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RESEARCH PAPER

Leaf litter nutrient content reveals benefits to traditional cropping systems in the Amazon

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Abstract

E. M. B. de Paula, J. M. da Cunha, M. C. C. Campos, B. C. Mantovanelli1, D. M. P. da Silva, A. F. L. de Lima, W. B. M. Brito, R. S. Macedo, and F. P. de Oliveira. 2024. Leaf litter nutrient content reveals benefits to traditional cropping systems in the Amazon. Int. J. Agric. Nat. Resour. 99-113. Soil fertility in the Amazon rainforest is very dependent to litter decomposition as a source of organic carbon and nutrients. Thus, land use that promote high litter decomposition might play a positive influence on soil chemical properties. The present study aimed to quantify the nutritional content of litter in anthropized and natural environments in Southern Amazonas. The study was conducted on two properties in the municipality of Canutama, in four areas: native forest, annatto, cupuassu, and guarana. In each area, 10 conical collectors (0.21 m²) were installed at a height of 0.3 m from the ground. The samples collected in each area for each month were dried in a forced circulation oven at 60ºC until reaching constant mass and weighed. Macro- and micronutrient content analyses were performed by sulfuric solubilization (N), nitric perchloric solubilization (Ca, Mg, P, K, Na, S, Cu, Fe, Mn, and Zn) and incineration (B). Variance analysis and comparison of means by Tukey test at the 5% probability level were applied to the data obtained, along with a multivariate analysis. This comparison was carried out by evaluating the overall average of a whole year of litter formation, as well as for formation within each month evaluated. Sulfur (S) was the only macronutrient that did not differ between environments (0.1 and 0.2 g kg^{-1}). Macronutrients and micronutrient contents of litter (N: 16.92; Mg: 1.08; Cu: 16.00; Zn: 31.70; B: 104.40; g kg^{-1}) were significantly highest in the annatto area. Annato also presents higher K (9.92 g kg^{-1}) and P (0.70 g kg^{-1}) contents. The litter of natural forest and guarana are richer in P (0.88 g kg^{-1}) and Ca (g kg^{-1}), respectively. Cupuassu litter showed lower nutritional contents, especially in macronutrients contents (N: 9.04; P: 0.51; K: 0.28; Ca: 0.76; Mg: 0.44; g kg^{-1}). This indicates that traditional Amazonian agroecosystems may positively to improve quality of litter and impact nutrient cycling in soils highly weathered in the region.

Key words: Agroforestry, Amazon rainforest, litterfall, nutrient cycling, soil health.

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Highlights

- This study investigated the impact of converting Amazonian forest to cupuassu, annatto, and guarana plantations on soil nutrient content.

- Litterfall nutrient concentrations were significantly higher in annatto and guarana plantations compared to native forest.

- Traditional cropping systems could offer a sustainable alternative to enhance soil fertility in the Amazon.

- Findings highlight the importance of considering land use change impacts on nutrient cycling in sensitive ecosystems.

Introduction

Most of the nutritional supply of plants in forest environments comes from the mineralization of organic matter, and the production and decomposition of litter returns nutrients to the soil (Ribeiro et al., 2017). In the Amazon ecosystem, the decomposition rate is high due to the high moisture and temperature, increasing nutrient recycling (Freitas et al., 2016). This recycling is the main factor responsible for conserving the forest in very acidic soils with low nutrient concentrations (Freire et al., 2020), where the largest reserve of nutrients is the forest itself (Castro et al., 2017).

It is well known that an important function of the plant colonization process is the litter input, and litter plays an important role in soil conservation in low fertility lands and even in degraded conditions. For example, litter accumulation can reduce soil temperature, capture and retain rainfall, increase soil nutrients, improve soil microbial activity (Cui et al., 2021; Liu et al., 2021) and improve soil physical structure (Wu et al., 2020). Litter decomposition also positively influences soil nutrients and plant growth (Schlesinger & Bernhardt, 2013) and eventually provides benefits to degraded lands from soil and plant community restoration.

Part of the Western Amazon is formed by soils of low natural fertility (Quesada et al., 2011), whose management can be one of the most limiting factors in regional agricultural productivity, conditioned to the maintenance of an efficient nutrient cycling (Freitas et al., 2016). This nutrient cycling is strongly influenced by exposed organic matter from mulch, which is a major nitrogen store and an extraordinary source of phosphorus, calcium, potassium, and magnesium for plants (Sayer et al., 2012).

Studies with nutrient cycling in natural forests are difficult because they cover cycles, such as geochemical and biological (biogeochemical and biogeochemical cycle) (Pereira et al., 2017). To this end, this complex is usually analyzed in parts, leading to the portion that most provides matter for nutrient absorption and transfer, which is the litter (biogeochemical cycle) (Ferreira et al., 2007). Also scarce are studies that evaluated the influence of litter composition and associated effects on the chemical properties of highly weathered soils in family agroecosystems. In the Amazon region, these systems use plants recognized for their cultural, social, and economic importance, including guarana (*Paullinia cupana* [Mart.] Ducke), cupuaçu (*Theobroma grandiflorum* [Willd. ex. Spreng] Schum), and annatto (*Bixa orellana* L) (Lima et al., 2021). Previous studies have demonstrated the contribution of these crops to improving the chemical and physical quality of the soil, especially in relation to soil aggregation (Souza et al., 2020; Lima et al., 2021, 2024). However, the chemical quality of the litter in agroecosystems and its release of nutrients for rapid plant growth remain unknown.

