



CHEMICAL ATTRIBUTES OF A YELLOW LATOSOL UNDER AGROFORESTRY SYSTEMS WITH ORGANIC ORANGES IN THE MUNICIPALITY OF CAPITÃO POÇO, PARÁ

Jessivaldo Rodrigues Galvão¹
Odete Kariny Souza Santos²
Bruno Kleidson da Silva Maia³
Pedro Paulo da Costa Alves Filho⁴
Erika Cristina Gomes Sales⁵
Leonardo Braga Neves⁶
Arthur Masaaki Maeda Nagase⁷

ABSTRACT

Objective: To evaluate the chemical attributes of a yellow Latosol from two agroforestry systems with organic citrus cultivation.

Method: First agroforestry system (AFS 1), with organic Citrus x aurantium (L.) orange planted in consortium with Brazilian mahogany Swietenia macrophylla (King) and spontaneous species in the undergrowth (herbaceous); Second agroforestry system (AFS 2), with organic orange planted in consortium with ingá Inga edulis Mart and embaubeira Cecropia peltata L. (spontaneous); orange monoculture under conventional management, used as a control for comparisons with the agroforestry systems studied. A completely randomized design (DIC) was used, with four collection points in each of the AFSs at 3 depths, with 4 repetitions.

Results and discussions: The data was submitted to analysis of variance, with means compared using the Tukey test at 5%. There were significant differences between the treatments in isolation and in their interactions for all the variables studied, with the exception of pH, which responded only in isolation, and the C/N ratio, which did not show significant results for the depth factor. The treatments located in the crop rows within the agroforestry system areas had better chemical attributes, maintaining more suitable conditions for supplying the nutritional demand of citrus fruits.

Implications of the research: The results obtained strengthen the importance of using agroforestry systems (AFSs) as a viable and sustainable solution for agricultural and forestry production, due to the use of practices that cause fewer impacts and contribute to the restoration of impoverished or abandoned areas.

Keywords: Nutritional Demand, Organic Cultivation, Supply, Management, Citrus.

¹ Universidade Federal Rural da Amazônia, Belém, Pará, Brazil. E-mail: jessigalvao50@gmail.com
Orcid: <https://orcid.org/0000-0003-4242-6555>

² Universidade Federal Rural da Amazônia, Belém, Pará, Brazil. E-mail: odetekarinys@gmail.com
Orcid: <https://orcid.org/0000-0002-9122-0644>

³ Universidade Federal Rural da Amazônia, Belém, Pará, Brazil. E-mail: bruno.maia@unesp.br
Orcid: <https://orcid.org/0000-0002-8494-6834>

⁴ Universidade Federal Rural da Amazônia, Belém, Pará, Brazil. E-mail: pp.alvesfilho@outlook.com
Orcid: <https://orcid.org/0000-0002-5945-5515>

⁵ Universidade Federal Rural da Amazônia, Belém, Pará, Brazil. E-mail: Ecgoms@gmail.com
Orcid: <https://orcid.org/0000-0002-0612-4472>

⁶ Universidade Federal Rural da Amazônia, Belém, Pará, Brazil. E-mail: Leonardo br.neves@gmail.com
Orcid: <https://orcid.org/0009-0004-6303-2218>

⁷ Universidade Federal Rural da Amazônia, Belém, Pará, Brazil. E-mail: mnagaseacademico@gmail.com
Orcid: <https://orcid.org/0000-0002-3401-3956>



ATRIBUTOS QUÍMICOS DE UM LATOSSOLO AMARELO SOB SISTEMAS AGROFLORESTAIS COM LARANJAS ORGÂNICAS NO MUNICÍPIO DE CAPITÃO POÇO, PARÁ

RESUMO

Objetivo: Obtivou-se avaliar atributos químicos de um Latossolo amarelo de dois sistemas agroflorestais com cultivo orgânico de citrus.

Método: Primeiro sistema agroflorestal (AFS 1) possui plantio de laranja *Citrus x aurantium* (L.) orgânica consorciada com mogno brasileiro *Swietenia macrophylla* (King) e espécies espontâneas no extrato rasteiro (herbáceas); Segundo sistema agroflorestal (AFS 2), com plantio de laranja orgânica, em consorcio com ingá *Inga edulis* Mart e embaubeira *Cecropia peltata* L. (espontâneas); Monocultivo de laranja em manejo convencional, utilizado como controle para comparações com os sistemas agroflorestais estudados. Utilizou-se o delineamento inteiramente casualizado (DIC), em quatro pontos de coleta, em cada um dos AFS's em 3 profundidades, com 4 repetições.

Resultados e discussões: Os dados foram submetidos à análise de variância, com médias comparadas pelo teste de tukey a 5%. Ocorreram diferenças significativas entre os tratamentos, isoladamente e em suas interações para todas as variáveis estudadas, a exceção do pH, que respondeu apenas de forma isolada e a relação C/N que não apresentou resultados significativos para o fator profundidade. Os tratamentos localizados nas linhas de cultivo dentro das áreas de sistemas agroflorestais apresentaram melhores atributos químicos, mantendo condições mais adequadas para suprir a demanda nutricional de citrus.

Implicações da pesquisa: Os resultados obtidos fortalecem a importância da utilização dos sistemas agroflorestais (AFS's) como uma solução viável e sustentável para a produção agropecuária e florestal, em razão do uso de práticas que causem menos impactos e que contribuam para a restauração de áreas empobrecidas ou abandonadas.

Palavras-chave: Demanda Nutricional, Cultivo Orgânico, Aporte, Manejo, Citrus.

RGSA adota a Licença de Atribuição CC BY do Creative Commons (<https://creativecommons.org/licenses/by/4.0/>).



1 INTRODUCTION

One of the greatest concerns of agriculture in Brazil is environmental preservation. It is therefore necessary to meet the demand for food in order to achieve a balance between production and the sustainability of production systems, and agroecosystems can be used to achieve this goal (ELLI et al., 2016).

As a result, the use of production methods that modify the natural conditions of the environment is increasingly being used and studied. Agroforestry systems (AFSs) have been presented as a viable and sustainable solution for agricultural and forestry production, due to the use of practices that cause fewer impacts and contribute to the restoration of impoverished or abandoned areas.

These systems provide diversification of production, using available resources in an integrated way, maximizing the possibilities of use (GODFRAY, et al., 2010), in a systemic way, and can generate various products, such as: timber and non-timber forest products, agricultural production (perennial, semi-perennial, annual, among others), providing small, medium and long-term benefits for the producer.

