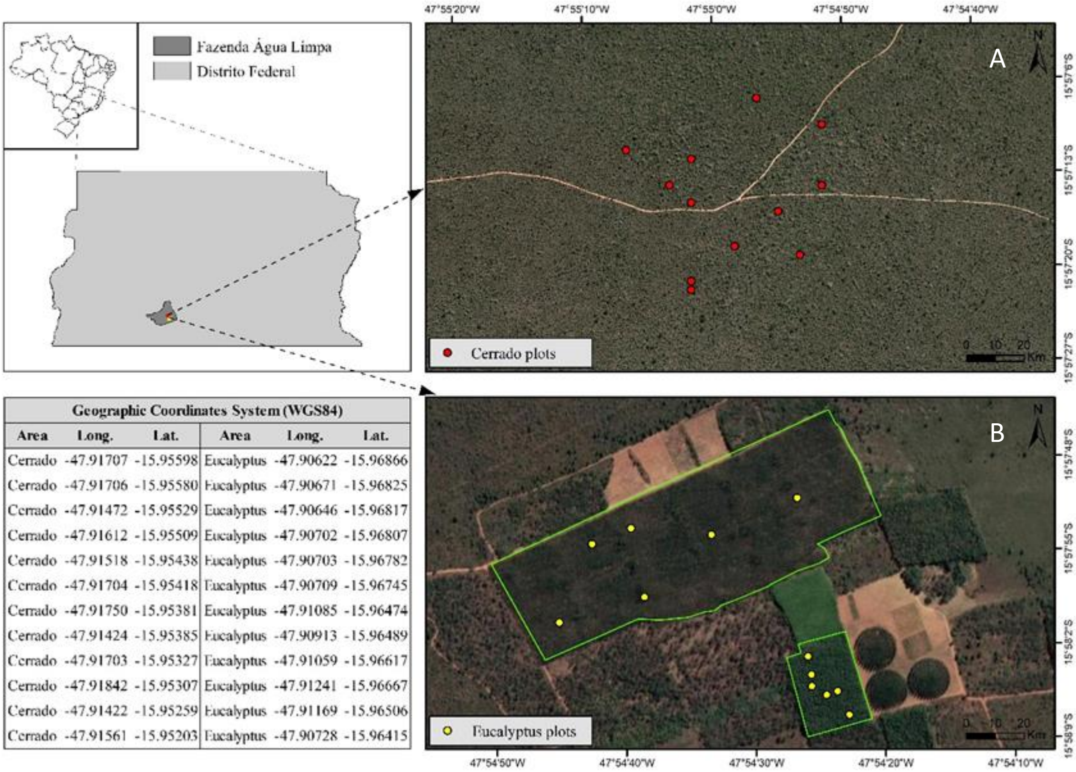
5.2 MATERIAL AND METHODS

5.2.1 Study sites description

The study was conducted at the University of Brasilia's experimental research station (Fazenda Água Limpa; 15°56 '- 15°59' S and 47°55' - 47°58' W). The property covers >4.3 thousand hectares and it's inserted on Environmental Protection Area Gama and Cabeça-de-Veado, which is part of the Cerrado Biosphere Reserve. About 86% of the farm is preserved, and 45% of the land covered by native vegetation is classified as Cerrado *stricto sensu* (FELFILI et al., 2000). Of that 14% (~600 hectares) area left, 153.5 hectares are used for silviculture, mainly Eucalyptus plantations. The region's climate is classified as AW according to Köppen's classification with well-defined dry and rainy seasons. The mean annual precipitation is 1552 mm, where monthly means range from 9 mm in June to 249 mm in December (NIMER, 1989). Soils in the study site are mainly Oxisols (U.S. soil classification system) or Red Latosols (EMBRAPA classification system), characterized by high acidity and low nutrient (*e.g.*, phosphorus-P) availability (HARIDASAN, 2008).

Two adjacent Eucalyptus stands and a cerrado area (less than 1 km apart from each other) were selected for this study due to the proximity of the areas with different land uses. In the Cerrado area, we randomly selected 12 plots with 20 m x 50 m following previously established protocols by (FELFILI et al., 2000), in a total of 1.2 hectares of native well conserved Cerrado *stricto sensu* were covered (Figure 1). The 12 sampling units present the following characteristics: basal area about ~13,11 m² ha^{-1}, ~156 woody individuals, and 36 woody species per plot (MOTA, 2017). To the best of our knowledge, an accidental fire occurred in 2011 within this area, which is a typical type of disturbance in the Cerrado ecoregion in Central Brazil.

Six plots of 10 m x 10 m were randomly allocated in each one of the two Eucalyptus stands for a more representative sampling of this type of land use, resulting in twelve plots of one treatment called Eucalyptus stands (Figure). The Eucalyptus stands differ in three years of age: The Mature stand (3.3 ha) was established in January 2010 and was eight years old when we started this experiment. *Eucalyptus urophylla* ST Blake x *Eucalyptus grandis* Hill ex-Maiden is the clone planted in the Mature stand, arranged in 3 m x 2 m spacing with soil tillage to 40 cm depth and fertilizer application along the planting line with 100 g of super simple phosphate in addition to 100 g of NPK (4-30-16). The Juvenile stand (23 ha) was planted in 2013 with a hybrid clonal planting: *Eucalyptus grandis* × *Eucalyptus urophylla* (GG 100), with 3 m × 3m spacing. Before planting, subsoiling was performed up to 70 cm in depth and 600 kg ha^{-1} of super simple phosphate was applied. Fertilization was carried out in pits with 200 g per well of NPK (20-05-20) applied 15 cm away from the seedling with applications at fifteen days, two months, one year, and two years after planting. It's worth mention that the Eucalyptus areas are commercial stands and were previously implanted before the experimental implantation of the plots. Also, the difference between the plots areas was due to the heterogeneity of the cerrado canopy structure and the homogeneity of the Eucalyptus canopy structure that led to a small plot area.



Geographic Coordinates System (WGS84)					
Area	Long.	Lat.	Area	Long.	Lat.
Cerrado	-47.91707	-15.95598	Eucalyptus	-47.90622	-15.96866
Cerrado	-47.91706	-15.95580	Eucalyptus	-47.90671	-15.96825
Cerrado	-47.91472	-15.95529	Eucalyptus	-47.90646	-15.96817
Cerrado	-47.91612	-15.95509	Eucalyptus	-47.90702	-15.96807
Cerrado	-47.91518	-15.95438	Eucalyptus	-47.90703	-15.96782
Cerrado	-47.91704	-15.95418	Eucalyptus	-47.90709	-15.96745
Cerrado	-47.91750	-15.95381	Eucalyptus	-47.91085	-15.96474
Cerrado	-47.91424	-15.95385	Eucalyptus	-47.90913	-15.96489
Cerrado	-47.91703	-15.95327	Eucalyptus	-47.91059	-15.96617
Cerrado	-47.91842	-15.95307	Eucalyptus	-47.91241	-15.96667
Cerrado	-47.91422	-15.95259	Eucalyptus	-47.91169	-15.96506
Cerrado	-47.91561	-15.95203	Eucalyptus	-47.90728	-15.96415

Figure 1. Study site location in Brazil's Federal District, and the two land use areas composed by a well conserved native cerrado *sensu stricto* **(a)** and 2 eucalyptus stands **(b)** at the University of Brasilia's research station. 12 plots randomly allocated in each one of the two land-uses.