Thus, the greater the contribution of litter, the lower the speed of its decomposition and the greater the amount of material in the soil. This condition favors greater environmental stabilization (Krishna & Mohan, 2017), since the decrease in decomposition promotes these nutrients' storage in the litter, not making them available to plants in the short term.

Litter decomposition impacts physico-chemical soil properties (e.g., soil water infiltration ad content), and is vitally important to nutrient cycling and maintaining forest ecosystems' stability (Prieto et al., 2019; Cui et al., 2021). The liter also is an important soil protection agent, effectively intercepting the rainfall, increasing its infiltration and preventing runoff and soil loss (Acharya et al., 2017; Liu et al., 2017; Wang et al., 2022), the nutritional status of litter and its accumulation thus represent the fertility potential of the soil. The link between litter nutrient stock and nutrients' availability to the soil is defined from the decomposition of organic matter (Krishna & Mohan, 2017). The present study thus aimed to analyze the nutrient contents in the litter contribution, quantify the nutritional stock of the litter, and compare from multivariate techniques the characteristics in natural forest environments and monocultural plantations of cupuassu, annatto, and guarana.

Material and Methods

Location and description of the study areas

The study was carried out in two properties (A and B) containing 3 cultivated areas and in a forest area adjacent to the crops, located in the São Francisco settlement, municipality of Canutama, Southern region of Amazonas, Brazil (Figure 1). Each use type has been georeferenced and are located under the following coordinates: forest: 64° 0' 46.625" W, 8° 12' 53.108" S; cupuassu: 64° 0' 24.488" W, 8° 13' 25.060" S; guarana: 64° 0' 49.384" W, 8° 13' 23.942" S; and annatto: 64° 0' 53.068" W, 8° 13' 23.447" S. Property "A" is focused on cultivation of cupuassu, while property "B" has guarana and annatto. The description of these areas' use history under forest and under agroecosystems is shown in Table 1.

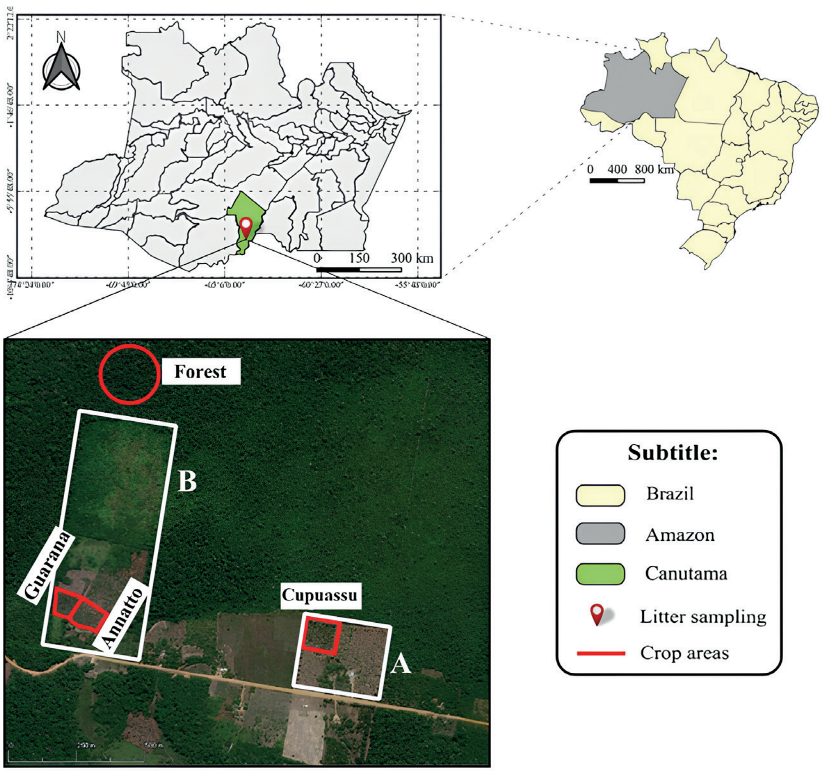

Figure 1. Location map of the litter collection in areas under natural forest and agroecosystems under monoculture with guarana, cupuassu, and annatto, in the Southern region of Amazonas.

Source: Authors (2022).

Table 1. Use history in areas of natural forest and agroecosystems with monocropping of guarana, cupuassu, and annatto in the Southern region of Amazonas.

Land use	Usage history
Guarana (*Paullinia cupana*)	Area resulting from slash-and-burn forest clearance, with manual clearing and removal of stumps from the area in the first year of cultivation in a monoculture system. There has never been fertilization or liming in the cultivated areas, regular spacings of 5.0 × 5.0 m are used, with periodic pruning and cleaning for pest control, and it has been in effective cultivation for 7 years.
Cupuassu (*Theobroma grandiflorum)*	Area resulting from slash-and-burn forest clearance, with manual clearing and removal of stumps from the area in the first year of cultivation in a monoculture system. There has never been fertilization or liming in the cultivated areas, regular spacing of 7.0 × 7.0 m is used, with periodic pruning and cleaning for pest control, and it has been in effective cultivation for 7 years.
Annatto (*Bixa orellana)*	Area resulting from slash-and-burn forest clearance, with manual clearing and removal of stumps from the area in the first year of cultivation in a monoculture system. There has never been fertilization or liming in the cultivated areas, regular spacing of 4.0 × 4.0 m are used, with periodic pruning and cleaning for pest control, and it has been in effective cultivation for 3 years.
Forest	Characterized as a dense tropical forest, with evergreen vegetation, composed of dense, multi-stratified trees between 20 and 50 m high.

