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Soil Chemical Attributes under Agrosilvopastoral Systems and Pasture

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Abstract
Agrosilvopastoral systems involve the consortium of trees, agricultural crops, and pasture, in the same area, concomitant or sequential, based on agroecological bases and on the cycling of organic matter and nutrients. This research compares soil fertility under pasture and agrosilvopastoral system. The area of 5 ha, is located on the Campus of the Federal University of Viçosa in Florestal city, central region of Minas Gerais state, formed by *Urochloa decumbens* for about 30 years, in an argisolic dystrophic Red Yellow Latosol. Two agrosilvopastoral systems - in single lines 2 x 10 m and double lines 2 x 2 + 10 m - were compared with pasture without trees. The soil preparation was conventional, with ploughing and leveling grids, in December 2009. Seedlings of the hybrid *Eucalyptpus urophylla* and *E. grandis*, clone GG100, were planted in level and subsoiler lines, which received 500 kg ha^{-1} of reactive phosphate at a depth of 0.5 m. At planting, each seedling received 120 g of N:P:K 10:28:06 + 0.3% B + 0.5% Zn; and 120 g of N:P:K 20:00:20, at 60 days. The corn was sown in the alleys, receiving 360 kg ha^{-1} of N:P:K 08:28:16 + 0.5% Zn, at planting, and 240 kg of urea ha^{-1}, at 30 days. After the corn harvest, the pasture was formed naturally from the seed bank. At 135 months post-planting, five composite soil samples were collected in each studied area, obtained from ten simple samples of the 0-5 cm layer. The following attributes were analyzed: pH, P, K, Ca, Mg, Al, H + Al, OM, and Prem. The results were submitted to analysis of variance and F test (p,0.05), and the means of the significant treatments were compared by the Scott Knott test ($p<0.05$). Both APS provided an increase in the levels of OM, P, Ca, SB, t, and H + Al in the soil, keeping unchanged the other attributes analyzed in relation to conventional pasture. No significant differences in fertility were detected between the two agrosilvopastoral systems studied.

Keywords
Agroforestry systems — Crop-livestock-forest integration — Wooded pasture — Soil fertility

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1. Introduction

Brazilian agribusiness faces the challenge of producing more food without increasing the area of deforestation. In the Amazon alone, the area of pastures grew by 200% between 1985 and 2020. Brazil has 154.7 Mha of hectares of pasture, more than half of which have a certain degree of degradation, that is, 38 % intermediate and 14.3 % severe degradation (Mapbiomas, 2021; Santos et al., 2022).

In this context, it is also worth mentioning that the technical standards of the Green Revolution, which emerged after the Second World War (Industrial Agriculture), in addition to immensely increasing the appropriation of natural resources, also distanced agricultural activities from the ecological processes responsible for the environmental and functional integrity of the planet and ecosystems, promoting negative impacts of great magnitude on soil, water and the atmosphere. Currently there is a broad worldwide consensus that this productive model is exhausted, since it deteriorates the biophysical basis necessary for its own reproduction (Petersen et al, 2009).

In addition, the livestock sector contributes 14.5% of global greenhouse gas emissions (Rojas-Downing et al., 2017). Therefore, the recovery of degraded pastures is an excellent option for a more productive, sustainable, and low-carbon livestock (Resende et al., 2020). Appropriate combinations of crops, animals, and trees in agroforestry systems can not only increase agricultural yields, but also capture carbon and greater ecological, economic, and social resilience in the face of climate change, because the components of the system and

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their interactions will respond differently to environmental disturbances (Dawson et al., 2013).

”An agrosilvopastoral system integrates agricultural, livestock and forestry activities in the same area, in consortium, succession or rotation, in the search to obtain synergistic effects between the components, environmental adequacy, valorization of man and economic viability” (Balbino et al., 2011). This system has been consolidating itself as one of the most promising and sustainable alternatives for the recovery of degraded pasture areas, because in addition to the pasture reform, it also provides the production of grains and forest products, and can be implemented in all regional conditions of Brazil (Macedo et al., 2019a;b), including being one of the Brazilian proposals taken to COP 27 – 2022, in Egypt.

A point that deserves to be highlighted is the potential for sustainability provided by the adoption of an agrosilvopastoral system. Considering the concept of sustainable development in the Brundtland Report, prepared by the United Nations World Commission on Environment and Development in 1987, the Food and Agriculture Organization of the United Nations *(*FAO) proposed the concept of sustainable agriculture and rural development (FAO, SARD) (Hardaker, 1997), as being the ”management and conservation of the natural resource base and the technological and institutional orientation in order to ensure the continuous satisfaction of the human needs of present and future generations, establishing that sustainable development in agriculture implies the conservation of land, water, animal and plant genetic resources, without degrading the environment, in a technically appropriate, economically viable and socially acceptable manner” (Basso, 2014).