5.2.2 Soil epigeic fauna abundance and diversity

Soil epigeic fauna was evaluated during the dry (September 2018) and rainy (January 2020) seasons. Five fall plastic traps per plot randomly allocated (15-cm diameter) containing ~ 200 ml of water and 10 ml of colorless neutral detergent were used as described by (BARETTA et al., 2007) and left in the field for 48 hours, after which they were collected and taken to the laboratory where all organisms were manually separated with the aid of a 0.125-mesh sieve and transferred to flasks containing absolute ethyl alcohol for fixation. Then, the organisms were identified at the highest possible taxonomic level (gender, order, or family whenever possible) using a magnifying lens and the assistance of taxonomic keys.

5.2.3 Soil chemical analyses

In each study area, we randomly collected four soil samples at two depths (0–20 cm; 20–40 cm) per plot and combined them into one sample per depth per plot, at may 2018. After the sampling, soils were air-dried in the shade, and then, the dry soil samples were analyzed according to (EMBRAPA, 1998), by the following methods: Exchangeable aluminum (Al^{3+}), potential acidity (H + Al) by titration. Phosphorus (P) and potassium (K) by Mehlich-1 extractor, where remaining P (Prem) was determined using molecular absorption spectrophotometer as well as calcium (Ca^{2+}) and magnesium (Mg^{2+}), and K by photometer of flame. Soil organic matter (OM) was determined by extraction and titration. For all samples, we calculated the total cation exchange capacity (CEC_t), effective cation exchange capacity (CEC_e), the sum of bases (SB), base saturation (V), and aluminum saturation (m).

5.2.4 Statistical analysis

Soil epigeic fauna data was tabulated and Shannon's diversity index (h') was calculated for each plot. Diversity among treatments and seasons was compared using a t-test at a 95% confidence level. An Analysis of similarities (Anosim) was performed to compare the soil epigeic fauna abundance of groups in both land uses and seasons. This analysis was then complemented by a Simper analyses (a percentage similarity analyzes) to calculate the contribution of each species (%) to the dissimilarity between the two land-uses, where both analyses utilized the Bray-Curtis index. Also, soil epigeic fauna abundance data were tabulated and submitted to a Principal Component Analysis (PCA) comparing land use in the two collection seasons. Finally, in order to verify the correlation between edaphic fauna groups and soil chemical parameters a redundancy analysis (RDA) was performed with the soil chemistry data considered as explanatory environmental variables. Collinear edaphic parameters were removed from the analysis.

5.3 RESULTS

5.3.1 Soil epigeic fauna composition, abundance and diversity among land use types during rainy and dry seasons

A total of 12,917 soil epigeic fauna individuals were collected during the dry and rainy seasons in the two land-use systems, and separated into 31 broad taxonomic groups. In the cerrado area, Isoptera was the dominant group, in both seasons, contributing with 42.4% and 37.1% in rainy and dry seasons, respectively. Formicidae was the second most abundant group, contributing with 17.2 and 46.2% in rainy and dry seasons, respectively. While in the Eucalyptus treatment, Formicidae was the most dominant group, contemplating more than half of the collected individuals in both seasons (63.6% and 56.6%, in rainy and dry seasons, respectively). The other two groups that had higher abundance in the plantations stands were Collembola in the rainy season (12.5%) and Diplopoda in the dry season (22%).

The Anosim showed significant dissimilarities in both seasons ($p < 0.01$), presenting a higher R during the rainy season, showing a higher distinction between the two treatments ($R = 0.54$) when compared to the dry season ($R = 0.26$) collections, since that R is a ratio between within-group and between-group dissimilarities (Figure 2).

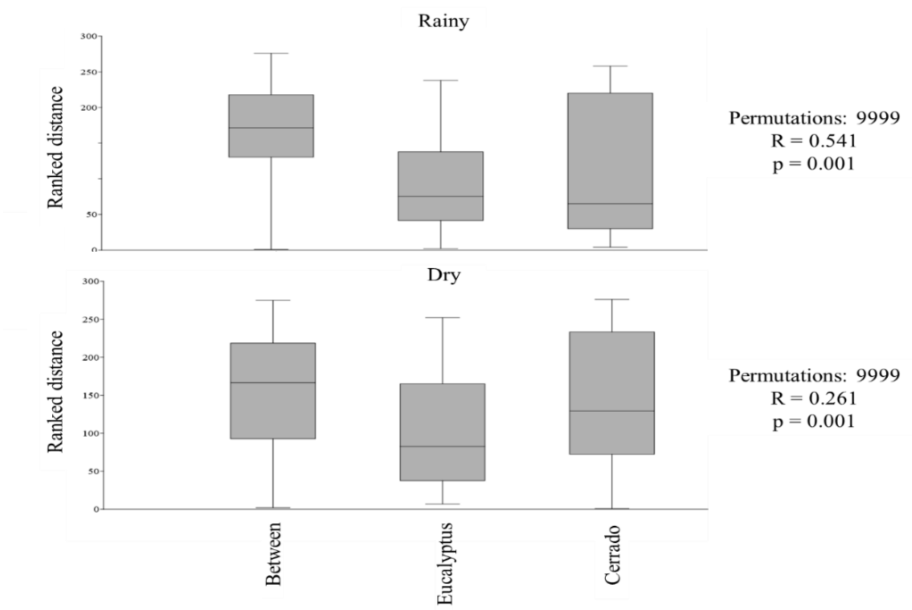


Figure 2. Similarity analyses (Anosim) by Bray-Curtis index in a native cerrado and adjacent Eucalyptus stands in Central Brazil, during rainy and dry seasons. Boxes indicates values from 25th (bottom) to 75th (top) percentile; horizontal black line indicate the median; box width is proportional to sample size. Whiskers indicate the maximum and minimum values.

According to SIMPER, in the rainy season, four groups were responsible for 85% of the dissimilarity: Collembola, Isoptera, Formicidae, and Diptera contributed with 31.1%, 22.8%, 20.1%, and 11.7% respectively. From those groups, only Formicidae was higher in Eucalyptus than in the cerrado, while all other three groups were more abundant in the cerrado area (Table 1).

Table 1. SIMPER analyses of soil epigeic fauna in Cerrado and Eucalyptus plantations in Central Brazil, Brasília-DF, during dry and rainy seasons collections.

