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Litter stock and nutrients under different restoration methods in the eastern Amazon

Estoque de serrapilheira e nutrientes em áreas de restauração florestal na Amazônia oriental.

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ABSTRACT

Litter production contributes to soil fertility through the decomposition process, especially in Amazonian soils, which have low fertility. Amazonian ecosystems are dependent on the forest to ensure their maintenance through nutrient cycling, via litter. The objective of this work was to evaluate litter stock and nutrient content under different restoration methods in abandoned pasture areas in the eastern Amazon. The macronutrient content via litter followed the order: Ca > N > P >Mg > K >Na. Calcium was the macronutrient that most returns to the soil via litter. The restoration method through silvipastoral system presented the highest values of nitrogen. The area under passive restoration proved to be the most efficient method to recover areas degraded by pasture in the eastern Amazon, due to the highest litter stock and nutrient content.

Keywords: Abandoned pastures; Nutrient cycling; Tropical forest; Resilience; Degraded areas.

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RESUMO

A produção da serrapilheira contribui na fertilidade dos solos através do processo de decomposição, sobretudo nos solos da região amazônica, que naturalmente são pouco férteis. Isso porque esses ecossistemas são dependentes da floresta para garantir sua manutenção através da ciclagem de nutrientes, via serrapilheira. O objetivo deste estudo foi avaliar qual o método de restauração proporciona maior estoque de serrapilheira e melhor teor de nutriente em áreas de pastagens abandonadas na Amazônia Oriental. O conteúdo de macronutrientes via serrapilheira obedeceu à seguinte ordem: Ca > N > P >Mg > K >Na. Cálcio é o macronutriente que mais retorna ao solo via serrapilheira. O método de restauração utilizando o SAF, obteve melhores valores para nitrogênio. A área sob restauração passiva se mostrou o método mais eficiente para recuperação de áreas degradadas por pastagem na Amazônia Oriental, pelo maior estoque de serrapilheira e melhor teor de nutrientes.

Palavras-chave: Pastagens abandonadas; Ciclagem de nutrientes; Floresta tropical; Resiliência; Áreas degradadas.

INTRODUÇÃO

Soils in tropical regions commonly have low natural fertility due to intense weathering. Tropical soils depend on the forest to ensure their maintenance through nutrient cycling, via litter (BARREIROS et al. 2022). In this sense, extractive cycles, such as forestry, coffee farming, and livestock farming are activities that decrease soil fertility and consequently ecosystem services in the Amazon (MATEUS et al. 2013, SILVEIRA et al. 2015, REBÊLO et al. 2021). Litter is formed by leaves, branches, trunks, flowers, fruits, and seeds that fall to the ground, and by insects, other animals, and fecal waste. It works as a buffer for the hydrodynamic force of rain, preventing erosion, and also retains water, reducing soil temperature, and providing the means for more efficient nutrient cycling (PIOVESAN et al. 2012). Material accumulation varies depending on the origin of plant species, forest cover, successional stage, collection period, and forest type. Quality is determined by the plant species present in the sampled are (VIGULU et al. 2019).

Litter production contributes to soil fertility through the decomposition process, especially in Amazonian soils, which are naturally low fertile. It is the main way to transfer nutrients to the soil, enabling nutrients reabsorption by plants, thus constituting the main route in biogeochemical cycles (flow of nutrients in the soil-plant-soil system) that enable trees to synthesize organic matter through photosynthesis (SCHUMACHER et al. 2005, QUESADA et al. 2011, LABEGALINI et al. 2016). Thus, the presence of litter in areas under initial restoration is essential (LORENZO & CAMPAGNARO 2017).

In the Brazilian Amazon, large areas of pasture are abandoned due to losses in their productive capacity (DIAS-FILHO E ANDRADE 2006, LERNER et al. 2015, IPAM 2021), which tests the ecosystem resilience. The ecosystem resilience or the ability to recover on its own is considered a passive restoring method. Active restoration methods can also be applied, such as planting seedlings of native and exotic, pioneer and non-pioneer species to accelerate restoration through litter accumulation (COSTA et al. 2017). The stock and concentration of macronutrients and micronutrients work as an indicator of forest recovery, allowing the process evaluation of the vegetation reestablishment (PEREIRA et al. 2013).