The climate characterization for the region is Tropical Rainy of the Köppen subtype Am (tropical monson climate), presenting a short dry period (Alvares et al., 2013). Average rainfall varies between 2,500 and 2,800 mm per year, and the average annual temperature is 26 °C. The rainy season in the Amazon region occurs between November and March, and the dry season between May and September (Fisch et al., 1998). The months of April and October are transition months between one regime and the other (Figure 2), where the average monthly distribution of precipitation and temperature during the evaluation and data collection period are shown.

The soil of the area was classified as Ultisol (Soil Survey Staff, 1999), located on the Amazonian Plain between the Purus and Madeira rivers. The geology of the studied area is formed by ancient undifferentiated alluvium dating back to the Holocene. The sediments of this formation come from two cycles of sedimentation: a) lower sandy banks, which represent pluvial-fluvial sedimentation; and b) upper clayey sediments, indicating lacustrine sedimentation (Braun & Ramos, 1959).

Soil collection and analysis

The sampling was performed in two homogeneous areas of 1000 m^2 with five collection points (experimental units). At each collection point three simple deformed soil samples were collected (0-20 cm), which constituted a composite sample that was dried in air and passed through a 2 mm sieve (TFSA).

Physical and chemical soil analyses were done at the Federal University of Amazonas according to methodologies proposed by Teixeira et al. (2017). Particle size and water dispersed clay analyses were performed by the pipette method, using NaOH as dispersants. The pH was determined in water (1:2.5). The exchangeable contents of Ca^{2+}, Mg^{2+} and Al^{3+} were extracted with KCl 1 mol L -1, while P, K^+ and Na^+ were extracted with Mehlich 1 solution (HCl 0.05 mol L-1 + H_2SO_4 0.0125 mol L -1). Potential acidity (H + Al) was extracted with 0.5 mol L-1 calcium acetate pH 7.0. Ca^{2+} and Mg^{2+} were determined by complexometry, Al^{3+} by titration, K^+ and Na^+ by flame photometry and P by colorimetry. Soil analysis results were interpreted according to Hazelton & Murphy (2007).

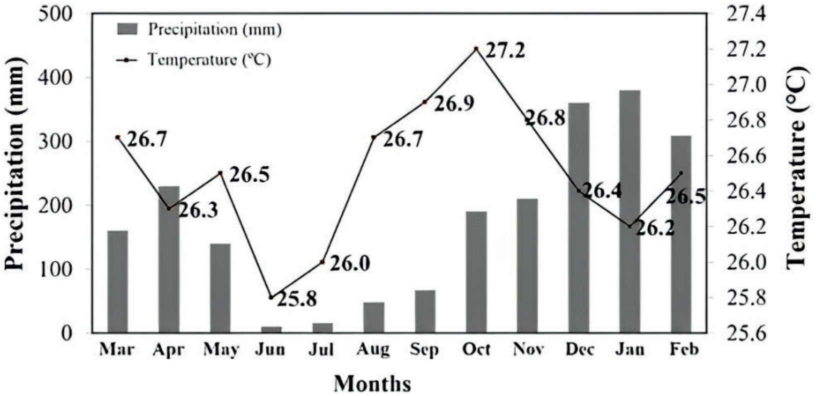

Figure 2. Temperature and accumulated rainfall from March 2020 to February 2021 in native forest areas and in agroecosystems cultivated with guarana, cupuassu, and annatto in the Southern region of Amazonas.

Source: Instituto Nacional de Meteorologia – INMET - http://www.inmet.gov.br.

Experiment installation and litter collection

To collect and evaluate litter, 10 conical collectors with an area of 0.21 m² (perimeter = 1.62 m) were installed, randomly distributed within each area. Each collector was constructed of ¾" polyethylene plastic tubing with 1 mm mesh and a nylon mesh bottom to allow water to escape and prevent loss of smaller material. The collectors were installed at a height of 0.3 m above the ground to prevent litter losses due to the transit of small animals and to avoid decomposition by microorganisms. Each collector was identified with a number, and production was assessed from naturally deposited material.

Collections were carried out monthly from March 2020 to February 2021. In the collectors, the litter was removed manually and packed in identified plastic bags. The samples collected in each area for each month were dried in a forced circulation oven in the laboratory at 60 ºC until they reached constant mass, after which the material was weighed on a precision balance.

Nutritional analysis of litter

After weighing, the samples were ground in a Willey mill and sieved to 30 mesh to determine the nutritional content of the litter. The stock of macro- and micronutrients was evaluated according to the methodology described by Carmo et al. (2000).

Nitrogen (N) was extracted from the dry mass by sulfuric solubilization and then by the Kjeldahl method and determined by titration.

Calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), sodium (Na), sulphur (S), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) were extracted by nitric perchloric solubilization. P was determined by colorimetry and S by turbidimetry, with readings taken by UV-Vis spectrophotometry at 420 nm. K and Na were determined by flame emission photometry. Ca, Mg, Cu, Fe, Mn, and Zn were determined by atomic absorption spectrometry.

Boron (B) was extracted via the dry method, in which tissue samples were incinerated in an electric muffle furnace at a temperature between 500 and 550 ºC. The resulting ash was dissolved in dilute nitric acid solution. It was then determined by colorimetry in a UV-Vis spectrophotometer at 420 nm.

Statistical analysis

After meeting homoscedasticity assumptions, normality and independence on the residues, the data obtained were submitted to analysis of variance (ANOVA) and test of means. A Tukey test was applied at 5% probability level for comparison of means. The overall annual averages of litter formation were compared, as well as the monthly litter formation in each system studied (natural forest and guarana, annatto and cupuaçu crops). Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS), version 21.0.