Rainy collections					
Overall average dissimilarity (sum of Average dissimilarity) – 58.3					
Taxon	**Average dissimilarity**	**Contribution %**	**Cumulative %**	**Mean Eucalyptus**	**Mean Cerrado**
Collembola	18.1	31.05	31.05	15.5	82.9
Isoptera	13.3	22.82	53.87	1.17	168
Formicidae	11.69	20.05	73.91	78.8	68.3
Diptera	6.824	11.7	85.62	12.5	40.3
Hemiptera	3.78	6.484	92.1	3.58	16.3
Coleoptera	1.492	2.559	94.66	1.42	9.42
Araneae	1.122	1.925	96.59	6.5	5.5
Ortoptera	0.8821	1.513	98.1	0.5	3.92
Hymenoptera	0.2816	0.4831	98.58	1.08	0.25
Others	0.2481	0.4256	99.01	0.917	0
Diplopoda	0.241	0.4134	99.42	0.917	0
Blattodea	0.236	0.4048	99.83	0.0833	0.833
Neuroptera	0.1014	0.1739	100	0.333	0.0833
Dry season					
Overall average dissimilarity - 62.79					
Taxon	**Average dissimilarity**	**Contribution %**	**Cumulative %**	**Mean Eucalyptus**	**Mean Cerrado**
Formicidae	28.75	45.8	45.8	91.8	198
Isoptera	13.98	22.27	68.06	2	159
Diplopoda	6.779	10.8	78.86	28	0.167
Diptera	3.723	5.93	84.79	9.67	30.3
Coleoptera	2.262	3.602	88.39	4.5	11.3
Araneae	2.033	3.239	91.63	12.8	3.75
Hymenoptera	1.025	1.633	93.26	2.25	6.17
Collembola	0.919	1.464	94.73	1.17	3.92
Others	0.7098	1.13	95.86	0.167	2.83
Hemiptera	0.5647	0.8994	96.76	2.17	3
Thysanoptera	0.5268	0.8391	97.59	0	1.92
Ortoptera	0.4608	0.734	98.33	1.25	1.92
Neuroptera	0.4186	0.6668	99	1.67	0
Acarina	0.2436	0.3879	99.38	0.25	3.67
Psocoptera	0.159	0.2532	99.64	0	0.75
Blattodea	0.1367	0.2177	99.85	0.417	0.333
Siphonaptera	0.09155	0.1458	100	0.25	0.417

In the dry season collections, also for groups was responsible for almost 85,62% of the dissimilarity between the two areas, where Formicidae, Isoptera, Diplopoda, and Diptera contributed with 45.8, 22.27, 10.8, and 5.93% respectively. Following a similar trend to the rainy season analyses, only one of these four groups was higher in Eucalyptus stands during the dry season (Diplopoda), when all other three were more abundant in the cerrado area (Table 1.).

The Principal Component Analyses (PCA) also showed distinguished distribution between the two treatments and seasons. The PCA in the rainy collections explained 51.95% of the variance on the first two principal components in the rainy season, where the most robust gradient (PC1) explains 36.15% of the variation, whereas the second axis (PC2) which explain 15.76% of the variation. The groups of Formicidae, Araneae, Hymenoptera, and Neuroptera groups clustered together with the Eucalyptus plots while all other groups stayed clustered together with the cerrado plots (**Erro! Fonte de referência não encontrada.**a).

In the dry season, the PCA explained 43.3% of the variance on the first two principal components in the rainy season, where the most robust gradient (PC1) explains 25.77% of the variation, whereas the second axis (PC2) explains 17.57% of the variation. The groups of Diplopoda and Neuroptera clustered together with the Eucalyptus plots while all other groups stayed clustered together with the cerrado plots, even that the distinction of the two areas was less perceptive than in the rainy evaluation (**Erro! Fonte de referência não encontrada.**b). Regardless of season collection, the cerrado area presented a higher correlation with more epigeic fauna groups than the Eucalyptus. This trend is clear given the majority of groups clustered together in the cerrado plots.

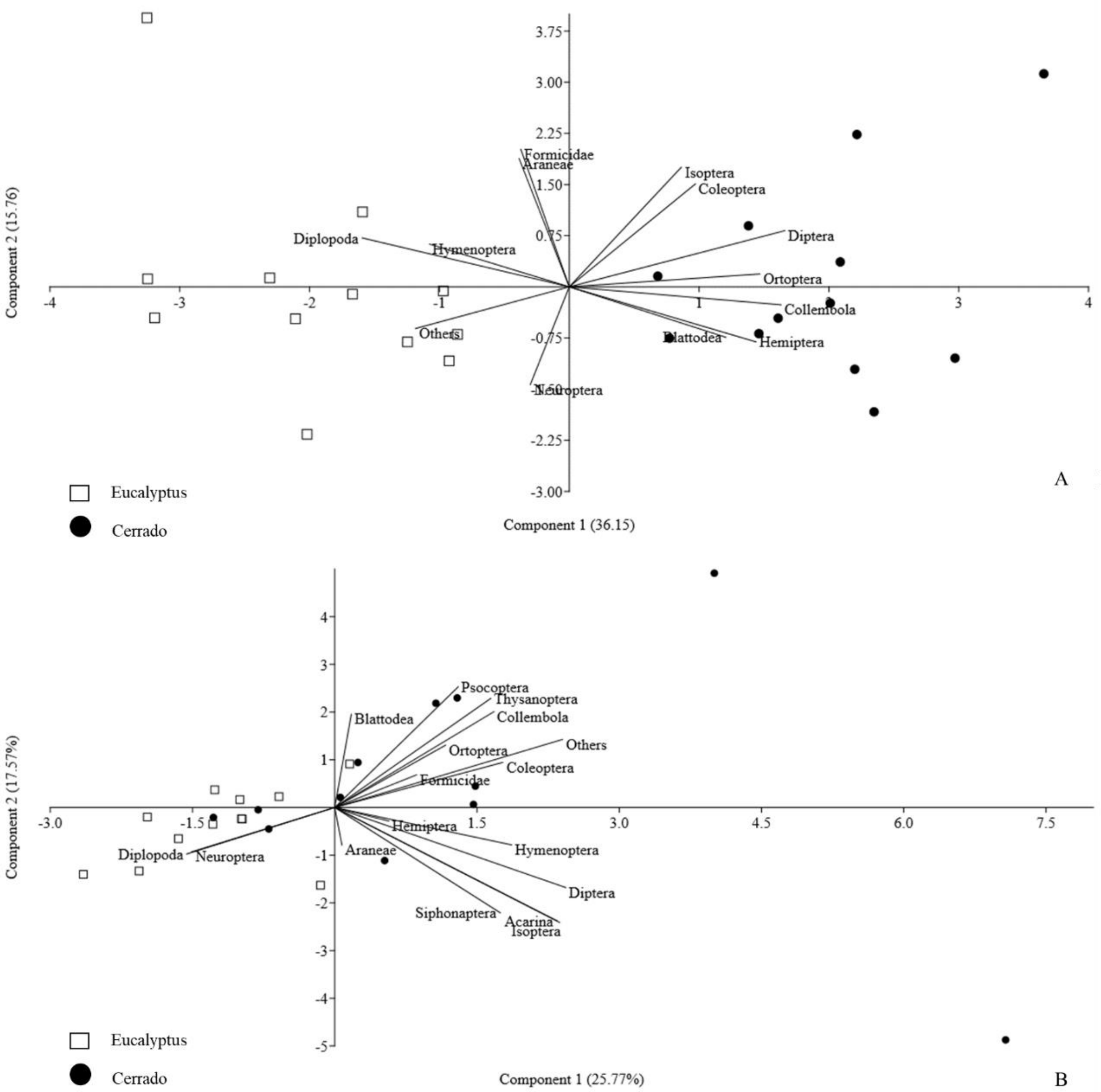


Figure 3. Principal component analysis (PCA) for epigeic fauna groups found in native Cerrado and Eucalyptus plantations in central Brazil – Brasília. In rainy **(a)** and dry **(b)** seasons.

