Chapter

Organic Fertilization with Residues of Cupuassu (*Theobroma grandiflorum*) and Inga (*Inga edulis*) for Improving Soil Fertility in Central Amazonia

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Abstract

The cupuassu (*Theobroma grandiflorum* (Willd. Ex Spreng.) K. Schum.) is a native fruit tree which has, in the past years, acquired great social and economic importance for the regional farmers. The nutrient-rich and often wasted cupuassu tree fruit shell residues can contribute to the improvement of the low fertility soil of Amazonia. A trial was carried out on a small holder's cupuassu plantation in Central Amazonia to ascertain the effect of organic fertilization on the recovery of soil fertility and plant nutrition by using material from cupuassu shell residues and *Inga edulis* pruning (branches and leaves). The fertilization with cupuassu rinds + Inga prunings improved soil fertility, mainly by the increase of K and Ca in the soil, but only with liming, which appears to favor the mineralization of these nutrients. At the 0–10 cm depth, the Ca level increased about 50% compared to the control and the K level increased 75% compared to the cupuassu shell treatments. The significant increase of about 30% in N absorption by trees in the plots without liming shows that the application of green manure can increase the mineralization of N in Oxisols. These results show that the organic residue sources used can result in a nutrient-bearing organic fertilizer and become a low-cost alternative for recycling cupuassu processing residues.

Keywords: cupuassu shell, Inga pruning, decomposition, nutrients, liming

1. Introduction

The cupuassu (*Theobroma grandiflorum* (Willd. Ex Spreng.) K. Schum.) is a native fruit tree which has, in the past years, acquired great social and economic importance to the regional farmers. Most soils, where this species is cultivated, are of low natural fertility. Successive crops with no nutrient replenishment can bring about soil exhaustion and become detrimental to the system's sustainability [1, 2]. Problems, such as population unevenness, nutritional deficiencies, the occurrence

Of witch's broom disease caused by a fungi (*Moniliophtora perniciosa*), and cultivation of plants susceptible to it, have imposed a crop yield decrease, causing losses to the rural producers [2–4].

The municipality of Presidente Figueiredo in the Amazonas state has great potential for cupuassu agribusiness, despite the producers have been faced with problems related to the decrease in cupuassu yield due to the soil's natural fertility loss throughout years of cultivation, plus the occurrence of pests and diseases. Since most producers in this municipality cannot afford agricultural inputs, an alternative technology for conserving and recovering soils must be economically viable to be adopted by the farmers in the region. Hence, low-cost soil management alternatives, such as the use of organic residues, must be prioritized.

The often wasted cupuassu tree fruit shells could be used in contributing to fertilize the soils. The recycling of these wastes, as well as a better use of natural resources, has become very important when it comes to sustainable agriculture since it reduces production costs and minimizes environmental impact [5, 6]. Furthermore, organic residues can bear phytopathogenic suppressing microorganisms present in the soil, in addition to stimulating the growth of a more diversified and competitive/suppressing microbiota, reducing the occurrence of plant diseases [7, 8].

As most fruits, especially cupussu, are rich in potassium (K) and their productivity depends on the contents of this nutrient in the soil, their replenishment becomes necessary to maintain the cupuassu productivity [1, 9, 10]. Large amounts of organic residues from cupuassu pulping processing are currently found available piled up near the dwellings and/or agroindustries in the municipality of Presidente Figueiredo. These residues are a low-cost fertilizer alternative source for the replenishment of nutrients exported by harvesting or lost by leaching. On the other hand, the mixing of the cupuassu shells with N-rich materials could help the cupuassu shells' decomposition and mineralization without the soil's N immobilization in the soil. Thus, the addition of pruning of some N_2-fixing leguminous species, such as the Inga tree (*Inga edulis* Mart.), also known as ice cream bean, which is very frequent in the properties of the farmers of the Amazonas, might be used for this purpose. Hence, an experimental assay was implemented in the site of a smallholder farmer in the municipality of Presidente Figueiredo, in Central Amazonia, aiming to evaluate the effect of an organic fertilizer, by using plant materials from cupuassu shell residues and Inga tree pruning, on recovering the fertility of an Oxisol.