In general, the term sustainability is based on the idea of sustained yield, that is, a condition that allows harvesting biomass from an agroecosystem in perpetuity, so that its resilience is not compromised. However, perpetuity can never be demonstrated in the present, as proof of sustainability will always be in the future, out of reach, making it impossible to know with certainty whether a particular practice or model is sustainable (Gliessman, 2014). However, sustainability can be assessed by monitoring several factors in an agroecosystem (Daniel et al., 2001), such as the preservation and/or reconstruction of soil fertility, the prevention of erosion and the maintenance of ecological balance and soil health.

”Sustainability implies minimal dependence on external agrochemical and energy inputs, where ecological interactions and synergisms between the biological components of the agroecosystem themselves create soil fertility, crop productivity and protection, complementarity in resource use, interspecific facilitation and changes in resource partitioning, and temporal complementarity, spatial and eco physiological” (Altieri, 2004).

The insertion of the tree component in the pasture provides microclimatic improvement and contributes to the pasture remaining green and palatable for longer, including in the dry season. In this way, in addition to reducing environmental impacts, it favors animal welfare, providing shade and thermal comfort (Pulrolnik et al., 2019). On the other hand, trees contribute to the increase of organic matter and the cycling of organic matter and nutrients in the soil-plant system (Freitas et al., 2013), in addition to the short, medium, and long-term economic return - green forest savings (Macedo et al., 2019b). In the agrosilvopastoral system, the tree component functions as a negentropic element (Fantappiè, 2011), that is, it contributes to the balance and to the organizational and syntropic development of the agroecosystem (Nair, 1993).

The species with the greatest potential for use in the agrosilvopastoral system in Brazil is eucalyptus, due to its rapid growth, the supply of seeds, clones and seedlings adapted to various edaphoclimatic conditions, having a thin and narrow canopy and the possibilities of generating products for multiple uses, timber and non-timber (Macedo et al., 2019b; Melotto et al., 2019).

In this context, this research focuses on sustainability from the perspective of the chemical attributes of the soil (fertility) resulting from the insertion of the tree element in the agrosilvopastoral system, providing an increase in the cycling of organic matter (OM) and nutrients, where the material from the tree component, added to that of the forage component, surpasses the latter, when in isolation (Freitas et al., 2013).

Research on the effects of nutrient cycling on soil fertility in agrosilvopastoral systems is scarce, notably because it is a recent model in Brazil (Bungenstab et al., 2019), and whose effective results require a relatively long period of time, from at least one to two decades (Macedo et al., 2019b).

In the bibliographic research on this topic, the literature reports improvement of soil fertility by the agrosilvopastoral system, such as Freitas et al. (2013), Carvalho et al. (2015), Guardiola et al (2016), Frazão & Freitas (2022) and Tsufac et al. (2021), when compared to conventional pasture systems, while others present adverse results (Freitas et al., 2019; Veloso et al., 2016), or even absence of effect (Silva Junior et al., 2021; Melo et al., 2013, 2014; Freitas et al., 2019). However, it was commonly observed the trend of increase in the contents of organic matter (OM) and some nutrients in the soil. It is worth noting, however, that differences in age, density, spacing and planting arrangement, tree species, edaphoclimatic condition, history of use of the area, depth of soil sampling, make comparisons and generalizations of the results difficult.

Considering it to be one of the most relevant points for the sustainability of the agroecosystem, this research aims to evaluate and compare the chemical attributes of the soil between different agrosilvopastoral systems and with conventional pasture without trees. ”The greater litter deposition and addition of nutrients resulting from the introduction of the tree component in agricultural systems can help improve the chemical properties of the soil, highlighting the cycling and nutrient intake, providing nutritional quality of the pasture, reflecting on the animal support capacity in the agrosilvopastoral system (Ribeiro et al, 2022).

Two hypotheses are considered: (i) the agrosilvopastoral system provides improvement in soil fertility compared to conventional pasture without trees; (ii) the agrosilvopastoral system with a higher number of trees per unit area presents better soil fertility in relation to the one with lower density.