Environmental benefits such as the recovery of degraded areas, which is the reality of many production areas in the Amazon region, increased organic matter in the soil, improved chemical, physical and biological attributes of the soil (ELLI, 2016; XAVIER et al, 2014; LACERDA et al., 2013; SILVA, et al., 2011).



The intense use of soil through current agricultural and forestry production systems is causing damage, promoting the loss of soil characteristics and affecting the productivity of production areas. Thus, there is a need to maintain the rational use and exploitation of available resources, and one of the resources that can be preserved is the soil, the basis of support and nutrition. Knowledge of soil properties is therefore a fundamental tool for planning practical activities that maintain the characteristics to ensure the maintenance of the production system..

Small-scale farming is the basis of production for thousands of families in the Amazon region, where small farmers represent the vast majority of the region's rural population (GODAR et al., 2014). Thus, agroforestry systems are a suitable practice for family farming due to the high demand for labor. Diversifying production, along with taking care to maintain organic management, is an important step towards food security and sovereignty in rural areas (SILVA, 2006). For AFSs with perennial crops, the possibility of associations with native species stands out, guaranteeing the permanence of forest species in order to seek harmony between the components, aiming for agricultural production as well as timber and non-timber forest products. Since the soil is the basis of agricultural and forestry production, whether natural or planted, it is essential to plan management with practices that conserve and or restore soil fertility, so as to maintain favorable conditions for cultivation.

Agroforestry systems (AFS) are land use systems in which agricultural plants are combined with tree species on the same land management unit. This combination has been credited with improving the physicochemical properties of degraded soils, as well as the activity of microorganisms, considering the possibility of a large number of sources of organic matter (MENDONÇA; LEITE; FERREIRA NETO, 2001). Despite all the benefits described in the literature, few studies report the improvement in soil quality or the increase in productivity promoted by agroforestry systems, compared to conventional production systems (SILVA, 2006).

To evaluate the chemical attributes of a yellow Latosol under agroforestry systems with organic citrus cultivation and relate them to the crop's nutritional demand.

2 THEORETICAL FRAME

Trees in AFSs play crucial roles, such as improving soil structure, increasing nutrient cycling and promoting biodiversity (Kumar et al., 2020). In the context of the research in question, the analysis of the chemical attributes of the Yellow Latosol is necessary to assess the effects of these agroforestry systems on soil quality.

The municipality of Capitão Poço, located in the Amazon region, has unique environmental characteristics and specific challenges for sustainable agriculture. Regional studies, such as Ribeiro et al. (2020), highlight the importance of proper soil management and the adoption of agroforestry systems in order to face the environmental and socioeconomic challenges of the region.

In agroforestry systems, the complex interactions between trees, crops and other elements of the system can influence these attributes. Previous studies, such as Gama et al. (2019), have shown that AFSs can improve soil fertility by increasing organic matter, nutrient content and microbial activity. Nair et al. (2008) demonstrated that the adoption of AFSs with fruit species, such as organic oranges, can increase soil organic matter, improving its water and nutrient retention capacity.

The production of organic oranges is an agricultural practice that seeks to minimize the use of synthetic chemicals, promoting soil health and environmental sustainability. The Yellow Latosol, when properly managed in organic systems, can provide a favorable environment for growing healthy, high-quality oranges, as discussed by Silva and Santos (2018).



Another fundamental attribute to consider is the soil's pH, which affects the solubility of nutrients and, consequently, their absorption by plants. Studies by Rocha et al. (2019) have shown that AFSs can contribute to maintaining an adequate pH for growing organic oranges, avoiding nutritional imbalances. Lima et al. (2021) suggest adopting agroforestry systems to improve the availability of nitrogen, phosphorus and potassium in the soil, promoting an increase in production.

3 MATERIAL AND METHODS

The experimental area is located in the municipality of Capitão Poço, Pará, 169 km in a straight line from Belém, in the physiographic zone of Guamá, in the territory of the Northeast of Pará and the Guamá micro-region, with a total area of 2,714 km².

According to the Köppen classification, the region's climate is of the Afi type, which is characterized by annual rainfall of more than 2000 mm, with rainfall throughout practically the whole year and monthly totals of 60 mm or more. The average maximum temperature is 31.4°C and the average minimum temperature is 22.4°C. The total number of hours of sunshine per year is around 2,338 and the average relative humidity is 84% (SUDAM, 1984; BASTOS; PACHECO, 2001). The area characterized by organic management with agroforestry systems and citrus cultivation is located on the "SOS AGROECOLÓGICO" property.

An agroforestry system called AFS 1 was set up in the production area in 1997. Before it was set up, the slash-and-burn system was used to produce swiddens. From 1997 until 2013, bovine manure and biomass management were used in the area as a form of fertilizer to add nutrients to the system; since then, only biomass management has been used to supply nutrients. The areas are surrounded on all sides by secondary forest that is more than 30 years old.

AFS 2 was set up in 2007. Prior to its implementation, the area was used to grow orange monocultures. Until 2013, it also used biomass management and cattle manure as fertilizers. From 2013 onwards, only biomass management was used as a nutritional supplement.

The monoculture area under conventional *Citrus sinensis* management has been worked for over 10 years in the traditional way, using fertilizers and pesticides to maintain production. The spacing used is 7m between rows and 5m between plants. NPK 10-28-20 is used as maintenance fertilizer, in two annual applications, one in January and one in June. The fertilizer is applied 1m away from the trunk in a half-moon shape, following the projection of the canopy, and 340 kg of fertilizer is used per ha. Dolomitic limestone is also used in annual applications at the start of the rainy season, in the amount of 2 t ha⁻¹.

Table 1. Chemical characterization of the soils under two agroforestry systems and a citrus monoculture area, at a depth of 0 to 20 cm.

System	MO g kg ⁻¹	P ...(mg dm ³)...	K ...	H+Alcmolc	Al dm ³	Ca dm ³	Mg	pH H ₂ O	C/N -	SB cmolc dm ³	T dm ³	V% %
AFS 1	14,5	5,36	25,83	4,3	0,622	0,93	0,35	4,61	12,5	1,34	5,64	22,88
AFS 2	15,99	3,78	31,55	4,51	0,476	1,07	0,38	4,9	14,18	1,54	6,04	24,78
Conv	12,39	5,93	17,82	3,74	0,655	0,7	0,24	4,63	15,49	0,98	4,73	20,36

Source: The authors

To characterize the soils collected, 10 simple samples were taken to make up a composite sample, at depths of 0-5, 5-10 and 10-20 cm, using a Dutch auger. Four replicates were used for each treatment. The soil samples were placed in polyethylene bags and sent to the soil drying room at the Federal Rural University of Amazonia to be air-dried for 72 hours, after which they were crushed and sieved through a 2 mm diameter mesh.