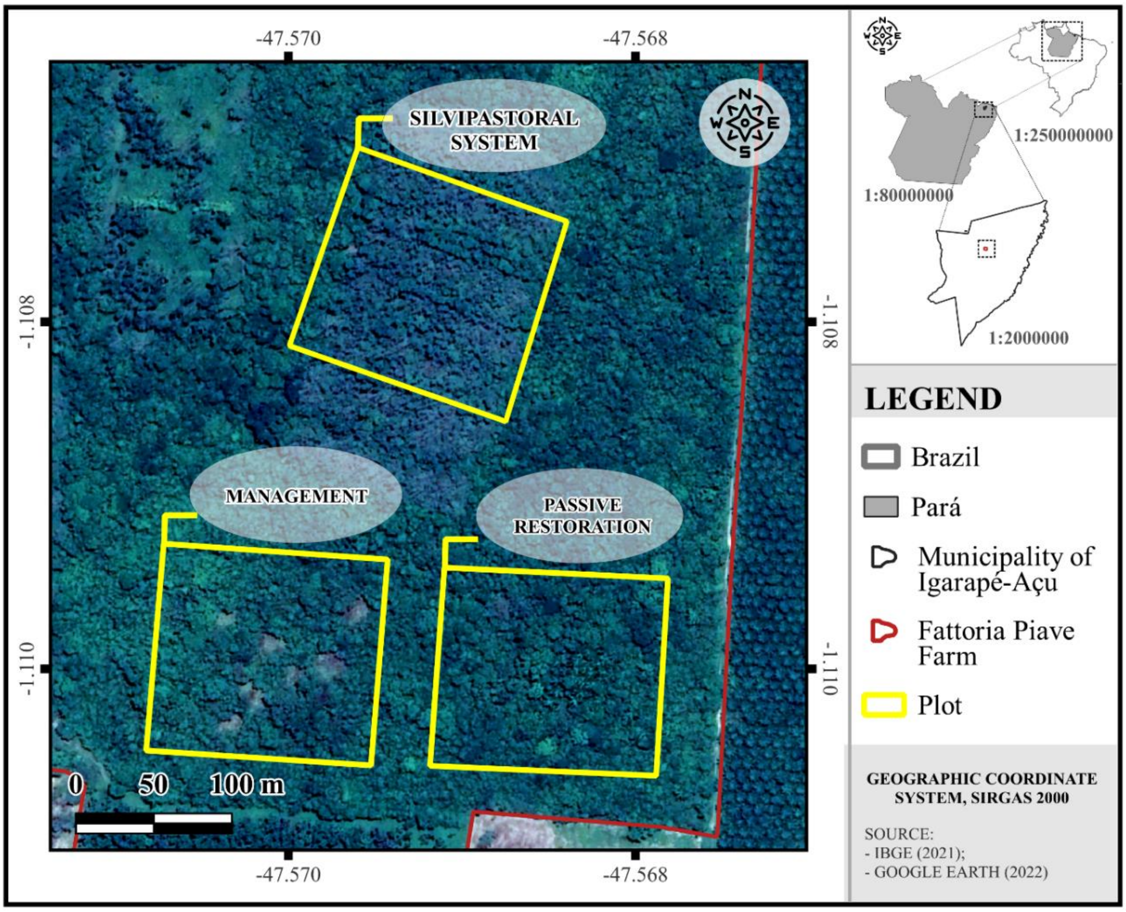
Therefore, the objective of this study was to evaluate three different restoration methods in relation to litter stock and nutrient content in abandoned pasture areas in the eastern Amazon.

MATERIALS AND METHODS

a) Study site

The study was carried out in a *Terra Firme* 18-year-old secondary forest located in the municipality of Igarapé-Açu, Pará state, Eastern Amazon, Brazil (Figure 1). The forest belongs to the Legal Reserve (LR) area of the *Fattoria Piave* Farm (Lat: 01º06'27.52" S and Long: 47º34'17.87" W), which has a total area of 79.16 ha.

Figure 1- Location of the study area under different restoration methods in a 18-year-old secondary forest, municipality of Igarapé-Açú, eastern Amazon, Brazil.



Source: Costa (2023)

Dense Ombrophilous Forest is the region's characteristic ecosystem (IBGE, 2012). According to the Köppen classification, the region's climate is “Am”, tropical rainy, with an average annual temperature of 25 ºC; annual precipitation 2,350 mm, and relative humidity of 85%. The soil is a cohesive Dystrophic Yellow Oxisol, with medium texture, well drained, with low base saturation, low cation exchange capacity, low assimilable phosphorus content, and medium to low organic matter content. It has a cohesive and dense layer, between depths of 20 cm and 25 cm and 40 cm to 45 cm (FALESI et al. 2012).