Along with ANOVA and the mean test, multivariate analysis was applied to verify the existence of interactions between the macro- and micronutrients present in the litter with the environments studied. Principal component analysis (PCA) was performed in order to obtain the set of smallest linear combinations of nutrients present in the litter, which preserves most of the information provided by the studied environments (Silva et al., 2010). Attribute values were normalized to mean equal to zero and variance equal to one. When choosing the number of components, those with eigenvalues above 1.00 (Kaiser criterion) were selected, and which managed to synthesize a cumulative variance above 70%. The orthogonal rotation (varimax) was performed and represented in a factorial plane of the attributes and scores for the PC, in order to simplify the factor analysis (Burak et al., 2010).

Results and Discussion

Physical and chemical soil attributes appear in Table 1. The textural class of the forest and guarana soils is loam, while the cupuassu and annato soils are clay loam (Table 1). All soils are very strongly acidic (pH 3.69-3.82). Due to the increase of acidity exchangeable, the aluminum contents are considered high, with the highest values being found in forest (5.03 $cmol_c$ dm^{-3}) and guarana soils (5.73 $cmol_c$ dm^{-3}). Consequently, aluminum saturation is also high in all soils, notably in the forest (92%).

The Ca^{2+} contents in all soils are very low (0-0.2 $cmol_c$ dm^{-3}), with slightly higher levels in soils under cupuassu (0.96 $cmol_c$ dm^{-3}) and annato (1.49 $cmol_c$ dm^{-3}) (Table 1). The Mg^{2+} contents are low in annatto soils (0.41 $cmol_c$ dm^{-3}) and very low in other agroecosystems (0-0.27 $cmol_c$ dm^{-3}). The K^+ contents in all soils are very low (0-0.1 $cmol_c$ dm^{-3}). The potential acidity was higher in guarana soils (10.68 $cmol_c$ dm^{-3}). The CEC contents are higher in agroecosystems (guarana: 12.14; cupuassu: 10.68; Annatto: 11.79; $cmol_c$ dm^{-3}) than in the forest (9.77 $cmol_c$ dm^{-3}). The P contents are very low in soils under cupuassu (3.33 mg dm^{-3}) and guarana (4.56 mg dm^{-3}) and low in soils under forest (7.07 mg dm^{-3}) and annatto (6.62 mg dm^{-3}). These CEC values are considered moderate (12-25 $cmol_c$ dm^{-3}) in guarana soils and low in other agroecosystems (Table 1). The base saturation is low in all agroecosystems, indicating that these soils are very strongly leached (Hazelton & Murphy, 2007). Despite this, the soils of the agroecosystems presented two to four times more BS (guarana: 10%; cupuassu: 12%; annatto: 19%) compared to the forest soils (4%).

The low levels of easily weatherable minerals in the sedimentary parent material, free drainage, and the local bioclimatic conditions (e.g., high precipitation and temperature) result in deep soils and in advanced stage of weathering, whose main characteristics are high acidity, higher dystrophy, with high levels of exchangeable Al^{3+} and low levels of sum of bases and cation exchange capacity (Shaefer et al., 2017). These characteristics were also observed in this research, indicating a strong process of desaturation in the studied soils (Table 2). However, our result showed that forest conversion for typical Amazonian crops (agroecosystems) can be an alternative for improving soils' chemical quality, especially when compared to the natural environment. Anthropic changes in vegetation structure most likely contribute to variations in the organic matter decomposition process, increasing soil nutrient contents. For proper monitoring of converted areas, we thus recommend evaluating the decomposition process in relation to the effects on soil chemical attributes.

Table 2. Characterization of physical and chemical soil attributes in the 0.0-0.2 m layer in native forest areas and in agroecosystems cultivated with guarana, cupuassu, and annatto in the Southern region of Amazonas.

Variables	Forest	Guarana	Cupuassu	Annatto
Sand (g kg^{-1})	239	352	289	385
Silt (g kg^{-1})	488	415	408	315
Clay (g kg^{-1})	273	233	303	300
pH (H_2O)	3.69	3.84	3.83	3.92
Al^{3+} ($cmol_c$ dm^{-3})	5.03	5.73	4.91	4.73
H + Al ($cmol_c$ dm^{-3})	9.05	10.68	9.06	9.41
K^+ ($cmol_c$ dm^{-3})	0.06	0.06	0.06	0.10
Ca^{2+} ($cmol_c$ dm^{-3})	0.25	0.79	0.96	1.49
Mg^{2+} ($cmol_c$ dm^{-3})	0.07	0.27	0.18	0.41
P (mg dm^{-3})	7.07	4.56	3.33	6.62
EB ($cmol_c$ dm^{-3})	0.41	1.15	1.21	2.34
CEC ($cmol_c$ dm^{-3})	9.77	12.14	10.68	11.79
BS (%)	4	10	12	19
AS (%)	92	83	79	69

EB: exchangeable cations; CEC: cation exchange capacity; BS: base saturation; AS: aluminum saturation

Nutritional content of litter

Litter macronutrient contents appear in Table 3, indicating significant differences between the cultivated environments and the natural forest area. Litter biogeochemistry also were more susceptible than soil biogeochemistry to logging-induced changes in forest in Central Amazonia (Bomfim et al., 2020). N levels were significantly highest in the annatto area and lowest in the cupuassu area ($p < 0.05$. The largest soil aggregation also we observed in annatto in Amazonia, which is related to crop debris and invasive plants left in the area to cover the soil, minimizing soil degradation and increasing carbon contents and the formation of macroaggregates (Lima et al., 2024). In fact SOC could be stabilized in response to N addition, decreasing decomposition of labile substances and increasing mineal-associated organic C formation within macroaggregate-occluded microaggregates (Chen et al., 2022). This higher recycling of N from litter decomposition provides as essential resource for ecosystem productivity, since that amazon soils presents low contents in N.