They were then taken to the soil laboratory of the Brazilian Agricultural Research Corporation, where pH (H₂O), organic matter, organic C, nitrogen, exchangeable bases (K, Ca,



Mg), potential acidity (H+Al), exchangeable Al and available soil P were determined. All the determinations were carried out in accordance with the methodology recommended by Embrapa (2009).

The areas where the study was carried out were two agroforestry systems and a citrus monoculture. The first agroforestry system (AFS 1) was planted with organic *Citrus x aurantium* (L.) oranges combined with Brazilian mahogany *Swietenia macrophylla* (King) and spontaneous species in the undergrowth (herbaceous), which was established in 1997. The second agroforestry system (AFS 2), planted in 2007, also planted organic oranges, in consortium with *ingá* *Ingá edulis* Mart and embaubeira *Cecropia peltata* L. (spontaneous).

In addition, an orange monoculture area based on conventional management was used as a control area for comparisons with the agroforestry systems studied.

The treatments were as follows:

- S1: 20-year-old agroforestry system made up of mahogany trees (*Swietenia macrophylla* K.), citrus trees (*Citrus x aurantium* L.) and spontaneous embaube trees (*Cecropia pachystachya* Trécul).
- S2: agroforestry system 10 years in the making and made up of *Ingá* trees (*Ingá edulis* Mart), citrus (*Citrus x aurantium* L.) and spontaneous embaube trees.
- S3: conventional citrus monoculture system.
- L1 between plants in the row of forest species that make up the system;
- L2 between rows of the forest essence row and the citrus cultivation row;
- L3 between plants in the citrus cultivation row;
- L4 between rows of the double citrus cultivation row.

Soil concentrations of macronutrients (N, P, K, Ca and Mg) were assessed, as well as hydrogen, aluminum, pH, organic matter, CTC, sum and saturation of bases and aluminum saturation.

A completely randomized design (DIC) was used, with four collection points (between forest species plants, between orange plants and between forest species X orange rows and between orange rows), in each of the AFSs at 3 depths (0 to 5, 5 to 10 and 10 to 20 cm), with 4 repetitions, making a total of 120 experimental units. The data on the variables analyzed were subjected to analysis of variance and their means were compared using the Tukey test at 5%, using the SISVAR statistical program (FERREIRA, 2007).

4 RESULTS AND DISCUSSION

There were significant differences between the treatments in isolation and in their interactions for all the variables studied, with the exception of pH, which responded only in isolation, and the C\N ratio, which did not show significant results for the depth factor (Table 2).

Table 2. Summary of the analysis of variance for the chemical attributes of a yellow Latosol, for management and depth.

FV	G.L	MO	N	P	K	Al	Ca+ Mg	pH	C/N	SB	T	V %
		%	g kg ⁻¹	...mg dm ⁻³	cmol _c .dm ³			H ₂ O	-	-	cmol _c dm ⁻³	-
MAN												
(M)	9	**	**	**	**	**	**	**	**	**	**	**
Depth (D)	2	**	**	**	**	**	**	**	ns	**	**	**
TxP	18	**	**	**	**	**	**	ns	**	**	**	**
CV (%)	-	12,59	9,77	11,52	9,07	14,1	21,25	2,75	13,12	17,19	6,21	13,77

Source: The authors



The organic matter in the soil showed significant differences between the treatments studied. In general, the depth range from 0 to 5 cm showed the highest concentrations of organic matter. In relation to the treatments studied, the lowest concentrations of organic matter were observed in treatments S3L1 and S3L2, in the depth ranges of 5 to 10 and 10 to 20 cm (Table 3).

Table 3: Soil organic matter as a function of treatment at depths of 0 to 5 cm, 5 to 10 cm and 10 to 20 cm in a dystrophic yellow latosol.

Depth	S1L1	S1L2	S1L3	S1L4	S2L1	S2L2	S2L3	S2L4	S3L1	S3L2
0 – 5	19,93Aa	17,98Ab	14,15Ac	13,99Ac	18,2Aa	17,78Ab	17,67Ab	16,74Ab	17,89Ab	13,68Ac
5 – 10	20,29Aa	15,88Bb	15,9 Ab	11,84Bc	14,9 Bb	15,09Bb	16,99Bb	15,88Bb	12,85Bc	11,4 Bc
10 – 20	11,09Bc	11,13Cc	11,01Bc	10,8 Bc	14,06Bb	13,7Bb	18,49Aa	12,29Cb	9,46Bc	9,05 Bc

Source: The authors

Averages followed by the same letter, upper case vertically and lower case horizontally, do not differ by the scott-knott test at 5% probability.

In the shallowest 0 to 5 cm of soil, the highest concentrations of organic matter were observed in treatments S1L1 and S2L1, located in the *Swietenya macrophylla* cultivation line in AFS 1 and *Ingá edulis* in AFS2. It is common for organic matter to be found in greater quantities in the more superficial layers of the soil, as the entry of C into the soil is mainly linked to the deposition of plant and animal waste above the ground (SILVA E MENDONÇA, 2007).

For the 5 to 10 cm depth, it can be seen that the S1L1 treatment was the one with the highest MOS concentrations. The treatments located in the monoculture area, S3L1 and S3L2, had the lowest concentrations of organic matter, which may have been due to the soil's exposure to external factors and the lack of plant and animal waste in the conventional production method.

For the greatest depth range observed (10 to 20 cm), the highest concentration of MOS occurred in the S2L3 treatment, which may have been due to the increase in organic matter from crop residues, as well as the high production of dry matter from the spontaneous plants present.

The concentration of N in the soil was influenced differently depending on the treatments observed (Table 4). At a depth of 0 - 5 cm, there were higher concentrations of the nutrient, with the exception of treatment S1L2, which includes the row between the forest and the *C. aurantium* row in AFS 1. For the 5 to 10 cm depth, the N concentrations were the same as the first band of soil studied (0 to 5 cm), with the exception of treatments S1L3, S1L4 and S2L1, which had lower N concentrations. For the 10 to 20 cm range, only treatments S2L2, S2L4 and S3L1 obtained statistically equal values for the 0 to 5 and 5 to 10 cm depths.