2. Material and methods

2.1 Characterization study area and experimental design

This study was conducted on a farming site located at coordinates 02° 03′ 55.5″ S and 59° 22′ 55.5″ W, on the side roads called Morena, in the municipality of Presidente Figueiredo, about 150 km from Manaus-AM through highway BR-174, in the Central Amazonia region. The experimental site's soil was classified as Oxisol, with flat to slightly undulated relief and belonging to the very clayey textural class, with the following chemical characteristics (0–20 cm layer): pH (H_2O) 4.62; available P 3.67 mg kg^{-1}; total N 1.88 g kg^{-1}; and 0.36; 0.16; 0,07; 2.75 cmo_c kg^{-1} of exchangeable Ca, Mg, K, and Al, respectively.

The experiment was carried out in an eight-year-old cupuassu crop, with 5 × 5 m spacing between plants and 400 plants ha^{-1} density. The experimental design was a randomized block design with four blocks (replications), consisting of a 2 × 3 factorial scheme, in which the factors were two levels of liming and three types of fertilization, making a total of six treatments, totaling 24 plots with 10 cupuassu plants per plot and a total of 60 plants per block. Treatments were as follows: 1—soil control; 2—cupuassu shell 2 t ha^{-1}; 3—cupuassu shell 2 t ha^{-1} + Inga prunings 3 t ha^{-1}; 4—Limestone 2 t ha^{-1}; 5—cupuassu shell 2 t ha^{-1} + limestone 2 t ha^{-1}; 6—cupuassu shell 2 t ha^{-1} + Inga prunings 3 t ha^{-1} + limestone 2 t ha^{-1}.

The dolomitic limestone (2 t ha^{-1}) was applied within the area straight below the cupuassu plant canopy and superficially incorporated into the soil. Plant materials used as organic fertilizers were obtained from farmers growing sites. Cupuassu shells were removed from a pile of discarded cupuassu shells and ground in a disintegrator (chopper and grinder), whereas the plant material was obtained from adult Inga tree pruning. Pruning was done by cutting off branches bearing up to 1.0-cm-thick leaves, just prior to the fertilization. Organic fertilizers were applied within the area straight below the cupuassu tree canopies, 60 days after the limestone was applied.

Plant materials used as organic fertilizer were analyzed to determine their chemical characteristics according to Silva [11] methodology. Inga plant material held higher nutrient concentrations than those of cupuassu shell, except for K, the contents of which showed to be similar (**Table 1**).

2.2 Soil sampling and analyses

Soil and cupuassu leave samplings were carried out at the end of the 2007 harvest, so as to evaluate soil fertility and plant nutritional status. Soil samples, within the area below plant canopies, were collected at 0–10 and 10–20-cm deep, for a total of 10 simple subsamples to make up a composite sample, and 20–30-cm deep, in a total of 5 subsamples to form one composite sample. Soil samples were air-dried, sieved through a 2-mm mesh, and taken to INPA's Soil and Plants Laboratory, where they were analyzed according to the methodology used by Embrapa [12]. Soil pH was measured in water at a ratio of 1:2.5. The cations of Ca, Mg, and Al were extracted using KCl 1 N, and their concentration was measured using atomic absorption spectrophotometry. For P and K, the double acid extraction system (H_2SO_4 0.0125 M + HCl 0.05 M) was used. P levels were determined by spectrophotometry using ammonium molybdate. The organic carbon concentrations were obtained using the self-analyzer for C, H, and N from Carlo Erba manufacturer.

Four simple soil samples were collected at 0–5, 5–10, and 10–20-cm deep, within the area straight below the canopies of the four central plants in the plot, for 0, 30, 60, and 90 days following the organic fertilizers application, so as to determine the N in the ammonium (NH_4^+) and nitrate (NO_3^-) forms. Samples were placed in plastic bags and stored in a styrofoam box containing ice. They were then transported to the laboratory and weighed for mineral-N extraction. Mineral N contents were determined after having been extracted with 0.5 M K_2SO_4, by using 20 g of moist soil and 40 mL of K_2SO_4. Nitrate and ammonium contents were determined through colorimetry following Embrapa [12] methodologies.