Three hectares of permanent monitoring plots (PMP) were installed in March 2018. These areas, before abandonment, were used as pasture for more than 30 years. PMPs were installed following the RainForest protocol (OLIVER et al. 2021). One 1-ha (100 m x 100 m) plot, divided in 100 100-m^2 (10 m x 10 m) subplots was installed in each one of the three treatments. All individuals with DBH ≥ 5 cm were monitored as well as smaller individuals (height ≥ 30 cm) in smaller subplots. The three 1-ha PMPs had the following features:

1) Passive restoration plot: passive restoration with no interventions.

2) Silvipastoral system plot: forest restoration with different tree species types, including exotic (*Acacia mangium* Willd. and *Azadirachta indica* A.Juss.), native (*Jacaranda copaia* (Aubl.) D.Don and Carapa), and fruit species (Theobroma grandiflorum (Willd. ex Spreng) K. Schum.).

3) Management plot: seven canopy gaps with average size of 200 m^2 were opened inside the 1-ha plot and seedlings of two native tree species were planted; 101 individuals of *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke), Barneby (paricá) and 101 individuals of *Hymenaea courbaril* L. (jatobá). The plot also had vine and liana management (cutting).

b) Data collection

4.2.1- Litter

To sample the depositional litter, 30 of the 100 100-m^2 sub-plots of each treatment were drawn. A sampler with dimensions of 25 cm x 25 cm (625 cm^2) and 8 cm in height (thickness), with a collection volume of 5000 cm^3 was used. Subsequently, 10 composite soil samples were made from each treatment.

The calculated parameters were:

- Dry phytomass from the litter, obtained by drying litter in an oven for 72 hours at 70 ºC.

- Chemical analysis procedures on the plant material were implemented after sample preparation, drying litter at 70 °C for 48 hours and determining dry mass with accuracy of hundredths (0.010), and finally grinding it in a Wiley-type mill.

The chemical elements (C, N) were determined by a CHN analyzer. The elements P, K, Ca, Na, Mg, Mn, Fe, Cu, and Zn were obtained by digestion in double nitro-perchloric acid solution (HNO3 -HCLO4 solution 2:1) with spectrophotometer determination for P and K, and atomic absorption spectrophotometry (AAS) for Ca, Na, Mg, Mn, Fe, Cu, Zn (SILVA 1999).

The estimate of the average stock of elements was obtained by multiplying the means concentration (ppm) of the elements by the estimate of the mean dry mass of the litter biogeochemical matrix (g).

To estimate litter stock, the following formula was used:

Dry weight of litter (g) / collector area (m^2) x 0.01 (in megagrams per hectare)

c) Statistical analyses

The analytical results of the physical and chemical property data subpopulations were analyzed by multiple comparison and simple analysis of variance (ANOVA) methods.

To verify the assumptions of ANOVA, data were analyzed for: a) normality with the Shapiro-Wilk test ($p > 0.05$), b) homoelasticity using the Bartlett test ($p > 0.05$), and c) independence between experimental units. Once these assumptions were met, the data were subjected to ANOVA using the R program version 4.0.2. (R DEVELOPMENT CORE TEAM 2022). In case of differences among means, the Tukey's post-hoc test was applied ($p <0.05$) (Table 1).

Table 1. Means ± SD of macronutrients in areas under three different restoration methods (Passive Restoration, Silvipastoral System, and Management), municipality of Igarapé-Açú, eastern Amazon, Brazil.

Method/Nutrient	N	P	K	Na	Ca	Mg
	$g\ Kg^{-1}$					
Passive Restoration	5.85±0.76b	4.23±0.77b	1.12±0.46a	1.08±0.37a	13.61±2.19a	2.05±0.61a
Silvipastoral System	6.86±0.68a	5.40±0.37a	0.68±0.16b	0.90±0.28a	6.86±1.23c	1.21±0.27b
Management	5.75±0.79b	5.18±0.65a	1.15±0.35a	0.96±0.28a	9.39±2.26b	1.55±0.30b