2. Material and Methods

The study area is a Demonstration Unit (DU) of agrosilvopastoral system, implemented in the Forestry Campus of the Federal University of Viçosa (UFV) in December 2009. The area has about 5 ha, being originally covered by Montana Semideciduous Seasonal Forest and transformed into pasture with *Urochloa decumbens* (Stapf) R.D. Webster, about 30 years ago. The geographical coordinates of the site are 19º46'36.19”S and 42º 56'16.72”W. The pasture area of the DU was reformed using different arrangements of agrosilvopastoral systems with eucalyptus and corn, and conventional pasture plots without trees, which received only the planting of corn (agropastoral system).

The camp us of UFV is located in the municipality of Florestal, in the central region of the state of Minas Gerais (Figure 1); with altitude between 686 and 1,271 m, average of 815 m; maximum average annual temperatures of 28.0ºC, minimum of 14.4ºC, average annual precipitation of 1,393 mm year^{-1} (INMET, Climatological Normal of 1981-2010) and tropical climate of altitude Cwa, according to the Köppen classification. The relief of the municipality is characterized as 9 % flat, 20 % gentle undulating, 54 % undulating and 17 % mountainous, according to the Institute of Applied Geosciences of Minas Gerais (IGA-MG). The predominant vegetation cover is Semideciduous Seasonal Forest, according to the Economic Ecological Zoning of Minas Gerais (ZEE-MG).

The object of the research was to evaluate two models of agrosilvopastoral system, planting arrangements in single lines, with spacing of 2 x 10 m (2 m between plants and 10 m between planting lines), totaling 500 trees ha^{-1} (SAF1), and arrangement in double lines, with spacing 2 x 2 + 10 m (2 m between plants and between double lines and 10 m between rows) making up 833 trees ha^{-1} (SAF2), and addition to a plot of conventional pasture without trees, refurbished using an agropastoral system. Each treatment occupies an area of 50 x 50 m.

To receive eucalyptus planting, level lines were demarcated, subsoiled at 0.5 m depth and 500 kg of reactive natural phosphate per hectare were applied in the subsoiled furrows. The reactive natural phosphate has 24 % total P_2O_5, being 4 % soluble in citric acid, in addition to 23 to 27 % of Ca (CFSEMG, 1999), in addition to the physical characteristics of passing 100% in the 4.8 mm sieve (ABNT N0 4) and 80 % in the 2.8 mm sieve (ABNT Nº 7) (Lopes, 1999).

The soil of the area belongs to the argisolic dystrophic Red Yellow Latosol class, according to the Brazilian Soil Classification System (Santos et al., 2018). The land was prepared using ploughing grid and leveling grid, being built a system of terraces in level, with the use of reversible plow of three discs.

Seedlings of the hybrid urograndis (*Eucalyptpus urophylla* S. T. Blake and *Eucalyptus grandis* W. Hill), clone GG100, were planted in pits in the subsoiled furrows. At the time of planting, each seedling received 120 g of the formulation N:P:K 10:28:06 + 0.3 % B + 0.5 % Zn and, subsequently, 120 g of N:P:K 20:00:20, at 60 days.

In the alleys between the eucalyptus rows, fertilization was used according to the need of the corn crop, following the recommendations of the Soil Fertility Commission of the State of Minas Gerais (CFSEMG, 1999). In the area in question, 360 kg ha^{-1} of N:P:K 08:28:16 + 0.5% Zn were applied at planting, and 240 kg of urea ha^{-1} at 30 days. After the corn harvest, the pasture was formed naturally, from the seed bank of *U. decumbens*, pre-existing of the area. Beef cattle of the Nellore breed were reintroduced to the area after 12 months after the pasture reform.

After 135 months of planting, five composite soil samples were collected in each of the three systems studied, totaling fifteen samples. Each composite sample was obtained from the mixture of ten simple samples, collected at a depth of 0-5 cm, as recommended by CFSEMG (1999) for pastures formed. Samples were collected using a tubular soil sampler in stainless steel 70 x 22 x 2.5 cm.