In the rainy season, Shannon's diversity index in the cerrado area ranged from 0.339 to 0.761, with an average of 0.613 per plot. These values were higher than in the eucalyptus area that ranged from 0.259 to 0.708 with 0.526 (**Erro! Fonte de referência não encontrada.**). However, even with different mean values, there was no significant difference between treatments ($p > 0.05$).

We found no significant differences between both land uses during the dry season collections ($p > 0.05$). However, the means per plot in the eucalyptus were a little bit higher than the cerrado, with means of 0.498 and 0.438, respectively. The diversity index varied from 0.16 to 0.92 in the cerrado and 0.37 to 0.71 in the Eucalyptus area (**Erro! Fonte de referência não encontrada.**).

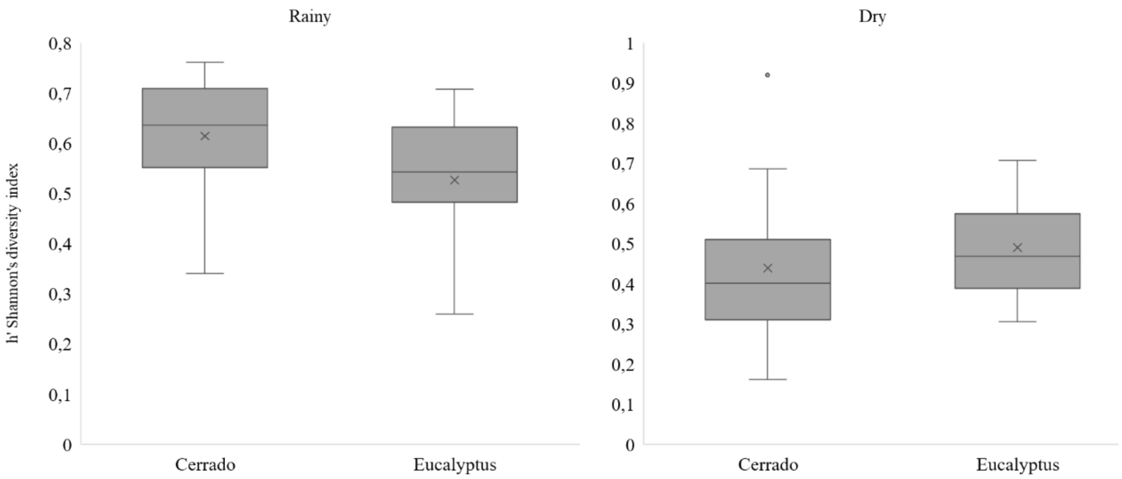


Figure 4. Shannon's diversity index in native cerrado and Eucalyptus stands in Central Brazil, during rainy and dry seasons. In each box, the middle band is the median value, x is the mean and the top and bottom of the box are the first and third quartiles, respectively. Whiskers indicate the maximum and minimum values.

5.3.2 Correlations between soil chemistry parameters and soil epigeic fauna

The relations between chemical parameters and soil epigeic fauna groups from the forward selection and Monte Carlo permutations suggests a high relationship between environmental variables (soil chemical attributes) and the response variable (edaphic epigeic fauna groups) ($P < 0.01$) in both seasons. The RDA performed with the data collected during the dry season showed 88.1% of the explanation of the variability in the first axis and 11.9% in the second axis, covering 100% of the total variability (**Erro! Fonte de referência não encontrada.**a). Among the soil chemical parameters that most influenced soil fauna, organic matter and potassium stand out, where Acarina and Hymenoptera are influenced by the OM content, while Hemiptera Thysanoptera and Formicidae are more influenced by k content. Also, it was possible to observe that Diplopoda, Neuroptera, and Blattodea are less influenced by these parameters.

In the rainy season collection, a different result was observed (**Erro! Fonte de referência não encontrada.**b), among the soil chemical parameters that are most influence in soil fauna, Ca, Ph, P, and K stand out, where Diplopoda is influenced by the Ca content and is low influenced by K contents. Isoptera, Neuroptera, and others (larvae) are influenced by Ph and P contents and Araneae and Formicidae are less influenced by these parameters. Diptera, Coleoptera, Blattodea, and specially Collembola presented a high influence caused by K contents.

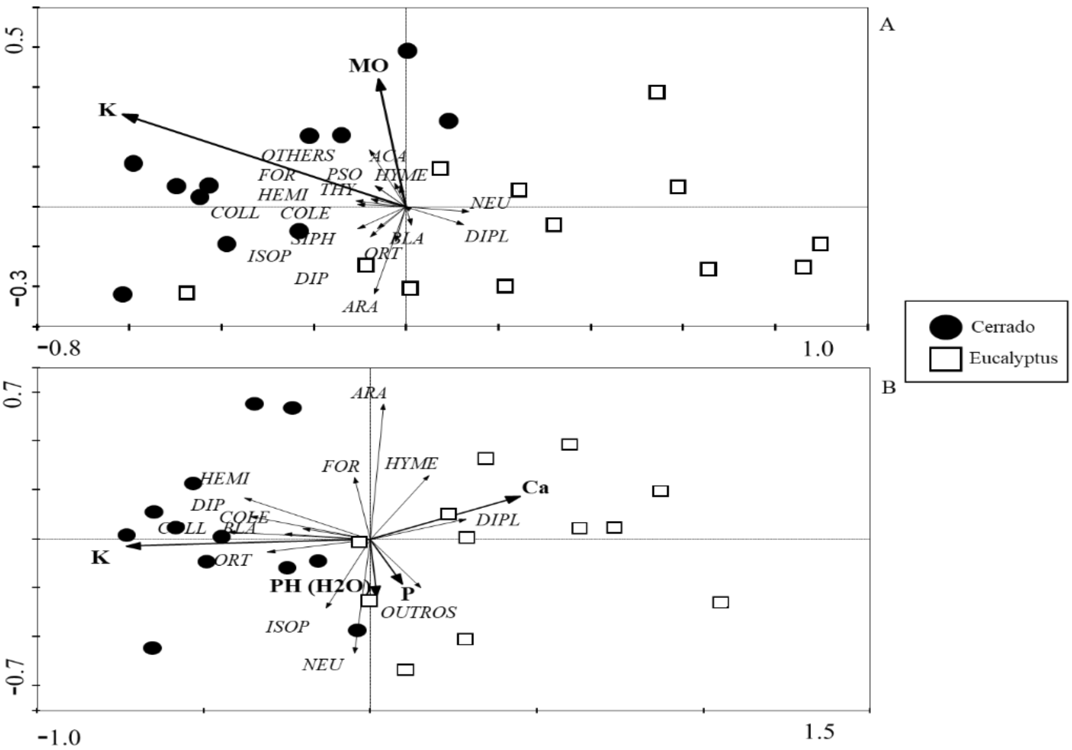


Figure 5. Redundancy Analysis (RDA) with chemical parameters as response variables to soil epigeic fauna distribution in native cerrado and Eucalyptus plantations in central Brazil – Brasília, in rainy**(a)** and dry **(b)** seasons. Thicker lines indicate the explanatory variables and thinner lines indicate the response variables.