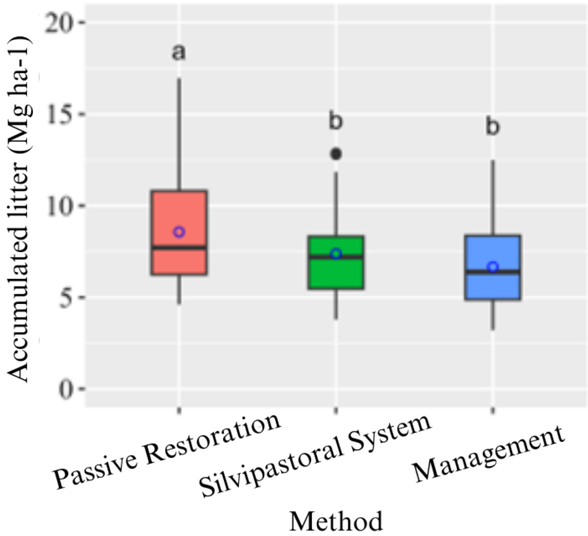
*Means followed by the same lowercase letter in the column do not differ from each other using the Tukey test at 5% probability.
Source: Costa (2023)

RESULTS AND DISCUSSION

Litter stock

There was a difference between the values of accumulated litter (or stock): 8.57 $Mg\ ha^{-1}$ in the treatment of passive restoration, 7.38 $Mg\ ha^{-1}$ in the silvipastoral system, and 6.66 $Mg\ ha^{-1}$ in management (Figure 2).

Figure 2. Litter stock in the area under three different restoration methods: Passive Restoration, Silvipastoral System, and Management, municipality of Igarapé-Açú, eastern Amazon, Brazil.



Source: Costa (2023)

Regarding the fractions of litter-forming material, the leaf fraction contributed the most in all treatments, corroborating the work of Gomes et al. (2010), Lima (2015), Villa et al. (2016), and Barreiros et al. (2022). This is explained by the fact that leaves have high transpiration rates, hence, plants deposit greater amounts of leaf fraction to reduce water loss (PIMENTEL 2021).

Barreiros et al. (2022), found 8.9 Mg ha^{-1} of accumulated litter collected during the rainy season in a managed dense rainforest, Amazonas state, Brazil, which is result close to that found in passive restoration. Pimentel et al. (2021), found an accumulation of 10.2 Mg ha^{-1} in an 8-year-old agroforestry system, after 15 years of pasture use. Such result differs from this study, possibly due to the shorter exposure time to the degradation source. Probably such area has strong resilience, with high litter stocks.

In Espírito Santo state, Brazil, two 20-year-old restoring areas (one with *Eucalyptus* and *Acacia* and another with different species) presented no differences in litter stocks (SPERANDIO et al. 2012). In another study with four fragments of secondary forests older than 90 years in the Atlantic Forest, there was also no statistical difference in the litter production, with an overall mean of 4.9 Mg ha^{-1} (GOMES et al. 2010).

Higher litter accumulation favors the reestablishment of new tree species, contributing to forest restoration (COSTA et al. 2010). Furthermore, it improves soil conditions by minimizing raindrops impacts, softening soil temperature, and improving nutrient cycling processes through decomposition (SPERANDIO et al. 2012, BOMFIM et al. 2020).

Balbinot et al. (2003) elucidate that, at the beginning of the establishment of natural forests and forest plantations, litter production is low. Production increases with age and may subsequently reduce in the forest climax state.

Macronutrients

The treatment passive restoration presented the lowest concentration of phosphorus (4.23±0.77 g/kg) and the highest concentration of calcium (13.61±2.19 g/kg) and magnesium (2.05±0.61g/kg) (Table 1). Silvipastoral system presented the highest nitrogen value (6.86±0.68 g/kg) and the lowest potassium (0.68±0.16 g/kg) and calcium (6.86±1.23 g/kg) amounts.

The low amount of phosphorus in the passive restoration may be related to the no pre-planting mineral fertilization of the area. In relation to calcium and magnesium, the regeneration of native species positively affected their levels in the soil, corroborating Olival et al. (2021).

The highest nitrogen values in silvipastoral system can be related to the presence of *Acacia mangium* Willd., which is a Fabaceae species, thus more efficient in nitrogen fixation, fast-growing, and contributing to greater nitrogen intake (PERRINEAU et al. 2011, MACHADO et al. 2016, TAIZ et al. 2017, ARÊAS et al. 2022). This corroborates Freitas et al. (2013) that found high nitrogen amounts in an agroforestry system with *A. mangium*.

Regarding potassium, the less diverse the ecosystem, the lower potassium values (GAMA-RODRIGUES, 2008). Possibly due to the allelopathy present in species of the genus *Acacia* and of the Meliaceae family as *Azadirachta indica* and *Carapa guianensis*, the species diversity in silvipastoral system was low (FRANÇA et al. 2008, SOUZA FILHO et al. 2010, ÁLVAREZ YEPES 2019; SANTANA-BANHEIROS et al. 2022; SCHAEFER et al. 2022). Regarding calcium, as it has rocky origin, it is naturally present in the soil. The silvipastoral system treatment was exposed to sources of degradation for a longer time, as cow and sheep cattle, which may have caused losses in calcium through leaching.