The sixth recently ripened sprouting leaf, downward from the tip of one of the mid-canopy branches, was established as a standard reference in the collection of

Plant material	N	Ca	Mg	K	P	C	C/N
			g kg^{-1}				
Cupuassu shell	6.19	1.29	0.90	6.58	0.33	495	68.3
Pruning of Inga	24.90	6.99	1.65	6.49	1.15	483	19.4

Table 1.
Nutrient concentrations in plant materials used as organic fertilizer, collected on farms in the Central Amazon region (n = 3).

cupuassu leaves. A total of five leaves were removed from each useful plant per plot, rapidly cleaned with distilled water-soaked cotton, dried in a forced ventilation oven at 65°C for three days, and then ground. Ca, Mg, K, and P concentrations were determined by nitro-perchloric digestion and the total N through sulfur digestion followed by distillation through the micro-Kjeldahl method [12].

2.3 Fruit production

The fruit production was evaluated by the number and weight of cupuaçu of 10 useful plants of each plot, from December to April (time of production cultivation), during the 2007/2008 harvest. The fruits, once detached from the plant, were counted and weighed. This operation was carried out once a week, during the entire harvest period.

2.4 Statistical analysis

Treatment effects significance was determined by the analysis of variance (ANOVA), and the comparisons between the means of the variables were performed by the Tukey test at 5% probability.

3. Results and discussions

3.1 Soil acidity and calcium and magnesium contents

As it was expected, liming significantly increased soil pH, Ca, and Mg contents and reduced the exchangeable Al at the three assessed depths (**Table 2**). Despite the 2 t ha^{-1} of limestone application significantly reduced the exchangeable Al content at the three evaluated depths, it still remained high at deeper layers (1.01–2.00 cmo_c kg^{-1}) [13]. The liming effect was more pronounced in the 0–10 cm layer, mainly in the treatments with the application of organic residues. There occurred an increase of the soil pH, as well as a more pronounced reduction of the Al content in the treatments with an application of organic residues, in the limestone plots, especially in the superficial layer of the soil. The increase in soil pH with the addition of plant residues has been observed [14]. Castro [15] observed Al content marked reduction with the application of organic fertilizers on an Ultisol in Central Amazonia. The intensity of the effects is linked to the characteristics of the plant material used. In general, legumes provide higher pH and Al neutralization in the soil than grasses, and this effect is linked to the cation content in the plant material [16]. This result would be due to the complexation of free H^+ and Al^{3+} with anionic organic compounds from the residues and the increased saturation of the cation exchange capacity by Ca, Mg, and K added with the plant residue, which would reduce the potential acidity [14]. The Oxisols of the Amazon are characterized by high acidity and the presence of toxic Al, and the application of organic matter has been suggested as an alternative for correcting the acidity and the neutralization of the exchangeable Al in the soil [17, 18].

3.2 Exchangeable K, available P, and organic C contents

The results of the **Table 3** showed a beneficial effect of liming on the decomposition of the organic material added, resulting in the increase of the mineralization of K in the soil, improving the efficiency of the organic fertilizers used. In that case, K concentration on the plant materials used on the organic fertilization may

Treatments	Soil depth (cm)					
	0–10		10–20		20–30	
	Without lime	With lime	Without lime	With lime	Without lime	With lime
			pH (H_2O)			
Controls	4.29	4.87 b	4.25	4.64	4.30	4.43
Cupuassu shell[1]	4.30	5.08 ab	4.25	4.66	4.26	4.51
Cupuassu shell + Inga2	4.24	5.31 a	4.20	4.60	4.20	4.39
Mean lime	4.28 B	5.09 A	4.23 B	4.63 A	4.25 B	4.44 A
			Al ($cmol_c\ kg^{-1}$)			
Controls	2.98	1.01	2.96	1.95	2.64 b	2.36
Cupuassu shell[1]	2.88	0.53	2.64	1.66	2.52 b	2.21
Cupuassu shell + Inga2	3.13	0.34	3.03	1.75	3.27 a	2.31
Mean lime	3.00 A	0.63 B	2.88 A	1.79 B	2.81 A	2.29 B
			Ca ($cmol_c\ kg^{-1}$)			
Controls	0.65	2.02 b	0.28	0.90	0.12	0.42
Cupuassu shell[1]	0.51	2.45 ab	0.23	0.95	0.10	0.45
Cupuassu shell + Inga2	0.32	3.02 a	0.22	0.86	0.12	0.35
Mean lime	0.49 B	2.50 A	0.24 B	0.90 A	0.11 B	0.41 A
			Mg^{2+} ($cmol_c\ kg^{-1}$)			
Controls	0.37	1.03	0.17	0.57	0.10	0.30
Cupuassu shell[1]	0.32	1.10	0.16	0.57	0.09	0.33
Cupuassu shell + Inga[2]	0.28	1.19	0.14	0.60	0.09	0.27
Mean lime	0.32 B	1.17 A	0.16 B	0.58 A	0.09 B	0.30 A