Where: Isopt = Isoptera; Coll = Collembola; For = Formicidae; Hemi = Hemipetra; Aca = Acarina; Hyme = Hymenoptera; Pso = Psocoptera; Thy = Thysanoptera; Cole = Coleoptera; Bla = Blattodea; Dip = Diptera; Siph = Siphonaptera; Ara = Araneae; Ort = Orthoptera; Dipl = Diplopoda; Neu = Neuroptera; Others = Larvae; K = Potassium; Ca = Calcium; PH (h_20) = Ph in watter base and MO = Organic Matter.

5.4 DISCUSSION

5.4.1 Differential soil epigeic fauna communities among land use types in both seasons.

Our results showed that soil epigeic fauna communities differed in composition between Eucalyptus and cerrado areas, in both seasons. Even though Shannon's diversity index didn't differ between both land uses, the higher mean values per plot in the cerrado during the rainy season may be linked to a high diversity of litter composition due to a diversity of plant species. Sauvadet et al., (2017) reported that the presence of detritivores (epigeic fauna) presence is tightly related to litter quality. Therefore, eucalyptus monoculture reduces the variety of litter composition compared to native cerrado that is composed of a large diversity of vegetable species. Also, interactions between management practices, as the application of inputs, the transit of machines, and the alteration of vegetation cover can be critical stress factors for the communities established there (ROSA et al., 2015).

We found that soil epigeic fauna abundance and diversity changed between cerrado and Eucalyptus areas, with a reduction of some species in the planted ecosystems, corroborating with several studies (POMPEO et al., 2020; ROSA et al., 2015, BARRETA et al., 2011) that also found this trend of reduction of some soil fauna groups by land-use changes.

The lower value of soil fauna diversity in the dry season when compared to the rainy seasons in the cerrado area could be a result of the vertical movement of edaphic fauna along the soil profile, due to the increase in temperature and the decrease of soil moisture on the surface during the dry seasons in the cerrado area. This, in turn, could induce soil organisms to enter deep areas of the soil profile (LAVELLE; SPAIN, 2001). Because the pitfall traps were allocated in the soil surface, this trend could be a result from the denser canopy structure composition that consequently reduced temperature and soil moisture oscillations in the Eucalyptus stands compared to the savanna area that has a more widely spaced canopy structure and less shaded areas (RIBEIRO; WALTER, 1998).

We found a higher presence of Diplopoda in Eucalyptus stands relative to the cerrado during the dry season. This result can be explained due to the fact that Diplopoda is one of the most present edaphic group in many Eucalyptus stands and is extremely dependent on litter for niche and food (ASSAD, 1997), and since that litter layer in

Eucalyptus is usually higher when compared to cerrado (RIBEIRO et al., 2018), due the canopy structure and higher density of trees, Diplopoda organism's may be more dependent on that configuration.

Also, this class presents a large diversity of habits behaviors, however, most of the species are considered soil detritivores being most abundant in leaf litter and commonly found in dry forest and woodland, or more associated with rotting wood in higher rainfall areas, showing a cosmopolitan trend (SILVA et al., 2017; MESIBOV et al., 2019).

Isoptera and Diptera were more abundant in the cerrado area, and explained a large portion of the dissimilarities between the two treatments in both seasons. Isoptera is present in many tropical and subtropical ecosystems worldwide, playing a key role in the litter decomposition process, improving soil structure and fertility, contributing to the fully nutrient cycling process (PRASTYANINGSIH et al., 2020). The response of this group to habitat changes may relate to the fact that these insects are considered bio indicators to land use management (BARROS et al., 2002). Given the establishment of Eucalyptus plantations reduced their abundance, it can become a problem to the sustainability of these ecosystems functions and for the Cerrado ecoregion soil's biodiversity.

Diptera order is not usually considered a soil group, although, some species have a temporary presence in soil and present a remarkable litter-decaying activity been one of the most important insect groups in soils (ASSAD, 1997; ROSA et al., 2015). Some studies report that Diptera order is one of the most abundant soil fauna group in Eucalyptus plantations (MARTINS et al., 2017; TACCA; KLEIN; PREUSS, 2017), and since that their presence was reduced in these ecosystems (less than a half of the abundance of the cerrado area, in both seasons), this can represent a major problem due to their contributions to the nutrient cycling process.

Another group that presented differences between Eucalyptus and cerrado areas was Collembola, being this abundance reduced in the plantations area during both seasons. Oliveira Filho et al., (2016) affirmed that Collembola is very influenced by environmental factors as, vegetation, biological, chemical and physical edaphic conditions, varying according to the land-use system. In the same study, they state that the Collembola communities' composition is a relevant soil quality indicator, which leads us to affirm that the reduction of this group in Eucalyptus areas in central Brazil can represent a significant problem for self-sustainability of this ecosystems since Collembola is highly correlated to nutrient cycling process (HOPKIN, 1997).

Formicidae was the most present group in both systems, being more present in the Eucalyptus area during the rainy season and in cerrado during the dry season. This group is generally reported as the most abundant group in soil fauna studies due to its crucial role in litter fragmentation and incorporation of organic material into the soil (TAVARES ET AL., 2020). Accordingly, Formicidae was one of the three most abundant families during both dry and rainy seasons, in both areas of our study. Also, Faria et al., (2021) found that Formicidae contributed with 42.28% of the total soil fauna collected in a regenerating cerrado, in Rio Verde state of Goiás, Brazil, which corroborates with our findings.

According to the PCA analyses (figure 3), regardless of season collection, Neuroptera order abundance was correlated to Eucalyptus areas. This group is worldwide present, especially in neotropical regions (VIANA; ALBUQUERQUE, 2009) and also common found associated with roots of Eucalyptus trees in the larvae phase in Australia (TAUBER; TAUBER; ALBUQUERQUE, 2009), which could explain the higher presence of this group in the Eucalyptus stands. Also, some species have a feeding habit of eating Araneae eggs (FREITAS; PENNY, 2012) and this order was also more present in the eucalyptus stands when compared to the cerrado area.

Since fauna communities are responsible for several ecosystem services, such as the improvement of the physical conditions of soils (i.e., aggregate stability, hydraulic conductivity, and total porosity) and are essential to decomposition and incorporation of soil organic matter that promotes the nutrient cycling (GUERRA et al., 2021), the reduction of some groups found in the eucalyptus area can represent a major problem for the soil biodiversity, highlighting the problem of land-use changes from native cerrado to Eucalyptus plantations, that can promote serious implications on the hole nutrient cycling process and sustainability of these ecosystems.

5.4.2 Soil fertility variables and pH correlated with soil epigeic fauna

According to Jiménez, Rossi and Lavelle (2001), little is known about the factors that controls or influence the spatial distribution patterns of soil fauna, where, presumably, environmental factors are responsible, at least in part, for the spatial pattern of these organisms. Our results indicate a high relation between soil chemical parameters and soil epigeic fauna, where Organic Matter, Calcium, Potassium, pH, and Phosphorous presented as good indicators, although, these interactions between soil fauna communities and fertility parameters are complex (POMPEO et al., 2020).