The chemical attributes of the soil analyzed were: pH in water ratio 1:2.5 (soil: water); exchangeable Al, Ca and Mg, extracted with KCl 1 mol L^{-1}, with Al determined by titration with 0.025 mol L^{-1} NaOH; and Ca + Mg by titration with 0.0125 mol L^{-1} EDTA; P and K available in Mehlich 1 extractor and determined by colorimetry and flame photometry, respectively; organic matter (OM) by wet digestion and dichromatometry in an acidic medium;

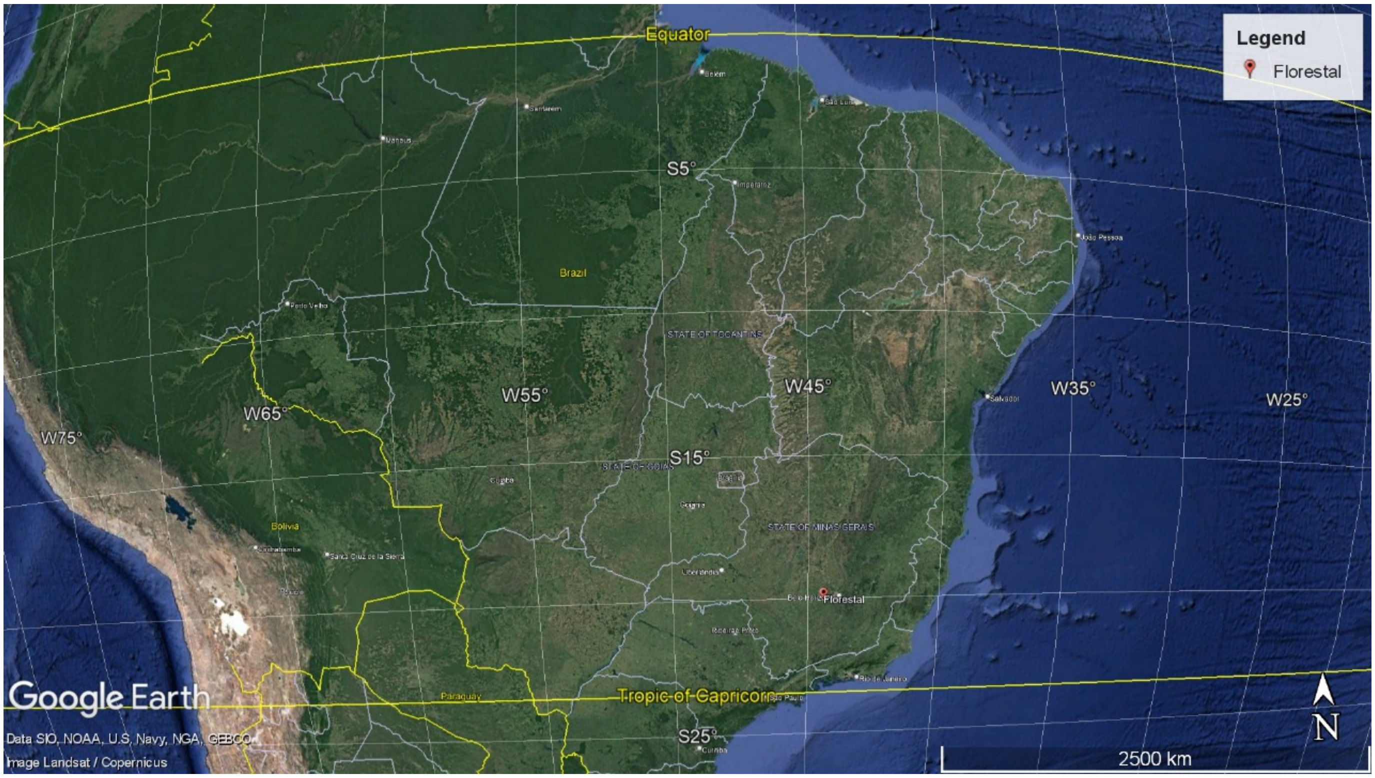

Figure 1. Location of the Agroforestry Systems Demonstration Unit in the municipality of Florestal - MG Source: Google Earth

potential acidity (H + Al) by the $Ca(OAc)_2$ 0.5 mol L^{-1} method at pH 7; P remaining as the P concentration of the equilibrium solution, after agitation for 1 h of 5 cm^3 of TFSA in 50 mL of $CaCl_2$ solution 10 mmol L^{-1}, containing 60 mg L^{-1} of P. The analysis of soil samples was conducted at the Soil Laboratory of the Viçosa Campus of UFV, following the methodologies described by Teixeira et al. (2017).

From the results of the soil analyses, the following were calculated: sum of bases (SB) = Ca + Mg + K+ Na; effective cation exchange capacity (t) = SB + Al; cation exchange capacity at pH 7 (T) = SB + (H + Al); aluminum saturation (m) = 100 Al/t; and base saturation (V) = 100 SB/T.

The data of the chemical attributes of the soil studied were submitted to analysis of variance, and those whose F test was significant ($p<0.05$), the means were compared by the Scott Knott test ($p<0.05$). Statistical analyses were performed using the SISVAR software (Ferreira, 2014).