Means followed by different lowercase letters in the columns, and different upper case letters in the lines, differ from each other, by Tukey test at 5% probability.
12 t ha^{-1} organic fertilization of residues of cupuassu shell.
22 t ha^{-1} organic fertilization of residues of cupuassu shell +3 t ha^{-1} Inga pruning.

Table 2.
Values of pH (H_2O), exchangeable aluminum (Al), calcium (Ca), and magnesium (Mg) in an Oxisol, cultivated with cupuassu tree, as a function of lime and organic fertilizer.

have been the determinant factor for such an effect, since in the treatment with *cupuassu shells + Inga prunings*, we applied almost twice the amount of K we had done in the treatment with just cupuassu shells. Similar results have also been observed by Alfaia et al. [9] in cupuassu agroforestry systems in Western Amazonia.

In general, the average levels of K in the soil observed in this study were low (<0.05–0.10 $cmol_c\ kg^{-1}$), according to Moreira and Fageria [13] criteria. Soils in Amazonia hold low K contents [6, 13, 19, 20] and, due to the relatively high demand many native plants have for it, K becomes one of the most limiting nutrients for

Treatments	Soil depth (cm)					
	0–10		10–20		20–30	
	Without lime	With lime	Without lime	With lime	Without lime	With lime
			K ($cmol_c$ kg^{-1})			
Controls	0.09 A	0.09 Aab	0.05 A	0.05 Aab	0.04	0.03
Cupuassu shell[1]	0.12 A	0.07 Ab	0.06 A	0.04 Bb	0.04	0.03
Cupuassu shell + Inga[2]	0.09 B	0.15 Aa	0.04 B	0.07 Aa	0.04	0.04
Mean lime	0.10	0.10	0.05	0.05	0.04	0.03
			P (mg kg^{-1})			
Controls	4.4	4.6	2.5	3.6	1.7	2.9
Cupuassu shell[1]	4.6	3.9	2.8	2.8	1.8	2.1
Cupuassu shell + Inga[2]	4.3	3.5	2.8	2.5	2.0	2.0
Mean lime	4.4	4.0	2.7	3.0	1.8 B	2.3 A
			Organic C (g kg^{-1})			
Controls	35.0	28.4	24.2	21.6	19.4	19.1
Cupuassu shell[1]	32.9	29.4	22.3	20.5	17.4	17.3
Cupuassu shell + Inga[2]	31.1	29.1	21.7	19.8	18.3	17.1
Mean lime	33.0 A	28.9 B	22.7 A	20.6 B	18.4	17.8

Means followed by different lowercase letters in the columns, and different upper case letters in the lines, differ from each other, by Tukey test at 5% probability.[1]*2 t ha^{-1} organic fertilization of residues of cupuassu shell.*
[2]*2 t ha^{-1} organic fertilization of residues of cupuassu shell +3 t ha^{-1} Inga pruning.*

Table 3.
Values of exchangeable potassium (K), available phosphorus (P), and organic carbon (C) in an Oxisol, cultivated with cupuassu tree, as a function of lime and organic fertilizer.

producing fruits in this region [21]. Studies conducted in the Manaus region have shown K to be the most exported nutrient through agroforestry products originating from Amazonian native species, such as cupuassu, peach palm (*Bactris gasipaes*), and assai (*Euterpe oleracea*), with higher concentration in shells, seeds, and infructescence petioles, which must be reincorporated into the planting areas to maintain sustainability [22].