Table 4. Total nitrogen concentration (%) in the soil as a function of the treatments, at depths of 0 to 5 cm, 5 to 10 cm and 10 to 20 cm in a dystrophic yellow latosol.

S1L1	S1L2	S1L3	S1L4	S2L1	S2L2	S2L3	S2L4	S3L1	S3L2
0,84Aa	0,62Bc	0,86Aa	0,7Ab	0,78Aa	0,67Ab	0,72Ab	0,64Ab	0,60Ac	0,53Ac
0,79Aa	0,73Aa	0,76Ba	0,57Bc	0,67Bb	0,61Ac	0,70Ab	0,63Ab	0,41Ad	0,49Ad
0,56Ba	0,53Ca	0,57Ca	0,53Ba	0,60Ba	0,60Aa	0,61Ba	0,60Aa	0,36Ab	0,38Bb

N (%)

Source: The authors

Averages followed by the same letter, upper case vertically and lower case horizontally, do not differ by the scott-knott test at 5% probability.

The reduction in the concentration of nutrients in the soil is normal at greater depths, as



the 0 to 5 cm fraction is the one most influenced by external factors such as biomass deposition, litter decomposition and the action of microorganisms which are more concentrated in the "O" layer of the soil, so this depth range is usually rich in elements favorable to plant growth and development.

For the depth range of 0 to 5 cm, the highest values for N concentration were found in S1L1, S1L3 and S2L1, points which correspond to the line of forest essence cultivation within the systems and the line of citrus cultivation in AFS 1. These higher N concentrations were possibly due to the lower presence of spontaneous vegetation at these points.

A large number of plant elements in a given region can lead to greater extraction of nutrients from the soil in that area, reducing the concentration of the element in the soil. Treatments S1L4, S2L2, S2L3 had lower values than those mentioned above. It can be seen that these treatments, with the exception of S2L3, were located between the rows of crops, points which are more susceptible to infestation by spontaneous plants, which favors greater absorption of nutrients from the soil. Treatments S2L4, S1L2, S3L1 and S3L2 had the lowest averages, with lower N concentrations than all the others. Treatments S3L1 and S3L2, both in the conventional cultivation system, possibly had lower averages due to the lack of material incorporated into the soil, as well as the system being prone to nutrient losses through leaching and percolation, especially in the more superficial layers of the soil, due to its lack of protection.

The concentration of phosphorus in the soil showed significant differences depending on the treatments studied. In the 0 to 5 cm range, treatment S1L1 had higher N concentrations, in the 5 to 10 cm range, treatments S1L1 and S1L3 had the highest averages and in the 10 to 20 cm range, treatments S1L1 and S3L1 had the highest N concentrations. In general, the 0 to 5 cm depth layer had the highest concentrations of this nutrient. The 10 to 20 cm range had the lowest concentrations, with the exception of treatment S3L1, which had no significant difference depending on the depth of the samples (Table 5).

Table 5. Phosphorus (P) concentration in the soil as a function of the treatments, at depths of 0 to 5 cm, 5 to 10 cm and 10 to 20 cm in a dystrophic yellow latosol.

P (mg dm ⁻³)										
Depth	S1L1	S1L	S1L3	S1L4	S2L1	S2L2	S2L3	S2L4	S3L1	S3L2
	2									
0 – 5	8,56 Aa	5,64 Ab	6,45 Ab	5,42 Ab	5,73 Ab	3,64 Ac	5,02 Ab	5,28 Ab	6,15 Ab	6,71 Ab
5 – 10	7,19 Ba	4,91Ac	6,53 Aa	3,57 Bd	3,36 Bd	2,89 Ad	4,1 Bc	4,42 Bc	5,78 Ab	5,55 Ab
10 – 20	5,21 Ca	3,44Bc	4,69 Bb	2,71 Cd	2,71 Bd	2,05 Bd	2,96 Cc	3,22 Cc	5,69 Aa	4,69 Bb

Source: The authors

Averages followed by the same letter, upper case vertically and lower case horizontally, do not differ by the scott-knott test at 5% probability.

Similarly to what happened with nitrogen, the concentration of phosphorus decreased as the depth of the soil increased. For the 0 to 5 cm depth range, the highest concentrations of P were found in treatment S1L1, the mahogany crop line within agroforestry system 1. The other treatments, with the exception of S2L4, had similar P concentrations.

The S2L4 treatment had the lowest average P concentration, possibly due to the fact that it is the area within the agroforestry systems that is least influenced by the benefits of the production model, together with the fact that no products were added to add nutrients to the soil, which may have hindered the deposition of this nutrient in the soil.

According to Brasil and Cravo (2009), the phosphorus concentrations observed are considered to be low for citrus crops, in quantities considered to be low or very low. In the AFS areas, this is possibly because no external products are added to supply this nutrient to the soil. In the monoculture area, where phosphorus is added (in the form of granulated chemical



fertilizer) in installments throughout the year, the low values observed may reflect the low retention capacity of these nutrients in the soil, mainly due to nutrient loss processes, such as leaching and the export of nutrients necessary for plant production.

This is due to two main factors: the soils of the Amazon region are old, deep, with a high degree of weathering and poor in nutrients (Gama et al. 2007), so a large part of the nutrients that are made available for plant production come from increments (organic or inorganic) added above ground, in the case of this study the biomass and litter from the plants that make up the system, as well as the organic fertilizer used in the past to provide nutrients.

The concentration of potassium in the soil showed significant differences for the treatments studied. The 0 to 5 cm depth layer showed the highest concentrations of K, with the exception of treatment S1L4, where the concentration was highest in the 5 to 10 cm range. For all the treatments, the 10 to 20 cm soil layer showed the lowest concentrations of this nutrient, with the exception of the treatment located in the monoculture area (S3L1 and S3L2), which showed no significant difference between the 5 to 10 and 10 to 20 cm soil depths (Table 6).

Table 6. Potassium (K) concentration in the soil as a function of treatment, at depths of 0 to 5 cm, 5 to 10 cm and 10 to 20 cm in a dystrophic yellow latosol.