Table 3. Average content of litter macronutrients in areas of natural forest and guarana, cupuassu, and annatto plantations in the Southern region of Amazonas, from March/2020 to February/2021.

Nutrient	Forest	Guarana	Cupuassu	Annatto
	(g kg^{-1})			
N	13.27 b	12.69 b	9.04 c	16.92 a
P	0.88 a	0.66 b	0.51 b	0.70 ab
K	5.58 b	11.10 a	0.28 c	9.92 a
Ca	0.70 b	1.19 a	0.76 b	0.90 b
Mg	0.49 b	0.63 b	0.44 b	1.08 a
S	0.20 a	0.11 a	0.16 a	0.19 a

Equal letters in the line do not differ by Tukey test at 5% probability level.

P contents were significantly higher in the natural forest (0.88 g kg^{-1}) and annatto (0.70 g kg^{-1}) ($p<0.05$); but there were no significant differences in the remaining agroecosystems (guarana: 0.66 g kg^{-1}; cupuassu; 0.51 g kg^{-1}; $p<0.05$) (Table 3). A study from Eastern Amazon comparing native and secondary forest areas found that the P content of native forest is twice as high as that provided by a secondary forest, and that litter removal does not cause a significant change in P content compared to a control treatment (Pereira et al., 2017). The highest values of litter deposition and C, N and P contents also was found on primary Amazon rainforest in relation to different land covers (Souza et al., 2023). Studies showed that the increase of soil highly labile P and moderately labile P might be due to the P release of litter and partly came from the mineralization of soil moderately labile organic phosphorus (Chi et al., 2022). These authors also showed that moderately labile organic phosphorus in forest soils were converted into soil highly labile P to maintain the rapid growth plants, confirming that litter decomposition is the primary supplements of P in forest soils. Thus, similar results found in annatto and forest area indicate that agroecosystem also has important P buffering role in the process of nutrient cycling in soils of Amazonia.

K contents increased significantly in guarana (11.10 g kg^{-1};) and annatto agroecosystems (9.92 g kg^{-1}) ($p<0.05$) (Table 3). This fact is probably due to K being the third nutrient that the annatto plant demands most, especially in fruiting, leading to its high availability. Similar results were found in an area of Terra Firme Forest in Western Amazonia (Freire et al., 2020). These authors concluded that the distribution of nutrients follows the following order of magnitude: N > Ca >K >Mg > P > S, both in the rainy and dry seasons. The higher K^+ and Mg^{2+} contents also were found in annatto areas in relation the secondary forest in south Amazonas, Brazil (Lima et al., 2021).

Ca levels were significantly higher in guarana (1.19 g kg^{-1}) than the other four agroecosystems ($p<0.05$), while Mg contents were significantly higher in annatto area (1.08 g kg^{-1}) compared to the other agroecosystems ($p<0.05$) (Table 3). On the other hand, S was the only macronutrient that showed no significant difference between environments, with values ranging from 0.1 to 0.2 g kg^{-1}. As expected from litter, the material to be decomposed is poor in Ca and Mg compared to an Atlantic forest, which can contain from 9.0 to 2.3 g kg^{-1}, respectively, of these nutrients (Clevelário Júnior et al., 2021).

Litter micronutrient contents appear in Table 4. The Fe content in the natural forest environment is double the level found in cultivated environments, with an average value of 2,429.33 mg kg^{-1}, while the cultivated environment with the highest iron content was the cupuassu area, with an average value of 1,805.60 mg kg^{-1} and the guarana area had the lowest value at 784.08 mg kg^{-1} (Table 4). Fe was thus significantly higher in forest, cupuassu, and annatto areas ($p<0.05$) These results are similar to those found in litter deposited in secondary forests on the coast of Paraná, Brazil (Bianchin et al., 2017)

Cu (16 mg kg^{-1}), Zn (31.7 mg kg^{-1}), and B (104.4 mg kg^{-1}) contents were significantly higher in the annatto agroecosystem ($p<0.05$) when compared to the natural forest area and other uses (Table 4). The variations in the increase of B, observed in the litter of different areas, may be due to its lower mobility in plant tissues (Raven, 1980) and because it is a constituent of rhamnogalacturonan II molecules, present in pectin, which is the largest component of the primary wall vegetable (Matoh et al., 1996).

Figure 3 shows the monthly average of macronutrients present in the litter. N and K are the main elements found in the litter (Figure 3) corroborating the previous studies under use systems in the Eastern Amazon (Freitas et al., 2016). Among the environments, forest litter has the most seasonal variation, with low N contents in April (10.5 g kg^{-1}), gradually rising each month to reach 21.0 g kg^{-1} in March. On the other hand, cupuassu and guarana crops show the least variation in their N contents, with an average of 7.0 and 10.5 g kg^{-1}, respectively, in the first months of the year and the highest average (10.5 and 14.0 g kg^{-1}) in the months from June to August.

Ca and Mg contents were higher in July in the forest environment, with respective values of 0.78 and 0.61 g kg^{-1}, while in the cultivated environments higher peaks were obtained from January to September, with average monthly values reaching 1.38 and 1.42 g kg^{-1}, respectively (Figure 3). This behavior is similar to observations in three Cerrado physiognomies of the Federal District (Ribeiro et al., 2017).