The low exchangeable K contents in the soils may also be related to its export through fruit harvesting in addition to losses by leaching, according to what was observed by Alfaia et al. [9]. The results of that study confirmed that mineralization and, the addition to the soil, of K-rich organic matter, such as cupuassu shells and Inga plant material, have the potential to restore this nutrient in the soil when associated with the correction of the soil acidity [9, 23].

With regard to P, it was observed that only at a depth of 20–30 cm the levels of this nutrient were significantly higher in the presence of liming, although the data in **Table 4** show a significant effect of liming on the absorption of P by cupuassu plants.

According to Khorramdel et al. [24], soil organic matter content is a result of the balance between the processes of addition of organic materials (plant residues, among

Treatments	N		P		K	
	Without lime	With lime	Without lime	With lime	Without lime	With lime
			$g\ kg^{-1}$			
Controls	12.5 Bb	14.7 A	0.83	0.89	4.48	5.04
Cupuassu shell	14.9 Aab	13.9 A	0.97	0.97	5.42	5.20
Cupuassu shell+ Inga	15.9 Aa	14.8 A	0.88	0.97	4.29	5.53
Mean lime	14.4	14.4	0.89 B	0.94 A	4.73 B	5.26 A

Means followed by different lowercase letters in the columns, and different upper-case letters in the lines, differ from each other, by Tukey test at 5% probability.
12 t ha^{-1} organic fertilization of residues of cupuassu shell.
22 t ha^{-1} organic fertilization of residues of cupuassu shell + 3 t ha^{-1} Inga pruning.

Table 4.
Concentrations of nitrogen (N), phosphorus (P), and potassium (K), in cupuassu tree, leaves planted in an Oxisol of Central Amazonia as a function of lime and organic fertilizer.

others) and their loss (mineralization and decomposition by the decomposing organisms present in the soil). Under the conditions this work was performed, the dolomitic liming might have stimulated the mineralization of the organic matter added to the soil in the form of plant residues, which, combined with the high temperatures and humidity moisture (rainy season), favored and accelerated the decomposing process.

Inputs of exogenous organic matter may accelerate or retard the mineralization of native soil organic carbon (SOC) through a priming effect, and thus have a potential to change SOC dynamics [25]. In general, the priming effect is induced by the exogenous organic C but its intensity is controlled by soil nutrient availability [26]. Under the conditions of this work, liming increased the mineralization of N, increasing the availability of this nutrient in the soil (**Figures 1** and **2**), which probably accelerated the decomposition of the native SOC, [26, 27]. However, more research is needed to clarify the influences of organic amendments on SOC build-up [28].

3.3 Mineral nitrogen contents (N-NH_4^+ and NO_3^-)

Figure 1 shows the results of the mineral N, in the soil, as nitrate (N-NO_3^-) and ammonium (N-NH_4^+). The predominant mineral N was the form of N-NH_4^+, especially in the treatment with the addition of Inga pruning, with presented this nutrient's highest releasing rate (0–5 cm layer) 60 days after its application. Mineral N predominant in the form of ammonium (N-NH_4^+) confirms the findings by other authors who claimed this ion to be a major N source for plants on Amazonian Oxisol [29]. The lower content of N in the form of nitrate (N-NO_3^-) might result from its greater losses through leaching and denitrification, such as documented by other authors [30, 31] and by its use by plants. On the other hand, the presence of the two forms of nitrogen in the soil can be highly positive for plant nutrition to maintain the internal ionic balance, since their uptake is in the form of N-NH_4^+ (positive charge) or in the form of N-NO_3^- (negative charge) keep the electrical equilibrium.