Other studies pointed that these parameters were valuable variables for the association between soil fauna and soil chemistry (BARETTA et al., 2014; YANG et al., 2021). We found that chemical parameters associations to soil epigeic fauna changed through seasons, which indicates that the analyzed environmental variables can influence the soil fauna groups in different ways between seasons, which corroborates with the founding's of Rosa et al., (2015) that affirmed that correlations of the environmental variables with soil macrofauna in different land-uses in southern of Brazil also found a similar trend, with changes in these relations across summer and winter.

Among the soil chemistry components, the Potassium parameter was the only environmental parameter that presented influence on soil epigeic fauna in both seasons. This nutrient showed a high influence on soil fauna groups which corroborates with findings all over the world, covering from China (YANG et al., 2021) to Brazil (BARETTA et al., 2014). Also, according to Rosa et al., (2015), Orthoptera and Diptera presented a correlation to K soil contents in different land uses in south Brazil, which corroborates with our findings during the dry period associations. In the rainy season, we could observe a high influence on Formicidae by K contents, which corroborates with the findings of Martins et al., (2020), who affirmed that the addition of k in soil increased the dominance of the Formicidae family in livestock crop integration land in central Brazil, and also, Zhu and Zhu (2015) found the same correlation trends between soil total K and Formicidae families in agricultural lands, in southwestern China.

The other soil parameter that stood out in rainy season collection was Organic Matter. Since that soil fauna is extremely necessary to the transformation of organic residues and incorporation of soil organic matter (LAVELLE et al., 1993), their association was expected. From the groups associated with soil organic matter, Acarina sub-class presented a high correlation with this environmental factor, and since this group presented lower abundance in Eucalyptus stands compared to the cerrado, this can represent a major problem for the nutrient cycling process and soil biodiversity. In this context, Carvalho et al., (2018) affirm that land-use changes in Central Brazil by the substitution of native forests to monocrop systems reduced the abundance, richness, and structuring of edaphic Acari communities, which corroborates with our findings.

Regarding Ca influence on soil epigeic fauna, the Diplopoda class presented a high association to this soil element in dry season. This may be linked to the importance of calcium to Diplopoda as it is the main impregnating element in their cuticle (KIME; GOLOVATCH, 2000). The Isoptera group showed an opposite trend, with low influence by Ca contents, which corroborates with Portilho et al., (2011) study in an oxisol in Cerrado, that affirmed that Isoptera order had more abundance on sites that presented low Ca+Mg contents and is also an indicator of degraded area, what also could be observed in our results, where Isoptera showed a negative association with Ca contents on the soil. Furthermore, regarding Ca contents influence on soil epigeic fauna, Coleoptera showed positive association to this soil element which was also found by Lourente et al., (2007) that affirmed that this group presented a positive correlation to Ca contents.

P content was positively associated to Isoptera, Neuroptera, and unidentified larvae organisms (called Others). According to Susser, Pelini, and Weintraub (2020), soil fauna may affect soil P concentrations through direct and indirect effects on litter decomposition by detritivores activities that can promote organic matter shredding or consuming microbes and mineralizing the P contents in their biomass, which may explain the relationship between these groups and the P soluble contents on the soil. Also, Peng et al., (2019) stated that soil P contents derived from litter are highly dependent on soil fauna activities by the fractionation of vegetable residues and organic matter.

Soil pH is usually a quality indicator of soils representing some limitations to life of vegetables or soil animals on low levels of this parameter due to the influences on cation capacity exchange and organic matter decomposition (JUHOS et al., 2019). Even that soil acidity generally limits the biodiversity of soil fauna, some groups can adapt to this type of environment and tolerate low levels of pH as it is common found in tropical soils (LAVELLE; CHAUVEL; FRAGOSO, 1995). We observed that most of the soil fauna groups presented a low association with the pH values, what could be explained by the low levels of pH found in the Oxisols (Latossols) in the Cerrado (HARIDASSAN, 2000), while only three soil fauna groups showed expressive influenced by the pH values, Neuroptera, Isoptera, and Larvae (others).

5.5 CONCLUSIONS

We investigated soil epigeic fauna community ecology in a cerrado area and Eucalyptus stands, quantifying changes in abundance, composition, diversity and correlations with soil chemical parameters. Comparing the soil epigeic fauna communities' composition between the two land uses, we found dissimilarities due to the fact that most groups of epigeic fauna are more present in the cerrado area. The land-use changes by Eucalyptus plantations may indicate a possible threat to soil ecological biodiversity and this trend can represent a major concern about possibly lead to the spoil of the hole nutrient cycling process and the full ecosystem functions.

Even though eucalyptus plantations are considered to be one of the least impactful monocultures on edaphic fauna communities, the implantation of these forests must be carried out in such a way as to minimize as much as possible their negative effects on the communities of soil organisms, aiming at conservationist implantation practices.

We also found that organic matter, potassium, calcium, phosphorous, and soil pH are good indicators to evaluated soil epigeic fauna communities, since they presented good association between environmental parameters and soil epigeic fauna groups. More comparative studies are encouraged, especially in a larger area of coverage in native savannas areas and eucalyptus stands, so we can better understand these trends and then use this information for management and conservation actions.

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5.6 REFERENCES

ASSAD, M. L. L. Fauna do solo. In: VARGAS, M. A. T.; HUNGRIA, M., (Eds) **Biologia dos solos dos cerrados**. 1. Ed. Planaltina: EMBRAPA, 1977. p. 363-443.

ASSIS, L. F. F. G. et al., A spatial data analytics infrastructure for large-scale thematic mapping. **International Journal of Geo-Information**, v. 8, n. 513, p. 1-27, 2019. https://doi.org/10.3390/ijgi8110513.

BARETTA, D. et al., Fauna edáfica avaliada por armadilha e por catação manual afetada pelo manejo do solo na região Oeste Catarinense. **Revista de Ciências Agroveterinárias**, v. 2, n. 2, p. 97-106, 2003.

BARETTA, D. et al., Trap and soil monolith sampled edaphic spiders (Arachnida: Araneae) in Araucaria angustifolia forest. **Scientia Agricola**, v. 64, n.4, p. 375-383, 2007.

BARETTA, D. et al. Fauna edáfica e qualidade do solo. In: KLAUBERG-FLHO, O.; MAFRA, Á. L.; GATIBONI, L. C. (ed.). **Tópicos em ciência do solo**. 7. ed. Viçosa: Sociedade Brasileira de Ciência do Solo, 2011. p. 119-170.

BARROS, E.; PASHANASI, B.; CONSTANTINO, R. & LAVELLE, P. Effects of land-use system on the soil macrofauna in western Brazilian Amazonia. **Biology and Fertility of. Soils**, v. 35, p.338-347, 2002.

BEAUMELLE, L. et al., Soil fauna diversity and chemical stressors: a review of knowledge gaps and roadmap for future research. **Ecography**, v. 44, p. 1–15, 2021.

BOENO, D. et al., Influence of eucalyptus development under soil fauna. **Brazilian Journal of Biology**, v. 80, n. 2, p. 345-353, 2020.

CARVALHO, T. A. F. et al., Edaphic mites and their response to the incorporation of organic matter from various species of Fabaceae into the soil beneath coffee trees. **Acarina**, v. 26, n. 2, p. 183–195, 2018.