In an area of dense Amazonian rainforest, the calcium content varied from 12.9±1.6 g Kg^{-1} to 15.1±2.6 g Kg^{-1}, values close to those of this work. The amounts of magnesium (5.5±0.5 g Kg^{-1} to 7.1±1.6 g Kg^{-1}), potassium (6.6±2.8 g Kg^{-1} to 8.6±4.4 g Kg^{-1}), and sodium (2.6±0.7 g Kg^{-1} to 1.6±0.5 g Kg^{-1}) were higher than those of in this work in all treatments (REBÊLO et al. 2021). The litter collection for this study was carried out in October 2021, an abnormal rainy period but explained by the La Niña, an oceanic event of moderate intensity, where surface waters in the central and eastern parts of the Equatorial Pacific reduce temperature, impacting temperature and rainfall regimes in several parts of the globe, including South America (INMET 2023). Potassium is soluble, hence susceptible to leaching, which may explain its low concentration in relation to the passive restoration (4.23±0.77 g Kg^{-1} to 5.40±0.37 g Kg^{-1}). The low concentration of sodium in the three treatments (0.90±0.28 g Kg^{-1} to 1.08±0.37 g Kg^{-1}) is related to its low demand by plants and also the greater possibility of its adsorption by clay minerals, a soil characteristic in the region (MALAVOLTA 2006).

When comparing a non-disturbed forest, restoring forests have lower macronutrient values, due to the lower litter stock and the degradation history that lead to nutrient losses. (MALAVOLTA 2006, PEREIRA 2010, REBÊLO et al. 2021). In this study, macronutrient contents via litter followed the order: Ca > N > P >Mg > K >Na. Different results for macronutrient content in litter were found in the Amazon in non-disturbed dense rainforests; Ca > K > Mg > Na (REBÊLO et al. 2021) and N > Ca> K> Mg> P> S (FREIRE et al. 2020). In restoring areas under different planting spacing, different results were found (N > Ca > K > Mg > P) (VILLA et al. 2016).

Calcium, considered a low mobile element in plants as it is fixed in structures, probably explains the higher values found in all treatments (CALDEIRA et al. 2013, VILLA et al. 2016, ALVES et al. 2017, REBÊLO et al. 2022).

Micronutrients

Passive restoration presented highest value of zinc (128.37±22.84 mg kg^{-1}) (Table 2). Silvipastoral system presented highest value of iron (609.81±328.13 mg kg^{-1}) and lowest value of manganese (163.27±42.41 mg kg^{-1}).

Table 2. Means ± SD of micronutrients in areas under three different restoration methods (Passive Restoration, Silvipastoral System, and Management), municipality of Igarapé-Açú, eastern Amazon, Brazil.

Method/Nutrient	Fe	Zn	Cu	Mn
	mg Kg^{-1}			
Passive Restoration	341.24±122.83b	128.37±22.84a	104.69±24.32a	345.89±134.81a
Silvipastoral System	609.81±328.13a	101.52±8.04b	80.94±15.43b	163.27±42.41b
Management	327.95±126.79b	108.17±7.25b	87.56±19.27ab	355.98±146.35a

*Means followed by the same lowercase letter in the column do not differ from each other using the Tukey test at 5% probability.
Source: Costa (2023)

Rebêlo et al. (2021), in a non-disturbed forest, found lower values of iron (210.3±54.7 mg kg^{-1} to 161±50.8 mg kg^{-1}) and zinc (53.6±7.5 mg kg^{-1} to 62.7±12.3 mg kg^{-1}), when compared to this study. High iron and zinc values are characteristic of oxisols, the soil in the area of this study, and enhanced by inadequate management (MALAVOLTA 2006, PEREIRA et al. 2010). And this high iron concentration can be attributed to its high solubility, due to the collection taking place during the rainy season, since iron does not translocate internally. Iron is absorbed by roots in the soil solution, therefore the rainy season also favors its highest concentration in litter (REBÊLO et al. 2021).

CONCLUSIONS

Considering the cost-benefit ratio, the passive restoration method proved to be the most efficient, as it does not required initial cost with pre-planting fertilization and other costs related to seedling planting an maintenance. Passive restoration presented highest values of several nutrients and litter stock.