Figure 2 shows the liming positive effect on the organic fertilizer mineralization 60 days following their application. The three depths showed to have occurred an increase in the total mineral N (N-NH_4^+ + N-NO_3^-) contents, confirming the data shown in **Figure 1** and adding the information of it that it was leached down to the depth of 20 cm, at least. At 60 days after the application of organic fertilizers, the mineral N total (NH_4^+ + NO_3^-) contents along the soil profile were higher in the treatments containing liming and cupuassu shells either with or without Inga residues, because adding

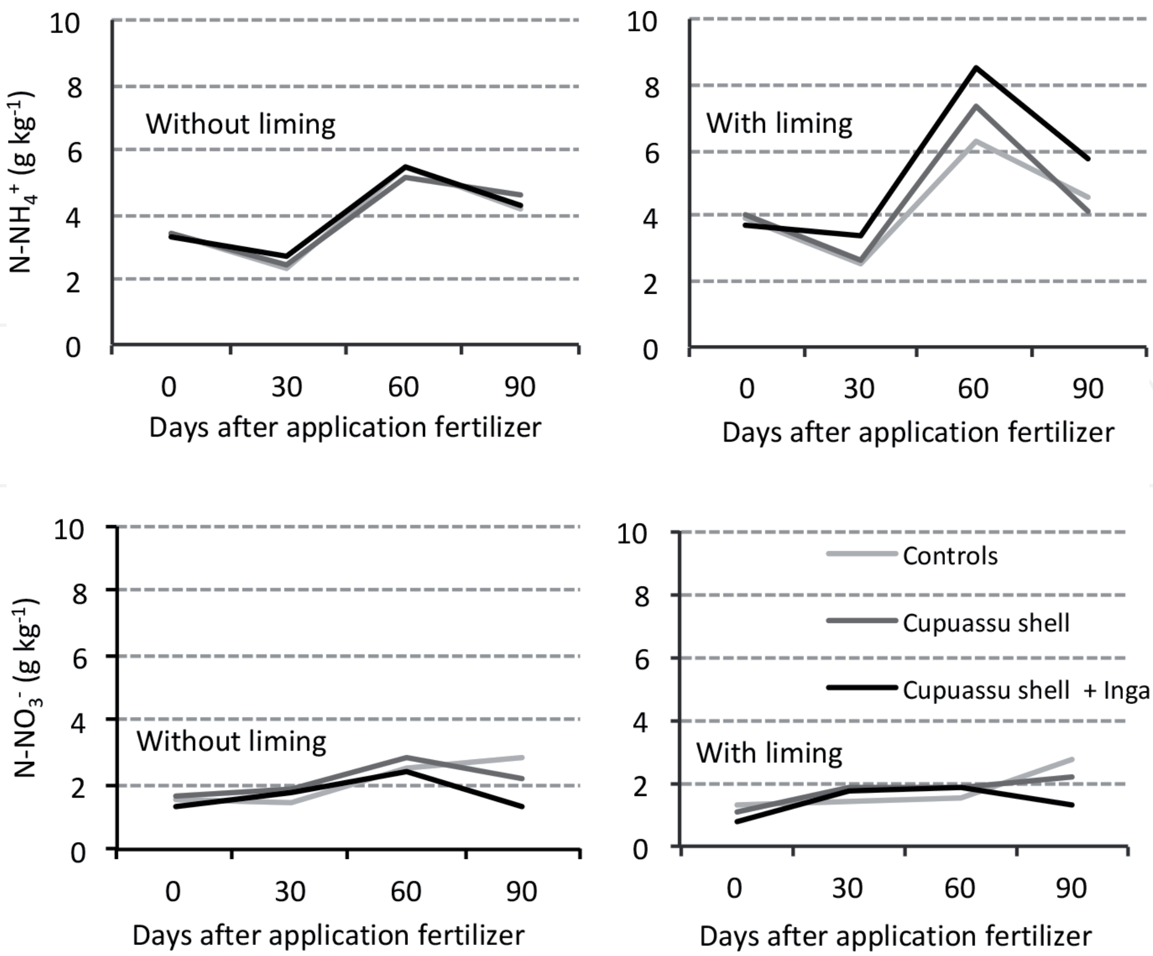

Figure 1.
N mineral content in the form of NH_4^+ and NO_3^- in an Oxisol, cultivated with cupuassu tree, as a function of lime and organic fertilization.

that organic material and raising the pH as well as the addition of Ca and Mg through dolomitic limestone increased the nitrogen contents through soil layer (**Figure 2**). It must take into account that part of this nutrient was uptake by the plants, or its contents would have shown to be higher in the soil profile due to leaching. The results obtained in this work confirm that the applications of green manure (leguminous plant prunings) are able to increase the mineralizable N in cupuassu crops in Oxisols.