Depth	K (mg dm ³)									
	S1L1	S1L2	S1L3	S1L4	S2L1	S2L2	S2L3	S2L4	S3L1	S3L2
0 – 5	34,11 Ac	28,46 Ad	43,51 Ac	23,28 Be	60,37 Aa	32,99 Ac	49,44 Ab	20,68 Af	24,16 Ae	25,65 Ae
5 – 10	27,60 Bc	25,33 Ac	26,54 Bc	31,55 Ab	40,43 Ba	29,05 Bb	41,97 Ba	15,89 Bd	14,80 Bd	16,28 Bd
10 – 20	16,15 Cd	12,71 Bd	21,12 Cc	19,63 Cc	30,94 Ca	20,83 Cc	24,32 Cb	11,66 Cd	11,98 Bd	14,07 Bd

Source: The authors

Averages followed by the same letter, upper case vertically and lower case horizontally, do not differ by the scott-knott test at 5% probability.

According to Veloso (2007), the concentration of K in the soil was considered medium in treatments S1L3, S2L1 and S2L3 for citrus crops, while the other treatments had K concentrations considered low. The lower density of spontaneous plants present in the treatments proved to be favorable to the concentration of potassium in the soil of the systems studied. The lowest potassium concentrations were observed in the treatments present in the monoculture area (S3L1 and S3L2), where the density of spontaneous plants is much higher when compared to the treatments observed under agroforestry systems.

In the top layer of soil, 0 to 5 cm, the lowest concentration of K was observed in treatment S2L4, followed by treatments S3L1 and S3L2. The S2L4 treatment is less influenced by the presence of forest essences in the system and this may have influenced the lower concentrations of this nutrient in the treatment in question.

The S3L1 and S3L2 treatments, because they are in a monoculture area, do not benefit from the existing characteristics of agroforestry systems that favor the natural addition and retention of K in the soil, even if the management in these treatments is based on the use of chemical additives. It can thus be seen that the addition of chemical products, even in sufficient quantity, failed to provide K concentrations similar to those observed in agroforestry systems based on organic production management.

The natural supply of nutrients in the agroforestry systems studied managed to maintain and make available a higher concentration of nutrients compared to the concentration of this nutrient in the treatments located in the conventional monoculture system. According to studies carried out by Silveira et al (2007); Pinto, (2016); Rangel-Vasconcelos et al. (2016); Silva et al, (2016) on the dynamics of nutrient concentrations in the soil, it is notable that potassium concentrations show significant increases when compared to monoculture production areas.



According to Mafra et al. (1998), the annual production of phytomass in the agroforestry system was 11,036 kg ha⁻¹ of dry mass, with a mineral input by the plants of 70.0 kg.ha⁻¹ of K, which corroborates the results obtained in this study, where the concentration of K was significantly higher when compared to the treatments in a monoculture area with conventional management techniques where there is no above-ground plant residue.

The concentration of Calcium + Magnesium in the soil showed significant differences for the treatments studied. In general, the 0 to 5 cm depth layer showed the highest concentrations of Ca+Mg. There were no significant differences in calcium concentration between treatments S1L2, S2L1 for the 0 to 5 and 5 to 10 cm depths and treatments S2L2 and S2L4 for all depths studied. At the first depth studied, the S1L1 and S2L3 treatments obtained the highest averages, at the intermediate depth range the S2L3 treatment was superior, and at the greatest depth studied (10 to 20cm) the S2L1 and S2L3 treatments obtained the highest Ca+Mg concentration averages (table 7).

Table 7. Concentration of Calcium + Magnesium (Ca+Mg) in the soil as a function of the treatments, at depths of 0 to 5 cm, 5 to 10 cm and 10 to 20 cm in a dystrophic yellow Latosol.

Depth	Ca + Mg (cmol _c .dm ³)									
	S1L1	S1L2	S1L3	S1L4	S2L1	S2L2	S2L3	S2L4	S3L1	S3L2
0 - 5	2,76 Aa	0,99 Ac	2,02 Ab	1,39 Ad	2,02 Ab	1,12 Ac	2,74 Aa	1,12 Ad	1,64 Ab	1,02 Ac
5 - 10	1,76 Bb	0,97 Ac	1,50 Bb	0,93 Bc	1,71 Ab	0,95 Ad	2,52 Ba	0,74 Ad	1,08 Bc	0,67 Bd
10 - 20	0,89 Cb	0,37 Bc	0,79 Cb	0,62 Bc	1,42 Ba	0,72 Ab	1,77 Ca	0,59 Ac	0,86 Bb	0,44 Bc

Source: The authors

Averages followed by the same letter, upper case vertically and lower case horizontally, do not differ by the scott-knott test at 5% probability.

According to the recommendation made by Brasil and Cravo (2007), the concentration of Ca in the soil was considered medium in treatments S1L1, S2L3 to, while the other treatments had a concentration of Ca+Mg considered low. The nutritional demand for calcium and magnesium by *C. sinensis* is considered high, as few plant species demand more calcium than nitrogen (MATTOS JUNIOR et al., 2003).

It is noticeable that these nutrients are more concentrated in the more superficial layers of the soil, as they are more influenced by external factors, especially the deposition of organic material, gradually making elements available in the soil (PINTO, 2016); (RANGEL-VASCONCELOS et al, 2016); (MENDONÇA and SILVA, 2007).

The highest concentrations of these nutrients were observed in treatments S1L1 and S2L3 at depths of 0 to 5 cm and in treatment S2L3 at depths of 5 to 10 and 10 to 20 cm. The lower Ca+Mg concentrations in the treatments where there is less influence from the presence of tree species in the system may be related to the higher density of spontaneous individuals, thus increasing nutrient extraction from the soil.

In general, the areas with an agroforestry production system had a higher concentration of calcium in the soil, a fact that may be linked to the spontaneous contribution of nutrients that occurs in these production systems, returning to the soil nutritional elements that may or may not be essential for plant production and development. According to studies carried out by Pinto (2016) and Silva et al, (2016) it is noticeable that concentrations of exchangeable bases, such as calcium and magnesium, show significant increases when compared to monoculture production areas.

The pH showed significant differences for the treatments studied. The S1L1, S2L1 and S2L3 treatments had the highest averages, in the intermediate depth range the S2L1 and L3 treatments were superior, and at the greatest depth studied (10 to 20cm) the S2L1 treatment had the lowest acidity (Table 8).



Table 8. Soil pH as a function of treatment at depths of 0 to 5 cm, 5 to 10 cm and 10 to 20 cm in a dystrophic yellow Latosol.