Empresa Brasileira de Pesquisa Agropecuária (Embrapa); **Manual de Métodos de Análises Químicas para Avaliação da Fertilidade do Solo**; DA SILVA, F. C.; DA EIRA, P. A.; BARRETO, W. O.; PÉREZ, D. V.; SILVA, C. A. eds.; EMBRAPA-CNPS: Rio de Janeiro. 1998, 56 p.

FARIA, A. C. G. S. de. et al., Macrofauna edáfica em área de cerrado regenerado. **Revista de biologia e ciências da terra**, v. 21, n. 1, p. 39-45, 2021.

FELFILI, J. M. et al., Changes in the floristic composition of Cerrado sensu stricto in Brazil over a nine-year period. **Journal of Tropical Ecology**, v. 16, p. 579-590, 2000.

FREITAS, S.; PENNY, N. D. Neuroptera Linnaeus, 1758. In: RAFAEL, J. A.; MELO, G. A. R.; CARVALHO, C. J. B. de; CASARI, S. A.; CONSTANTINO, R. (Ed.). **Insetos do Brasil: diversidade e taxonomia**. Ribeirão Preto: Holos Editora, 2012. p. 537-546.

HARIDASAN, M. Nutritional adaptations of native plants of the cerrado biome in acid soils. **Brazilian Journal of Plant Physiology**, v. 20, n. 3, p. 83-195, 2008.

HOPKIN, S. P. **Biology of the Springtails (Insecta: Collembola)**. Oxford: Oxford University Press; 1997, 344p.

HURT, G. C. et al., Harmonization of global land use change and management for the period 850–2100 (LUH2) for CMIP6. **Geoscientific Model Development**, v.13, p.5425–5464, 2020.

JIMÉNEZ, J. J.; ROSSI, J. P.; LAVELLE, P. Spatial distribution of earthworms in acid-soil savannas of the eastern plains of Colombia. **Applied Soil Ecology**, v. 17, p. 267–278, 2001.

JUHOS, K. et al., Interpretation of soil quality indicators for land suitability assessment – A multivariate approach for Central European arable soils. **Ecological Indicators**, v. 99, p. 261–272, 2019.

KIME, R. D.; GOLOVATCH, S. I. Trends in the ecological strategies and evolution of millipedes (Diplopoda). **Biological Journal of the Linnean Society**, v. 69, p. 333-349, 2000.

LAMBIN, E. F. et al. Estimating the world's potentially available cropland using a bottom-up approach. **Global Environmental Change**, v. 23, n. 5, p. 892–901, 2013.

LAVELLE, P. et al., Hierarchical model for decomposition in terrestrial ecosystems: application to soils of the humid tropics. **Biotropica**, v. 25, p. 130-150, 1993.

LAVELLE, P.; CHAUVEL, A; FRAGOSO, C. Faunal activity in acid soils. In: DATE, R. A. **Plant Soil Interactions at Low pH**. Springer, Berlin, Germany, 1995, p. 201–211.

LAVELLE, P.; SPAIN, A. **Soil ecology**. Dordrecht, Kluwer Academic Publishers, 2001. 654p.

LOURENTE, E. R. P. et al., Macrofauna edáfica e sua interação com atributos químicos físicos do solo sob diferentes sistemas de manejo. **Acta Scientiarum-Agronomy**, v.29, p.17-22, 2007.

MARTINS, L. F. et al., Composição da macrofauna do solo sob diferentes usos da terra (cana-de-açúcar, eucalipto e mata nativa) em Jacutinga (MG). **Revista Agrogeoambiental**, v. 9, n. 1, 2017.

MESIBOV, R. Cambaloid millipedes of Tasmania, Australia, with remarks on family-level classification and descriptions of two new genera and four new species (Diplopoda, Spirostreptida). **ZooKeys**, v. 827, p. 1–17, 2019.

MORANDI, P. S. et al., Tree diversity and above-ground biomass in the South America Cerrado biome and their conservation implications. **Biodiversity and Conservation**, v. Online, p. 1–18, 2018.

MOTA, F. M. **Biomassa, fluxos de carbono e energia em área de Cerrado sentido restrito e plantio de eucalipto no Distrito Federal**. 2017. Tese (Doutorado em Ciências Florestais) – Faculdade de Tecnologia, Universidade de Brasília, Brasília.

MYERS, N. et al., Biodiversity hotspots for conservation priorities. **Nature**, v. 403, p. 853–858, 2000.

NIMER, E. **Climatologia do Brasil**. 2ª ed. Rio de Janeiro: IBGE. Departamento de Recursos Naturais e Estudos Ambientais, 1989, 421 p.

OLIVEIRA FILHO, L. C. I. et al., Collembola Community Structure as a Tool to Assess Land Use Effects on Soil Quality. **Revista Brasileira de Ciência do Solo**, v. 40, e0150432, 2016.

PENÃ-PENÃ, K.; IRMLER, U. Moisture seasonality, soil fauna, litter quality and land use as drivers of decomposition in Cerrado soils in SE-Mato Grosso, Brazil. **Applied Soil Ecology**, v. 107, p. 124–133, 2016.

PENG, Y. et al., Impacts of soil fauna on nitrogen and phosphorus release during litter decomposition were differently controlled by plant species and ecosystem type**. Journal of Forestry Research**, v. 30, n. 3, p. 921 – 930, 2019.

POMPEO, P. N. et al., Coleoptera Diversity and Soil Properties in Land Use Systems. Floresta e Ambiente, v. 27, n.3, e20180068, 2020.

PORTILHO, I. I. R. et al. Fauna invertebrada e atributos físicos e químicos do solo em sistemas de integração lavoura-pecuária. **Pesquisa Agropecuária Brasileira**, v. 46, n. 10, p. 1310–1320, out. 2011.

PRASTYANINGSIH, S. R. et al., Diversity of termites (Isoptera) on industrial forest plantation of Eucalyptus pellita stands of tropical ecosystem in Riau, Indonesia. **Biodiversitas**, v. 21, n.11, p. 5498-5505, 2020.

RIEFF, G. G. et al., Collembolans and mites communities as a tool for assessing soil quality: effect of eucalyptus plantations on soil mesofauna biodiversity. **Current science**, v. 110, n. 4, p. 713-719, 2016.

RIBEIRO, F. P. et al., Litter Dynamics in Eucalyptus and Native Forest in the Brazilian Cerrado. **Journal of Agricultural Science**, v. 10, n. 11, 2018.

RIBEIRO, J. F. & WALTER, B. M. T. Fitofisionomias do bioma Cerrado: os biomas do Cerrado. In: Sano, S. M. & Almeida, S. P. (eds.), **Cerrado: Ambiente e Flora**. Planaltina: Embrapa. 1998. pp. 89–166.

ROSA, M. G. et al., Macrofauna Edáfica e Atributos Físicos e Químicos em Sistemas de Uso do Solo no Planalto Catarinense. **Revista Brasileira de Ciência do Solo**, v. 39, n.6, p. 1544-1553, 2015.

SAUVADET, M. et al., Can changes in litter quality drive soil fauna structure and functions? **Soil Biology & Biochemistry**, v.107, p. 94-103, 2017.