Calcium is the macronutrient that most returned to the soil via litter in the three areas under different restoration methods.

REFERÊNCIAS

ÁLVAREZ, D.A.Y. Controladores de los biótipos de arroz e milho de Spodoptera frugiperda (Lepidoptera, Noctuidae) em espécies de Meliaceae. Dissertação de mestrado, Universidad Nacional de Colombia - Sede Medellín.2019.

ALVES, A.R.; FERREIRA, R. L.C.; SILVA, J. A. A.; JUNIOR, J. C. B. D.; OSAJIMA, J. A.; HOLANDA, A. C. Conteúdo de nutrientes na biomassa e eficiência nutricional em espécies da Caatinga. **Ciência Florestal**, v. 27, 2017.

ARÊAS, E. M. J.; ARÊAS, P. M. J.; CAMPELLO, E. F. C.; RESENDE, A. S. D. E. Banco de sementes do solo após 25 anos do plantio de leguminosas arbóreas em área de empréstimo - Seropédica, RJ. **Ciências Florestais**, v.2, n.32, 2022.

BALBINOT, R.; SCHUMACHER, M.V.; WATZLAWICK, L.F. Inventário do carbono orgânico em um plantio de Pinus taeda aos 5 anos de idade no Rio Grande do Sul. **Revista de Ciências Exatas e Naturais**, v. 5, n. 1, 2003.

BARREIROS, J. L.; OLIVEIRA, N.S.DE.; CERBONCINI, R.A.S.; JUNIOR, L.K. Does selective logging affect litter deposition rates in central Brazilian Amazonia?. **Anais da Academia Brasileira de Ciências**, v. 3, n.94, 2022.

BOMFIM, B.; SILVA, L. C. R.; PEREIRA, R. S.; GATTO, A.; EMMERT, F.; HIGUCHI, N. Litter and soil biogeochemical parameters as indicators of sustainable logging in Central Amazonia**. Science Total Environment**, v. 714, 2020.

CALDEIRA, M. V. W.; SILVA, R. D.D.A.;, KUNZ, S. H.; ZORZANELLI, J. P. F.; CASTRO, K. C.; GODINHO, T. DE. O. Biomassa e nutrientes da serapilheira em diferentes coberturas florestais. **Comunicata Scientiae**, v. 4, 2013.

COSTA,C. C. A.; CAMACHO, R. G. V.; MACEDO, I. D.; SILVA, P. C. M. Análise comparativa da produção de serrapilheira em fragmentos arbóreos e arbustivos em área de Caatinga na Flona de Açu – RN. **Revista Árvore**, v. 34, 2010.

COSTA, B.C.; SUZUKI, P. M.; MARTINS, W. B. R.; ANDRADE, V. M. S.; OLIVEIRA, F. A. Dinâmica da massa seca e propriedades químicas da liteira em *Virola surinamensis* e floresta sucessional na Amazônia oriental. **Revista Verde de Agroecologia e Desenvolvimento Sustentável,** v.12, 2017.

DIAS-FILHO, M. B.; ANDRADE, C. M. S. **Pastagens no trópico úmido**. Belém, PA: Embrapa Amazônia Oriental, 2006.

FALESI, I. C.; BITTENCOURT, I. C.F.P.M.; BITTENCOURT, R. H. F. P. M.; LÁU H. D.; BAENA, A.R.C. **Sistema Silvipastoril Sustentável com ovinos em pastejo rotacionado intensivo**. Belém, PA: Universidade Federal Rural da Amazônia, 2012.

FRANÇA, A.C.; SOUZA, I.F.; SANTOS, C.C.; OLIVEIRA, E.Q.; MARTINOTTO, C. Atividades alelopáticas de nim sobre o crescimento de sorgo, alface e picão-preto. **Ciência e agrotecnologia**, v. 32, 2008.

FREIRE, G.A.P.; VENTURA, D. J.; FOTOPOULOS, I.G.; ROSA, D.M.; AGUIAR, R.G.; ARAÚJO, A.C. Dinâmica de serrapilheira em uma área de floresta de terra firme, Amazônia Ocidental. **Pesquisas Agrárias e Ambientais**, v.8, 2020.

FREITAS, E. C. S.; NETO, S. N. O.; FONSECA, D.M.; SANTOS, M.V.; LEITE, H.G.; MACHADO, V. D. Deposição de serrapilheira e de nutrientes no solo em Sistema Agrossilvipastoril com eucalipto e acácia. **Revista Árvore**, v. 37, 2013.