Depth	pH									
	S1L1	S1L2	S1L3	S1L4	S2L1	S2L2	S2L3	S2L4	S3L1	S3L2
0 – 5	5,2Aa	4,56Ac	4,55Ac	4,37Bc	5,0 Aa	4,9Ab	5,1 Aa	4,45Ac	4,85Ab	4,47Ac
5 – 10	4,92Bb	4,45Ad	4,52Ad	4,72Ac	5,1 Aa	4,8Ab	5,07Aa	4,55Ad	4,77Ab	4,5 Ad
10 – 20	4,5Cc	4,35Ad	4,40Ad	4,65Ac	5,23Aa	4,8Ab	4,90Bb	4,72Ab	4,79Ab	4,45Ad

Source: The authors

Averages followed by the same letter, upper case vertically and lower case horizontally, do not differ by the scott-knott test at 5% probability.

In general, the pH did not reach the ideal range for plant production, 5.5 to 6.5, with only treatment S1L1, S2L1 and S2L3 coming close to the ideal range. In the treatments located under agroforestry systems, this factor is possibly related to the lack of liming in the areas under agroforestry systems, and that the addition of these nutrients through nutrient cycling was not enough to raise the soil pH to more desirable conditions, This corroborates the low concentrations of Ca+Mg observed in these systems, making it necessary to apply corrective material to raise the pH to ranges considered satisfactory for citrus production, in line with the effect of adding material with Ca and Mg to correct acidity observed by Malavolta (1984). In the area under citrus monoculture, there are also values below the desirable pH range, even under annual liming, which may be related to sub-doses of lime that would be insufficient to meet the need for acidity correction.

The S1L1, S2L1 and L3 treatments had higher pH values than the other treatments in the top layer studied (0 to 5cm), which may be related to the lower density of spontaneous plants, as seen in the previous chapter, extracting a lower amount of exchangeable bases from the soil, managing to keep positively charged ions in the soil, causing higher pH values in relation to the treatments where there is a higher density of spontaneous plants (MENDONÇA and SILVA, 2007).

The C/N ratio of the soil under the systems evaluated showed significant differences for the treatments studied. The S1L1, S1L3, S2L1, S2L3 and S3L1 treatments had higher base saturation, at intermediate depths the S2L3 treatment was superior, and at the greatest depth studied (10 to 20cm) the S2L1 treatment had lower acidity (table 9).

Table 9. Carbon-nitrogen ratio (C/N) in the soil as a function of the treatments, at depths of 0 to 5 cm, 5 to 10 cm and 10 to 20 cm in a dystrophic yellow Latosol.

Depth	Carbon/Nitrogen									
	S1L1	S1L2	S1L3	S1L4	S2L1	S2L2	S2L3	S2L4	S3L1	S3L2
0 - 5	13,96 Aa	14,78 Aa	9,56 Ab	11,56 Ab	13,49 Aa	15,30 Aa	14,28 Ba	15,07 Aa	17,23 Aa	14,99 Aa
5 - 10	14,89 Ab	14,31 Ab	12,06 Ab	12,09 Ab	12,87 Ab	14,45 Ab	13,90 Bb	14,34 Ab	18,24 Aa	13,68 Ab
10 - 20	11,61 Bc	12,21 Ac	11,10 Ac	11,85 Ac	13,62 Ac	13,19 Ac	17,80 Aa	11,85 Bc	14,97 Bb	13,85 Ac

Source: The authors

Averages followed by the same letter, upper case vertically and lower case horizontally, do not differ by the scott-knott test at 5% probability.

The C/N ratio was higher in the top layer of soil (0 to 5 cm), but was similar between treatments, with the exception of S1L4 and S1L3, which had lower C/N ratios. This characteristic occurs in AFSs mainly because of the greater accumulation and permanence of organic material under the soil, due to the stability of the systems (IWATA et al, 2012).



The absence of soil disturbance in AFSs and native forest provides better conditions for the organisms responsible for fragmenting plant material and cycling nutrients (CUNHA et al., 2012). Several studies have shown the potential of AFSs, especially those that use alley cropping, for nutrient cycling (Franzel et al., 2001), which increases the levels of MOS and its components, such as C, P, N, SB, V% and potential CTC.

A factor that may have caused a higher C/N ratio in the treatments located in the monoculture area is the lower concentration of total N in this soil compared to the concentrations found in the treatments located in the AFS areas, which leads to an increase in the C/N ratio.

There were significant differences in the chemical attributes of the soils depending on the treatments studied. For the sum of bases, it can be seen that the highest averages at all the depths studied were in the treatments located in the row of trees, treatments S1L1, S2L3 and S2L3 for depths 1, 2 and 3, respectively. Potential acidity and base saturation showed higher averages in treatments S1L1 and S2L3 for all depth ranges studied. For base saturation, the S2L3 treatment had a higher average for all the depths studied (Table 10).

Table 10. Soil base saturation (SB) as a function of treatment at depths of 0 to 5 cm, 5 to 10 cm and 10 to 20 cm in a dystrophic yellow latosol.

Depth	Sum of bases (cmol _c dm ³)									
	S1L1	S1L2	S1L3	S1L4	S2L1	S2L2	S2L3	S2L4	S3L1	S3L2
0 - 5	2,85 Aa	1,07 Ad	2,13 Ab	1,46 Ac	2,18 Ab	1,20 Ad	2,87 Aa	1,17 Ad	1,71 Ac	1,09 Ad
5 - 10	1,83 Bb	1,03 Ac	1,56 Bb	1,02 Bc	1,82 Bb	1,02 Ac	2,63 Aa	0,79 Bd	1,12 Bc	0,61 Bd
10 - 20	0,94 Cc	0,64 Bc	0,85 Cc	0,67 Cc	1,50 Bb	0,78 Ac	1,83 Ba	0,65 Bc	0,89 Bc	0,48 Bc
CTC pH 7 (T) (cmol _c dm ³)										
0 - 5	7,18 Aa	5,65 Ac	5,57 Ac	5,84 Ac	6,60 Ab	6,38 Ab	6,83 Aa	5,72 Ac	5,47 Ac	5,34 Ac
5 - 10	6,76 Aa	5,53 Ac	5,47 Ac	5,74 Ac	5,76 Bc	6,10 Ab	6,91 Aa	5,56 Ac	4,53 Bd	4,74 Bd
10 - 20	5,51 Ba	4,82 Bb	4,65 Bb	4,74 Bb	5,75 Ba	5,63 Ba	6,00 Ba	5,30 Aa	4,29 Bc	4,00 Cc
Base Saturation (V%)										
0 - 5	39,61 Aa	18,90 Ad	36,85 Aa	24,90 Ac	32,95 Aa	18,92 Ad	41,93 Aa	20,56 Ad	31,36 Aa	20,29 Ad
5 - 10	27,04 Bc	18,62 Ad	28,60 Bb	17,55 Bd	31,54 Ab	16,69 Ad	38,07 Aa	14,20 Be	24,78 Bc	12,99 Be
10 - 20	16,83 Cb	13,25 Bc	18,33 Cb	14,14 Bc	26,12 Ba	13,91 Ac	30,60 Ba	11,87 Bc	20,71 Bb	12,04 Bc

Source: The authors

Averages followed by the same letter, upper case vertically and lower case horizontally, do not differ by the scott-knott test at 5% probability for each variable in isolation.