SILVA, V. M. et al., Influence of the tropical millipede, Glyphiulus granulatus (Gervais, 1847), on aggregation, enzymatic activity, and phosphorus fractions in the soil. **Geoderma**, v. 289, p. 135–141, 2017.

SILVEIRA, E. R. et al., Diversidade e papel funcional da macrofauna do solo na Integração Lavoura-Pecuária. **Revista técnico Científica do CREA-PR**, 4ª ed., p.1-16, 2016.

SOUZA, S. T. de. et al., Abundance and Diversity of Soil Macrofauna in Native Forest, Eucalyptus Plantations, Perennial Pasture, Integrated Crop-Livestock, and No-Tillage Cropping. **Revista Brasileira de Ciência do Solo**, v. 40, n. 1, p. 1-14, 2016.

SUSSER, J. R.; PELINI, S. L.; WEINTRAUB, M. N. Can we reduce phosphorus runoff from agricultural fields by stimulating soil biota? **Journal of environmental Quality**, v. 49, p. 933-944, 2020.

TAUBER, C. A., TAUBER, M. J.; ALBUQUERQUE, G. S. Neuroptera (lacewings, antlions). In: Resh, V. H. & Cardé, R. T. (eds.). **Encyclopedia of Insects**, 2nd Edition. Elsevier. Amsterdam, 2009, 695-707p.

TAVARES, P. D., SILVA, C. F., PEREIRA, M. G., SILVA, E. M. R. da, Composition of the soil fauna community and leaf litter stock in agro-forestry systems and secondary forestry. **Bioscience Journal**. v.36, 2020.
https://doi.org/10.14393/BJ-v36n4a2020-42715

VENDRAME, P. R. S. et al. Relationship between macrofauna, mineralogy and exchangeable calcium and magnesium in Cerrado Oxisols under pasture. **Pesquisa Agropecuária Brasileira**, v. 44, n. 8, p. 996–1001, ago. 2009.

VIANA, G. G.; ALBUQUERQUE, G. S. Polimorfismo no padrão de machas tegumentares de larvas e adultos de Ceraeochrysa caligata (Neuroptera: Chrysopidae) e redescrição dos instares larvais. **Zoologia**, v. 26, n. 1, p. 166-174, 2009.

YANG, X. et al., Community characteristics and distribution patterns of soil fauna after vegetation restoration in the northern Loess Plateau. **Ecological Indicators**, v. 122, p. 107236, 2021.

ZHU, X.; ZHU, B. Diversity and abundance of soil fauna as influenced by long-term fertilization in cropland of purple soil, China. **Soil & Tillage Research**, v.146, p.39–46, 2015.

ZUIN, V. G. What Can Be Learnt from the Brazilian Cerrado? In: Mammino L. (eds) **Biomass Burning in Sub-Saharan Africa**. Springer, Dordrecht. p. 143-160, 2020.

6. CONSIDERAÇÕES FINAIS

Os resultados alcançados nesta tese permitiram evidenciar as relações entre os aspectos físicos, químicos e biológicos do solo, a relação solo-planta-serapilheira, e a ciclagem de nutrientes em área de cerrado sentido restrito e florestas de eucalipto. O levantamento de dados pelo período de dois anos consecutivos de avaliação, em três áreas distintas, com coletas mensais, envolvendo a deposição de serapilheira, coletas periódicas de decomposição da serapilheira, crescimento diamétrico de árvores e dados físicos, químicos e biológicos do solo com obtenção de resultados nos levantamentos a campo e laboratório, possibilitaram avançar o conhecimento a respeito dos processos de ciclagem de nutrientes nestes ecossistemas.

Em alguns momentos, os percalços ocorridos durante a pesquisa fugiram até do convencional compartilhamento de equipamentos de laboratório em escalas, de infestações de carrapato, ou até mesmo a visualização de animais peçonhentos nas coletas de campo, como o encontro indesejável com uma onça parda, que em outros momentos interferiu na coleta de dados por tentar derrubar coletores e mastigar as placas de alumínio das marcações das árvores e parcelas. Além do fato de ter sofrido um acidente de trabalho com o moinho de facas que me rendeu 12 pontos no dedo indicador da mão direita e uma longa recuperação. Embora estes eventos não sejam habituais, estamos sujeitos a tais ocorrências em prol da pesquisa e da ciência.

No primeiro capítulo desta tese, podemos constatar a falta de estudos a respeito do aporte e decomposição da serapilheira em diversas fitofisionomias do cerrado, o que evidencia uma necessidade de estudos nesse ecossistema, havendo uma lacuna a ser preenchida. Pôde-se também constatar uma expressiva desuniformidade nas metodologias utilizadas nos estudos levantados, o que evidencia a necessidade da criação de um protocolo único de avaliações para que a comparação entre os estudos seja mais eficiente e reporte a realidade de forma mais fidedigna. Além disso, observou-se pequena quantidade de estudos de longo prazo, o que pode em alguns casos mascarar alterações interanuais nos resultados obtidos, gerando dados não fidedignos das taxas de decomposição e aporte de serapilheira.

Em relação ao estudo na área de cerrado sentido restrito, observamos o quanto a sazonalidade das chuvas nestas áreas influencia na decomposição, aporte e composição da fauna epigeica do solo, além de constatar uma alta correlação entre a diversidade e abundância dos organismos da fauna do solo com a decomposição de galhos e folhas, respectivamente. Cabe ressaltar que por ser um dos poucos estudos publicados a respeito dos organismos da fauna do solo, e mais ainda por correlacionar estas comunidades com a decomposição de diferentes componentes da serapilheira, o estudo se apresenta como um ponto inicial para futuros estudos dentro desta temática.

Os resultados obtidos nos estudos realizados nas áreas de florestas de Eucalipto com enfoque nos impactos ocasionados pela remoção da camada de serapilheira evidenciaram o quão importante é a manutenção destes resíduos aportados ao solo para diferentes aspectos deste ecossistema, como a proteção do solo e manutenção da umidade desse, na composição e distribuição dos organismos da fauna epigeica, na fertilidade do solo, em especial nos teores de Fósforo remanescente, bem como para o crescimento e pleno desenvolvimento das árvores plantadas.

O quarto capítulo evidenciou os impactos da alteração de áreas de cerrado sentido restrito nativos em plantios de Eucalipto por meio da redução da abundância de diversos grupos de organismos da fauna epigeica nas áreas plantadas, sendo assim, a introdução de monocultivo deve ser realizado com alternativas que causem menos impactos nestes ambientes, uma vez que a fauna epigeica é responsável por diversos processos essenciais nestes ecossistemas, como a ciclagem de nutrientes, a estruturação do solo, o controle biológico de pragas e a manutenção da biodiversidade.

Espera-se que esta tese seja um ponto inicial para o desenvolvimento de outras pesquisas com a finalidade de avançarmos no entendimento a respeito da ciclagem de nutrientes no bioma cerrado, investigando as relações dos parâmetros químicos, físicos e principalmente os biológicos do solo, uma vez que estes conhecimentos são ainda muito incipientes e iniciais. Além disso, espera-se que os resultados aqui apresentados sejam utilizados como parâmetros para a produção de políticas públicas e ações de manejo e conservação de áreas pertencentes ao bioma cerrado.