GOMES, J.M.; PEREIRA, M.G.; PIÑA-RODRIGUES,F.C.M.; PEREIRA, G.H.A.; GONDIM, F.R.; SILVA, E.M.R. Aporte de serrapilheira e de nutrientes em fragmentos florestais da Mata Atlântica, RJ. **Revista Brasileira de Ciências Agrárias**, v.5, 2010.

INMET - Instituto Nacional de Meteorologia. 2023. Disponível em:https://portal.inmet.gov.br/noticias/ser%C3%A1-realmente-o-fim-da-la-ni%C3%B1a.

IPAM. **Gado em área de desmatamento na Amazônia**. 2021. Disponível em :https://ipam.org.br/pastagem-ocupa-75-da-area-desmatada-em-terras-publicas-na-amazonia.

LABEGALINI, N.S.; BUCHELT, A.C.; ANDRADE, L.; OLIVEIRA, S.C.; CAMPOS, L.M. Desenvolvimento da cultura do milho sob efeitos de diferentes profundidades de compactação do solo. **Revista de Agricultura Neotropical**, v.3, 2016.

LERNER, A. M.; RUDEL, T. K.; SCHNEIDER, L.C.; MCGRODDY, M.; BURBANO, D.V.; MENA, C.F. The spontaneous emergence of silvo-pastoral landscapes in the Ecuadorian Amazon: patterns and processes**. Regional Environmental Change**, v.15, 2015.

LIMA, N.L.; SILVA-NETO, C.M.; CALIL, F.N.; SOUZA, R.; MORAES, D.C. Acúmulo de Serrapilheira em Quatro Tipos de Vegetação no Estado de Goiás. **Enciclopédia Biosfera**,v.11, 2015.

LORENZO, L.; CAMPAGNARO, V.W. Litterfall production as a function of planting seedlings system in a two years forest restoration area in the coastal - plain of Caraguatatuba, São Paulo, Brazil. **Revista Árvore**, v.3, 2017.

LUZ, S.M.; SOUZA FILHO,A. P. S.; GUILOHN, G. M. S. P.;VILHENA, K. S. S. Atividade alelopática de substâncias químicas isoladas da *Acacia mangium* e suas variações em função do PH. **Planta daninha**, v.28, 2016.

MACHADO, M.R.; SAMPAIO, P. D. E. T. B.; FERRAZ, J.; CAMARA, R.; PEREIRA, M. G. Nutrient retranslocation in forest species in the Brazilian Amazon. **Acta Science Agrônomo**, v.38, 2016.

MALAVOLTA, E. **Manual de Nutrição Mineral de Plantas**. São Paulo: Agronômica Ceres, 2006.

MATEUS, F. A.; MIRANDA, C. D. O.; VALCARCEL, R.; FIGUEIREDO, P. H. A. Estoque e capacidade de retenção hídrica da serrapilheira acumulada na restauração florestal de áreas perturbadas na Mata Atlântica. **Floresta e Ambiente**,v.20, 2013

OLIVAL, A. A.; SOUZA, S. E. X. F.; MORAES, J. P. G.; CAMPANA, M. Effect of amazonian tree species on soil and pasture quality in silvopastoral systems agronomy and forestry. **Acta Amazônica**,v.51, 2021.

PEREIRA, A. A.; BORGES, J.D.; LEANDRO, W.M. Metais pesados e micronutrientes no solo e em folhas de *Brachiaria decumbens* às margens de rodovias. **Bioscience Journal**, v.26, 2010.

PEREIRA, G. H. A.; PEREIRA, M.G.; ANJOS, L. H. C.; AMORIM, T. A.; MENEZES, C. E. G. Decomposição da serrapilheira, diversidade e funcionalidade de invertebrados no solo em um fragmento de floresta atlântica. **Bioscience Journal**, v. 29, 2013.

PERRINEAU, M. M.; FARIA, S. D. E.; BALIEIRO, F.C. Genetic diversity of symbiotic Bradyrhizobiumelkanii populations recovered from inoculated and non-inoculated Acacia mangium field trials in Brazil. **Systematic and Applied Microbiology**, v. 34, 2011.

PHILLIPS, O.; BAKER, T.; FELDPAUSCH, T.; BRIENEN, R. RAINFOR: Field manual for plot establishment and re-measurement. URL: https://rainfor.org/wp-content/uploads/sites/129/2022/06/RAINFOR_field_manual_EN.pdf. 2021.