3.4 Cupuassu plant nutrient contents

Liming significantly increased the plant absorption of P, K (**Table 4**). On the other hand, in the plot without liming occurred a significant increase in the absorption of N in the treatment with *Inga + cupuassu shell* compared to the control. Probably, the incorporation of organic waste has contributed to increasing the mineralization of organic N in the soil, as has been reported in other studies [29, 32]. Studies on the Oxisol and Ultisol of Central Amazonia have mentioned the absence of N response in cupuassu fruit production, due to the high mineralization rate and, consequently, high availability of mineral N in these soils, especially in soils with leguminous cover [33, 34].

The average concentrations of N and P obtained in this work are below the levels found by other authors in cupuassu tree plantations in the Oxisols of Central Amazonia [33], while the average concentration of K is found well above the values obtained in other works in Amazonia [1, 33], which may be related to the effect of organic fertilizers on the supply of K to the cupuassu plants in the present work. On Cambisols of Central Amazonia, Ayres and Alfaia [1] observed that liming promoted a small increase in K uptake by cupuassu plants.

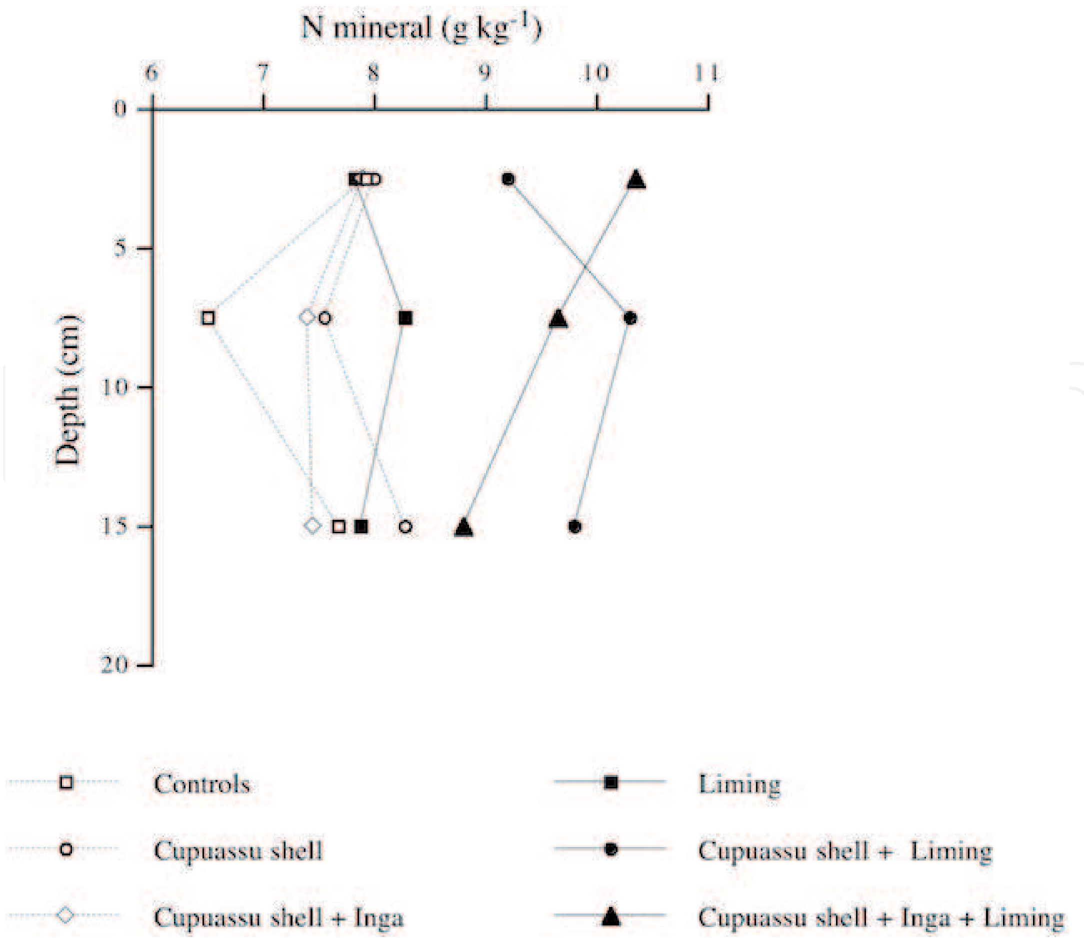

Figure 2.
N mineral total (NH_4^+ + NO_3^-) content in a Oxisol, cultivated with cupuassu tree, as a function of lime and organic fertilization.

3.5 Fruit production

The data in **Figure 3** showed that organic fertilization induced a slight, non-significant increase in fruit production. Alfaia et al. [9], in experiments using cupuassu bark residues with and without liming, also did not observe significant effects on fruit production during the first fruit harvest; however, the increase in production was most pronounced during the harvest of the following year. It is probable that in this work, the time after the application of the treatments was not enough for the decomposition of organic matter to occur.