P and S both present random monthly averages which oscillate throughout the year without differences regarding the type of environment evaluated. For K, the monthly averages show that the area with natural forest presents higher content during the beginning of the rainy season (September to December), with values up to 12.9 g kg^{-1}. However, cultivated areas manifest higher average in the rainy months (February to May), with K values that can reach up to 18.1 g kg^{-1}.

The forest area litter presents higher Fe concentrations between May and September, as well as from November to January, with averages that can reach 2.9 g kg^{-1} (Figure 4). For the cupuassu agroecosystem, the seasonality of cupuassu shows that the litter contains high Fe contents mainly between March and June, with averages also reaching 2.9 g kg^{-1}. The environment with annatto behaves similarly, although it has higher monthly averages in the months of August to December. Guarana litter has the lowest monthly averages of Fe, but shows the highest levels of Mn, especially at the beginning of the rainy season (October and November), with an average of 418 mg kg^{-1}. Similar result also were found in litter in the Atlantic Forest, with Fe content higher in the leaves and in the miscellaneous and Mn content higher in the branches (Banchin et al., 2017).

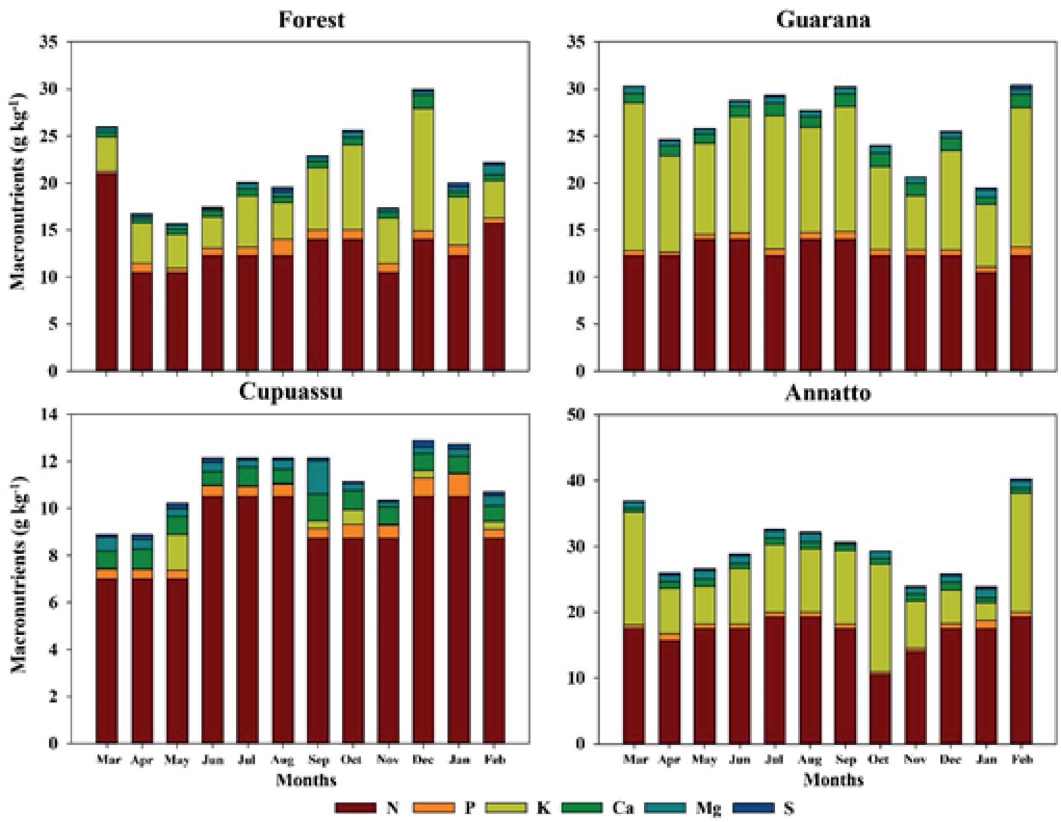

Figure 3. Monthly average of macronutrients present in the litter in areas of natural forest and plantations in the Southern region of Amazonas, from March 2020 to February 2021.

Source: Authors (2022).

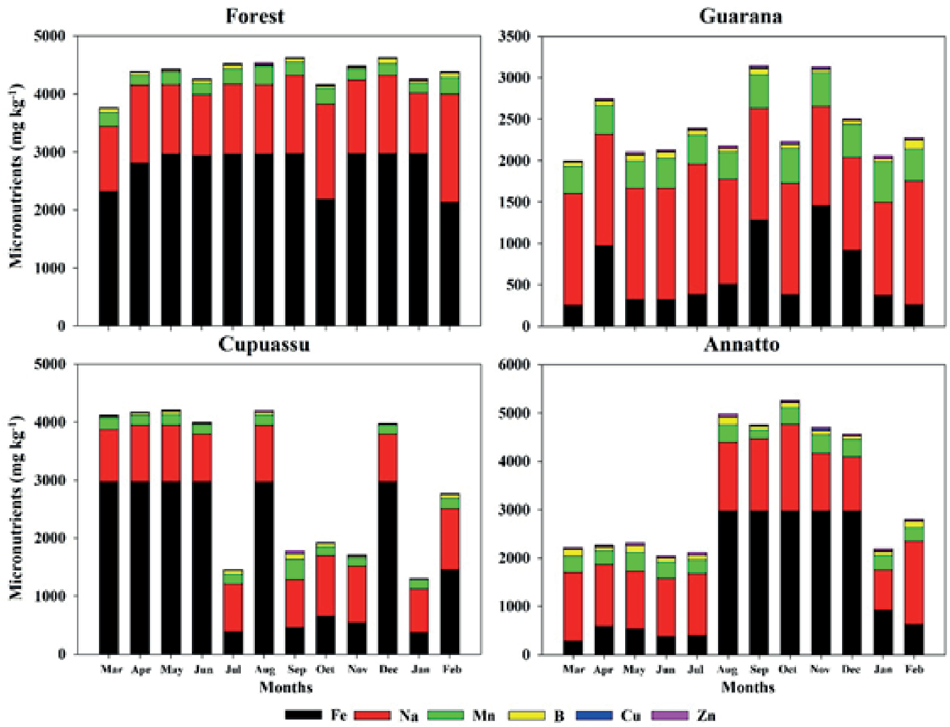

Figure 4. Monthly average of micronutrients present in litter in areas of natural forest and plantations in the Southern region of Amazonas, from March 2020 to February 2021.