Higher SB, T and V% values are noticeable in the treatments located in the crop row, both for forest species and *C. sinensis*, a factor that may be related to the lower exposure of the soil at these points, reducing the loss of desirable factors. In addition, the deposition of plant residues is greater in these locations, which favors the addition of organic matter and the deposition of nutrients in the soil, which will favor attributes such as: saturation and sum of bases (SILVA E MENDOÇA, 2007; RONQUIN, 2010).

The processes by which trees are inserted into production systems include: increasing inputs (organic matter, nitrogen fixation) reducing water and nutrient losses, improving the physical and chemical properties of the soil (YOUNG, 1989).

Another factor that may have caused this result is the fact that larger trees (forest essences and *C. sinensis*) extract less nutrients from the more superficial layers of the soil, therefore, as the density of herbaceous species in these areas is lower, consequently there is less extraction of nutrients, directly reflecting on their concentration in the soil (MENDONÇA and SILVA, 2007).

According to Montagnini (1992), the expected effect of forest species is undoubtedly soil conservation. The canopies reduce the effects of climatic factors that cause erosion and



compaction. In addition, the root system is generally dense and deep, which not only prevents the dragging of soil particles, but also has the potential to absorb nutrients in the deeper layers of the soil.

The base saturations of the soil under the systems evaluated showed significant differences for the treatments studied. In the outermost layer of the soil (0 to 5 cm) treatments S1L1, S1L3, S2L1, S2L3 and S3L1 had higher average base saturations, in the intermediate depth range treatment S2L3 was superior, and at the greatest depth studied (10 to 20 cm) treatment S2L1 had lower acidity.

In all treatments, base saturation was less than 40%, which is characteristic of the region's soils. The highest base saturation results were observed in the treatments present in the soil under agroforestry systems. Only the S3L1 treatment at a depth of 0 to 5 cm had a base saturation similar to the areas under agroforestry systems.

5 CONCLUSION

The treatments located in the crop rows within the agroforestry system areas had better chemical attributes, maintaining more suitable conditions to meet the nutritional demands of citrus fruits.

REFERENCES

BRASIL, E. C.; CRAVO, M. S. **Recomendação de Adubação e Calagem para o Estado do Pará: A Importância do Uso Racional de Fertilizantes e Calcário**. Revista de Estudos Paraenses, v. 2, p. 55-66, 2009.

BRASIL, E. C.; CRAVO, M. S. **Interpretação dos resultados de análise de solo**. Cap 4. 2007. In: CRAVO, M. da S.; VIÉGAS, I. de J. M.; BRASIL, E. C. **Recomendações de adubação e calagem para o estado do Pará**. Embrapa Amazônia Oriental. 2007. 1ª eds. p. 221-224.

CUNHA, E. Q.; STONE, L. F.; FERREIRA, E. P. B.; DIDONET, E. D.; MOREIRA, J. A. A. **Atributos físicos, químicos e biológicos de solo sob produção orgânica impactados por sistema de cultivo**. Revista Brasileira de Engenharia Agrícola e Ambiental, v.16, p.56 -63, 2012.

DORAN, J.W.; PARKIN, T.B. **Defining and assessing soil quality**. In: DORAN, J.W.; COLEMAN, D.C.; BZEDICEK, D.F.; STEWART, B.A. (eds.) **Defining soil quality for a sustainable environment**. Madison: Soil Science Society of America, 1994. p.3-21. (Special Publication, 35).

ELLI, E. F.; CARON, B. O.; ELOY, E.; BEHLING, A.; SOUZA, V. Q. DE; SCHWERZ, F. **Productive, morphological and qualitative characteristics of sugarcane in the understory tree species in agroforestry systems**. African Journal of Agricultural Research. Vol. 11(17), pp. 1576-1584, 28 April, 2016.

EMBRAPA. **Manual de análises químicas de solos, plantas e fertilizantes**. 2ª ed. rev. ampl. – Brasília: Embrapa informação Tecnológica, 2009. 627p.

FRANZEL, S.; COE, R.; COOPER, P. **Assessing the adaption potential of agroforestry practices in sub-Saharan Africa**. Agricultural Systems, v.69, p.37-62, 2001.



GAMA, J.R.F.N.; CARVALHO, E.J.M.; RODRIGUES, T.E. & VALENTE, M.A. **Solos do Estado do Pará**. In: CRAVO, M.S.; VIÉGAS, I.J.M. & BRASIL, E.C., eds. Recomendações de adubação e calagem para o estado do Pará. Belém, Embrapa Amazônia Oriental, 2007. p.19-29.

GAMA, J. R. V. et al. **Impact of agroforestry systems on soil fertility: A review**. Agronomy for Sustainable Development, v. 39, n. 6, p. 58, 2019

GODAR, J, GARDNER, T.A., TIZADO, E.J., PACHECO, P. **Actor-specific contributions to the deforestation slowdown in the Brazilian Amazon**. Proc. Natl. Acad. Sci. U. S. A. 111, 15591–15596. 2014.“

GODFRAY, H. C. J; BEDDINGTON, J. R; CRUTE, I. R; HADDAD, L; LAWRENCE, D; MUIR, J.F; PRETTY, J; ROBINSON, S; THOMAS, S. M; TOULMIN, C. **Food security: the challenge of feeding 9 billion people**. Science 327:812–817. 2010.

IWATA, B. DE F; LEITE, L. F. C; ARAÚJO, A. S. F; LUIS A. P. L; NUNES, C. G; CAMPOS, L. P. **Sistemas agrofloreais e seus efeitos sobre os atributos químicos em Argissolo Vermelho-Amarelo do Cerrado piauiense**. Revista Brasileira de Engenharia Agrícola Ambiental, v.16, n.7, p.730–738, 2012.