The largest increases of nitrogen in the soil occurred at 60 days after the application of fertilizers, shown a slow decomposition of organic material (**Figure 3**), even in the treatment with the addition of Inga, which has a lower C/N ratio and could help to accelerate the decomposition process [35]. The Inga, although being a legume, has low rates of decomposition and release of nutrients, when compared to other legume species [36]. In an Oxisol in the Central Amazon, Schwendener et al. [37] observed that the mixture of cupuassu litter (of low nutritional quality) and leaves of Inga (of slow decomposition) did not contribute to the increase of mineral N in the soil in the short term, in contrast to a legume such as gliricidia (*Gliricidia sepium*), of rapid decomposition. The results of this work show the potential of organic fertilization with cupuassu shell + Inga pruning as a supplier of nutrients for the cupuassu plants. However, more studies are needed, both on the effect of the application of residues in the long term, and tests of doses and mixing with other legumes and its use in the production of biochar and composting, which would prevent the immobilization of nutrients.

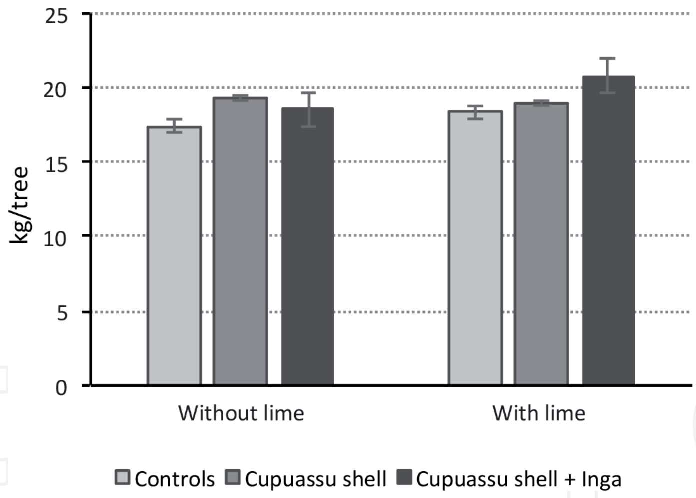

Figure 3.
Fruit production of cupuassu tree as a function of lime and organic fertilizer. Columns represent the mean of four replications and lines the standard error of the mean.

4. Conclusions

The organic fertilization with *cupuassu shell + Inga pruning* improved the chemical characteristics of the soil, mainly for the replacement of K and Ca, since applied with liming.

Without liming, there was a significant increase in the absorption of N by the cupuassu plants, showing that applications of green manure (legume pruning) can increase the N mineralization in Oxisols.

Liming also stimulated the mineralization of the organic fertilizers added to the soil, bringing about significant increases in P and K uptake by the cupuassu trees.

The assessed organic residues sources can result in a great nutrient-bearing organic fertilizer and become a low-cost alternative for recycling cupuassu processing residues.

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Conflict of interest

The author declares no conflict of interest.

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