Source: Authors (2022).

Litter seasonality shows that the highest sodium (Na) contents coincide in the same period of the year for all areas, with averages of 1,053 to 1,870 mg kg^{-1} in February (Figure 4). On the other hand, the annatto litter presents the highest averages of Cu (44 mg kg^{-1}), Zn (49 mg kg^{-1}), and B (158 mg kg^{-1}) among the environments from August to November. Conversely to the period found for annatto, the highest monthly averages of these micronutrients were obtained in January and February for the natural environment (Cu: 15 g kg^{-1}; Zn: 19 g kg^{-1}, and B: 78 g kg^{-1}). The results from the natural forest environment corroborate with the mention that Cu, Zn, and B are found in different proportions, indicating that these micronutrients average monthly contents are predominantly higher compared to the forest environment for most of the year (Abreu et al., 2020).

Table 5 shows the principal component analysis of litter nutrients. The factor analysis showed significant results (KMO=0.734 and $p<0.05$ for Barlett test of sphericity) for the nutrients present in the litter in the evaluated areas, showing suitability for the construction of Principal Components (PCs), which made it possible to reduce seven original variables into two factors (Table 5) (Figure 5).

Table 5. Principal components (PC) of litter nutrients in natural forest and plantation areas in the Southern region of Amazonas.

Attributes	Common variance	Factors	
		PC1	PC2
N	0.47	0.70*	0.20
P	0.41	-0.02	0.89*
Mg	0.79	0.92*	0.04
S	0.37	0.09	0.87*
Mn	0.45	0.72*	-0.04
B	0.61	0.83*	-0.10
Zn	0.75	0.88*	0.10
Variance explained (%)		48.41	22.67

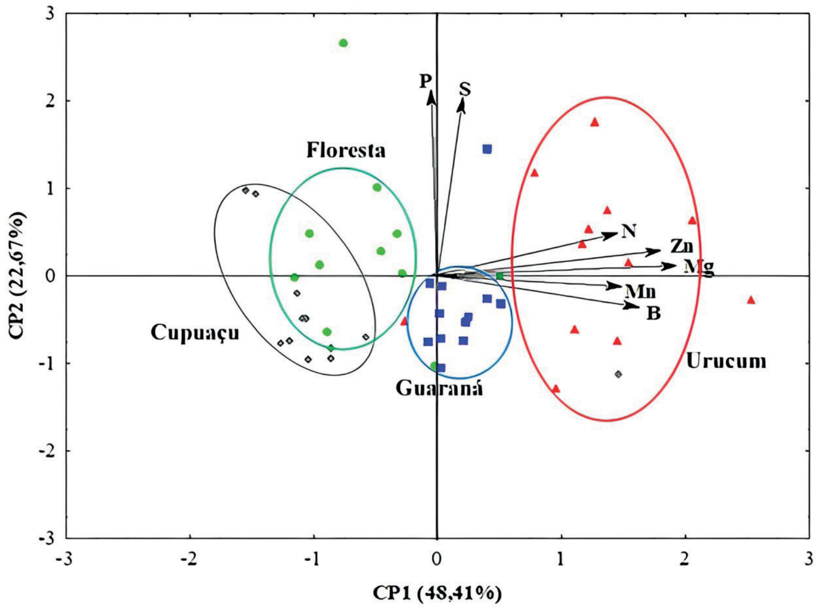

Figure 5. Factorial plan of litter nutrients in natural forest and plantation areas.

Source: Authors (2022).

For the areas studied, the two factors explained 71.08% of the variables' variance where eigenvalues were greater than 1. PC1 explains 48.41%, accounting for the nutrients N, Mg, Mn, B, and Zn, while PC2 explains 22.67% of the variance, accounting for P and S. In PC1, N, Mg, Mn, B, and Zn showed positive values. In PC2, P and S showed positive values (Table 5). These positive values observed in all nutritional variables for the two components indicate a direct correlation between them, i.e., that one nutrient favors the absorption and accumulation of the other in the litter, both raising their levels in the same proportionality.

When evaluating the factorial plan, it appears that the four areas are well separated; however, the natural forest area is closer to the cupuassu cultivation. These results confirms that litter and its nutrient-associated can be useful indicators of sustainable in uplands forests in Amazonia (Bomfim et al., 2020). Also confirm previous studies that showed that forest and annatto presented similar contents of organic carbon, carbon stock, silt, clay, aggregates 2-1 mm, <1 mm, and aggregate stability index (Souza et al., 2020). Annatto cultivation is characterized by having a litter rich in nutrients (N, Mg, Mn, B, and Zn), while natural forest whose litter is rich in P and S. However, low levels of nutrients are observed in the litter of the area under cupuassu, while the area under guarana presents an intermediate content of nutrients between the cultivated environments (Figure 5).