PIMENTEL, C. R.; PAULETTO, D.; REBÊLO, A. G. M.; SILVA, A. F.; PELEJA, V. L.; PALOMINO, E. C. Produção, acúmulo e decomposição de serrapilheira em três sistemas agroflorestais no Oeste do Pará. **Advances in forestry science**, v. 8, 2021.

PIOVESAN, G.; SCHUMACHERET, M.V.; VIEIRA, M.; LOPES, V. G.; WELTER, C. Deposição de serapilheira em povoamento de pinus. **Pesquisa Agropecuária Tropical**,v. 42, 2012

PRATA, S. S.; MIRANDA, I. S.; ALVES, S.A.O.; FARIAS, F.C.; JARDINS, F. C. DAS. Floristicgradient of the northeast paraense secondary forests. **Acta Amazônica**,v. 40: 2010.

R DEVELOPMENT CORE TEAM. R version 4.2.1. – In. R Foundation for Statistical Computing, Vienna, Austria, 2022.

SANTANA-BAÑOS, Y.; CONCEPCIÓN, A.B.; RODRÍGUEZ-ESPINOSA, F.L.; DÍAZ, S. C.; SÁNCHEZ, A.C.; DUEÑAS, Y. D. Efeito alelopático de extratos aquosos de *Azadirachta indica* na germinação de *Solanum lycopersicum*. **Ciência e tecnologia agrícola**, v. 23, 2022.

SCHAEFER, S. M.; SCHWARTZ, G.; SILVA, A. R.; LUNZ, A. M.; SOUZA, F. I. B. de; SANTIAGO, A. V.; FERREIRA, F. N.; SOARES, M. H. M.; FALESI, I. C. Monitoramento da restauração florestal e do manejo de floresta secundária em propriedade rural do Nordeste paraense. Belém, PA: *Embrapa Amazônia Oriental*, 2022.

QUESADA, C. A.; LLOYD, J.; ANDERSON, L. O.; FYLLAS, N. M.; SCHWARZ, M.; CZIMCZIK, C.I. Soils of Amazonian with particular reference to the rainfor sites. **Biogeosciences**, v.8, 2011.

REBÊLO, A. G. M.; MONTEIRO, M. T. F.; FERREIRA, S. J. F.; VILLAMIZAR, E. A. R.; JUNIOR, E. S.; BOLSON, M. A.; JUNIOR, S. D. Biogeoquímica espaço-temporal da liteira em ambiente de floresta natural na Amazônia central. **Química Nova**, v. 44, 2021.

REBÊLO, A. G. M.; CAPUCHO, H. L. V.; PAULETTO, D.; DANTAS, E. F. Estoque de nutrientes e decomposição da serrapilheira em sistemas agroflorestais no município de Belterra - Pará. **Ciência Florestal**,v.32, 2022.

SCHUMACHER, M.V.; BRUN, E. J.; HERNANDES, J. I.; KÖNIG, F. G. Produção de serrapilheira em uma floresta de Araucaria angustifolia (Bertol.) Kuntze no município de Pinhal Grande-RS. **Revista Árvore**, v.28, 2004.

SILVEIRA, L. P.; SOUTO, J. S.; DAMASCENO, M.M.; MUCIDA, D. P.; PEREIRA, I. M. Poleiros artificiais e enleiramento de galhada na restauração de área degradada no semiárido da Paraíba, Brasil. **Pesquisas Agrárias e Ambientais**, v.3, 2015.

SPERANDIO, H.V.; CECÍLIO, R. A.; SILVA,V. H.; LEAL, G. F.; BRINATE, I. B.; CALDEIRA, M.V.W. Emprego da serrapilheira acumulada na avaliação de sistemas de restauração florestal em Alegre-ES. **Floresta e Ambiente**, v.19, 2012.

TAIZ, L.; ZEIGER, E.; MOLLER, I. M.; MURPHY, A. **Fisiologia e Desenvolvimento Vegetal**. Rio Grande do Sul: Artmed, 2017.

VILLA, E. B.; PEREIRA, M.G.; ALONSO, J.M.; BEUTLER, S.J.; LELES, P.S.S. Aporte de Serrapilheira e Nutrientes em Área de Restauração Florestal com Diferentes Espaçamentos de Plantio. **Floresta e Ambiente**, v.23, 2016.

VIGULU, V.; BLUMFIELD, T.J.; REVERCHON, F.; BAI, S. H.; XU, Z. Nitrogen and carbon cycling associated with litterfall production in monoculture teak and mixed species teak and flueggea stands. **Journal of Soils and Sediments**, v.19, 2019.