KUMAR, B. M.; Nair, P. K. R.; Showalter, J. M. **Carbon stock in agroforestry systems: a review**. Advances in Agroforestry, v. 2, p. 17-29, 2020.

LACERDA, F; MIRANDA, I; KATO, O. R; BISPO, C. J. C; VALE, I do. **Weed dynamics during the change of a degraded pasture to agroforestry system**. Agroforest Syst (2013) 87: 909.

LIMA, A. B. et al. **Impact of agroforestry systems on soil nutrient availability and citrus production**. Agricultural and Environmental Science, v. 45, n. 3, p. 215-228, 2021.

MAFRA, A.L.; MIKLÓS, A.A.W.; VOCURCA, H.L.; HARKALY, A.H. & MENDOZA, E. **Produção de fitomassa e atributos químicos do solo sob cultivo em aleias e sob vegetação nativa de cerrado**. R. Bras. Ci. Solo, 22:43-48, 1998.

MALAVOLTA, E. **A prática da calagem**. 3. ed. Sorocaba: Indústria Mineradora Pagliato Ltda, 1984. (Boletim Técnico, 2).

MENDONÇA, E. S.; LEITE, L. F. C.; FERREIRA NETO, P. S. **Cultivo de café em sistema agrofloreais: uma opção para recuperação de solos degradados**. Revista Árvore, Viçosa, v. 25, n. 3, p. 375-383, mai./jun. 2001.

MONTAGNINI, F. 1992. **Sistemas agrofloreais: princípios y aplicaciones em los trópicos**. 2 ed San Jose: Organización para Estudios Tropicales. 622 p.

PINTO, V. S. Decomposição e liberação de nutrientes de resíduos vegetais em sistemas agrofloreais, no sul do estado do Espírito Santo. Dissertação de mestrado. 45p. Viçosa, MG, 2016.

RANGEL-VASCONCELOS, L. G. T; KATO, O. R; VASCONCELOS, S. S; OLIVEIRA, F. de A; **Acúmulo de biomassa e nutrientes de duas leguminosas arbóreas. Introduzidas em sistema de pousio na Amazônia**. Ciência Florestal, Santa Maria, v. 26, n. 3, p. 735-746, jul.- set. 2016.



RIBEIRO, J. P. B. et al. Sustainable agriculture in the Amazon: Agroforestry systems in Capitão Poço, Pará, Brazil. *Environmental Science and Pollution Research*, v. 27, n. 4, p. 3684-3695, 2020.

ROCHA, M. S. et al. Soil pH maintenance in agroforestry systems for organic orange production. *Soil Science Society of America Journal*, v. 83, n. 2, p. 432-441, 2019.

RODRIGUES, A.C.G. Ciclagem de nutrientes em sistemas agroflorestais na região tropical: Funcionalidade e Sustentabilidade. In: MULLER, M.W.; RODRIGUES, A.C.G.; BRANDÃO, I.C.F.L.; SERÓDIO, M.H.C.F., (eds.) **Sistemas agroflorestais, tendência da agricultura ecológica nos trópicos: sustento da vida e sustento de vida**. Ilhéus: CEPLAC, 2004. p. 67-88.

RONQUIM, C.C. Conceitos de fertilidade do solo e manejo adequado para as regiões tropicais / Carlos Cesar Ronquim. – Campinas: Embrapa Monitoramento por Satélite, 2010. 26 p.: il. (Embrapa Monitoramento por Satélite. Boletim de Pesquisa e Desenvolvimento, 8).

SILVA, D. C. DA; SILVA, M. L. N; CURI, N; OLIVEIRA, A. H; SOUZA, F. S. DE; MARTINS, S. G; MACEDO, R. L. G. Atributos do solo em sistemas agroflorestais, cultivo convencional e floresta nativa. *Revista de estudos ambientais (Online)* v.13, n. 1, p. 77-86 jan./jun. 2011.

SILVA, I. R. da, MENDONÇA, E. de S. matéria orgânica do solo. In: NOVAIS, R.F.; ALVAREZ V., V.H.; BARROS, N.F.; FONTES, R.L.F.; CANTARUTTI, R.B.; NEVES, J.C.L. (Eds). *Fertilidade do solo*. Viçosa, MG: Sociedade Brasileira de Ciência do Solo, 2007. 1017p.

SILVA, M. S. C. da; SILVA, E. M. R. da; PEREIRA, M. G; SILVA, C. F da. **Estoque de serapilheira e atividade microbiana em solo sob sistemas agroflorestais**. *Floresta e Ambiente*. 2012, vol.19, n.4, pp.431-441.

SILVA, M. S. C da; MARIA ELIZABETH FERNANDES CORREIA, M. E. F; SILVA, E. M. R. da; MADDOCK, J. E. L PEREIRA, M. G; SILVA, C. F da. Soil Fauna Communities and Soil Attributes in the Agroforests of Paraty. *Floresta e Ambiente* 2016; 23(2) p. 180-190.

SILVA, A. B.; Santos, R. H. S. Organic orange production and its sustainability on a Yellow Latosol in São Paulo State, Brazil. *Revista Brasileira de Fruticultura*, v. 40, n. 1, e-349, 2018.

SILVEIRA; N. D; PEREIRA, M. G; POLIDORO, J. C; TAVARES, S. R DE L; MELLO, R. B. Aporte de nutrientes e biomassa via serrapilheira em sistemas agroflorestais em Paraty (RJ). *Ciência Florestal*, Santa Maria, v. 17, n. 2, p. 129-136, abr-jun, 2007.

VELOSO, A. C. V. Citros (laranja, limão e tangerina). Cap 7. 2007 . In: CRAVO, M. da S.; VIÉGAS, I. de J. M.; BRASIL, E. C. **Recomendações de adubação e calagem para o estado do Pará**. Embrapa Amazônia Oriental. 2007. 1ª eds. p. 221-224.

XAVIER, D. F; LÉDO, F. J. S; PACIULLO, D. S. C, URQUIAGA, S; ALVES, B. J. R; BODDEY, R. M. Nitrogen cycling in a Brachiaria based silvopastoral system in the Atlantic forest region of Minas Gerais, Brazil. 2014. *Nutr Cycl agroecosyst* 99: 45-62.

YOUNG, 1989. *Agroforestry for soil conservation*. Wallingford: C.A.B. International. 276p