It is possible that the higher nutrient contents in the litter are associated with soil fertility levels in the area under annatto (Table 1). Similar results were observed in root development and soil chemical attributes in forest, guarana, cupuassu, and annatto areas, where the cultivated areas have fertility levels similar to the forest environment (Lima et al., 2021).

Studies developed under various use systems in the Southern region of Amazonas highlighted the importance of management aimed at improving acidity, exchangeable bases, organic components, and soil compaction (Jordão et al., 2021). Other authors observed that converting natural forests leads to litter enrichment in two ways: directly via the change of dominant species; and indirectly through increased nutrient uptake following fertilization (Becker et al., 2015).

Despite the above, our study has some limitations that should be highlighted. First, the agroecosystems in the Amazon have different arrangements, and the region has a complex pedological features, which requires that other systems and associated soils also be evaluated to verify the representativeness of our data. Second, the monitoring of litter decomposition and the activity of microorganisms should be evaluated and monitored for a longer period to establish the relationships between mineralization and immobilization of nutrients, with direct impacts on subsistence agriculture in the region. Third, the study did not evaluate the forms of nutrients present in the litter, since labile or readily available forms of some nutrients influence important soil services and functions in the short term, such as nutrient cycling, soil fertility, and plant growth.

Conclusions

The Amazon ecosystem is very diverse in terms of soil fertility distribution. Our results thus indicate that the strengthening of rational anthropization for traditional Amazonian crops can be an excellent alternative aimed at soil recovery and nutritional strengthening of the fertility of highly weathered soils, especially in comparisons from natural vegetation.

Litter has high N and K contents and high concentrations of micronutrients such as Fe, B, and Mn, constituting a potential cation reserve for the soil.

The natural forest presented the highest levels of P and Fe, while guarana cultivation litter had the highest values for K, Ca, and Mn. Cupuassu litter showed lower nutritional contents.

Macro- and micronutrients showed high annual variation between the months of the year for all environments; however, the natural forest area showed little variation for micronutrients, demonstrating resilience to temporal variation.

Our results have crucial implications for land use and soil management in Amazon. We found support that the adoption of agroecosystems with integrated systems can be a sustainable alternative to the agricultural model historically practiced in the Amazon. This fact is also important since that litter decomposition on these systems has the advantage of improving the chemical quality of the soils, mainly in the Amazon region, were the soils are characterized by low nutrient availability and scarce mineral reserves. Futures studies also may examine in detail the role of the diversity of decomposers since that the litter decomposition and its further decomposition and soil biota community are drivers that promote soil quality in the tropics. Lastly, soil ecosystems services also be accessed tom magnify the importance of these agroecosystems in relation to the services provides by forest soils.

Resumen

E. M. B. de Paula, J. M. da Cunha, M. C. C. Campos, B. C. Mantovanelli1, D. M. P. da Silva, A. F. L. de Lima, W. B. M. Brito, R. S. Macedo y F. P. de Oliveira. 2024. El contenido de nutrientes de la hojarasca revela beneficios para los sistemas agrícolas tradicionales em la Amazonía. 2024. Int. J. Agric. Nat. Resour. 99-113. La fertilidad del suelo em la Amazonía depende en gran medida de la descomposición de la hojarasca como fuente de carbono orgânico y nutrientes. Por lo tanto, el uso de la tierra que promueve una alta descomposición de la hojarasca podría tener uma influencia positiva em las propiedades químicas del suelo. Este estudio tuvo como objetivo cuantificar el contenido nutricional de la basura en ambientes antropizados y naturales del sur de Amazonas. El estudio se realizó en dos predios del municipio de Canutama, en cuatro áreas: bosque nativo, achiote, cupuazú y guaraná. En cada zona se instalaron 10 colectores en forma de cono (0,21 m²) a una altura de 0,3 m del suelo. Las muestras recolectadas en cada área para cada mes se secaron en estufa de circulación forzada a 60 ºC hasta alcanzar masa constante y se pesaron. Los contenidos de macro y micronutrientes se realizaron mediante solubilización sulfúrica (N), solubilización nítrica perclórica (Ca, Mg, P, K, Na, S, Cu, Fe, Mn y Zn) e incineración (B). A los datos obtenidos se les aplicó análisis de varianza y comparación de medias mediante prueba de Tukey al nivel de probabilidad del 5%, además de un análisis multivariado. Esta comparación se realizó evaluando el promedio general de un año completo de formación de camada y también la formación dentro de cada mes evaluado. El azufre (S) fue el único macronutriente que no difirió entre ambientes, con valores entre 0,1 y 0,2 g kg^{-1}. Los contenidos de macronutrientes y micronutrientes de la hojarasca (N: 16,92; Mg: 1,08; Cu: 16,00; Zn: 31,70; B: 104,40; g kg^{-1}) fueron significativamente mayores en el área de achiote. El achiote también presenta mayores contenidos de K (9,92 g kg^{-1}) y P (0,70 g kg^{-1}). La hojarasca de bosque natural y guaraná son más ricas en P (0,88 g kg^{-1}) y Ca (g kg^{-1}), respectivamente. La zona con cupuasú mostró menores contenidos nutricionales, especialmente en relación con los macronutrientes (N: 9,04; P: 0,51; K: 0,28; Ca: 0,76; Mg: 0,44; g kg^{-1}). Esto indica que los agroecosistemas tradicionales amazónicos pueden representar una alternativa para mejorar la calidad química de las capas superficiales de los suelos altamente meteorizados de la región.

Palabras clave: Basura, ciclo de nutrientes, salud del suelo, selva tropical, sistemas agroforestales.

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