After 11 years and 3 months of the implementation of the Demonstration Unit it was possible to observe significant differences in the chemical attributes of the soil under the conventional pasture without trees and the agrosilvopastoral systems (Table 1). Both agrosilvopastoral systems provided higher levels of OM, P, Ca, and H + Al in the soil, as well as elevation in and SB and t, keeping unchanged the other chemical attributes studied.

On the other hand, no significant difference in soil fertility was detected between the two agrosilvopastoral systems. Therefore, the higher density of trees did not promote a more pronounced effect on soil fertility, despite the greater amount of litter deposited in the denser spacings (Silveira et al., 2014). However, it is worth mentioning the most expressive values of variability (CV $>$ 20%) for the K and Mg attributes, which, in a way, may have compromised the detection of statistically significant differences between the two agrosilvopastoral systems.

The higher levels of OM in the soil indicate the role of the tree component in the cycling process in the agrosilvopastoral systems, and that the decomposition of OM promotes the release of nutrients (Abbadiko & Mulugeta, 2018; Freitas et al, 2020), as can be proven through the higher levels of Ca and P in the soil, promoting the elevation of the sum of exchangeable bases (SB).

The increase in potential acidity (H + Al) observed in agrosilvopastoral systems may be associated with H^+ ions dissociated from carboxylic and phenolic radicals of OM, but this did not affect soil pH. On the other hand, the increase in effective CTC (t) was probably due to

Table 1. Chemical attributes of a Red Yellow Latosol under agrosilvopastoral systems and conventional pasture at 135 months of planting.

System	pH	P	K	Ca	Mg	Al	H + Al
	H2O	mg dm-3		cmolC dm-3			
SAF1 (2x10)	4.6 a	5.0 a	50.4 a	1.41 a	0.38 a	1.52 a	11.64 a
SAF2 (2x2+10)	4.6 a	4.4 a	68.0 a	1.49 a	0.44 a	1.44 a	11.74 a
Pasture	4.6 a	2.9 b	60.0 a	0.92 b	0.39 a	1.37 a	9.72 b
CV (%)	2,70	23,35	28,78	15,61	23,22	14,44	5,97

System	SB	t	T	V	m	OM	Prem
	cmolC dm-3			%		dag kg-1	mg L-1
SAF1 (2x10)	1.91 a	3.43 a	13.5 a	14.1 a	44.3 a	5.31 a	15.86 a
SAF2 (2x2+10)	2.10 a	3.54 a	13.8 a	15.1 a	41.1 a	5.72 a	15.68 a
Pasture	1.49 b	2.85 b	11.2 a	13.5 a	48.0 a	4.76 b	17.22 a
CV (%)	16,83	4,82	4,16	18,80	16,86	7,63	9,69

The means followed by the same letter in the columns do not differ statistically from each other by the Scott Knott test at the 5% level.
CV = coefficient of variation; SB = sum of bases = Ca + Mg + K + Na; t = effective CTC = SB + Al; T = CTC pH 7 = SB + H + Al;
m = % saturation Al = 100 Al/t; V = % base saturation = 100 SB/T; OM = organic matter; Prem - remaining phosphorus.

the increase in OM content, since the colloidal organic fraction of humic substances presents high CTC (1,500 to 5,000 $mmol_c$ dm^{-3}), values much higher than those of soil mineral colloids, such as kaolinite (50 to 150 $mmol_c$ dm^{-3}) and Fe and Al oxides (20 to 50 $mmol_c$ dm^{-3}) (Ronquim, 2020).

The increase in P and Ca levels in the soil can be related to the application of reactive natural phosphate in the tree planting lines (500 kg ha^{-1}), and these nutrients are absorbed by the roots and redistributed throughout the area of the agrosilvopastoral systems, through the burlap cycling process. Allied to this, the greater volume of soil exploited by the roots of the trees certainly may also have contributed to the increase of nutrient cycling in the soil-plant system.

In a study comparing litter deposition and soil nutrients in agrosilvopastoral systems with *U. decumbens*, corn and eucalyptus, Freitas et al. (2013) verified higher relative litter deposition of forage litter in pasture without trees, and greater deposition of total litter (forage + trees) and nutrients in agrosilvopastoral systems, corroborating the hypothesis that can contribute to the recovery of degraded pastures and provide less dependence on external inputs (Daniel et al., 2001; Silva Lima et al., 2021).

It is worth noting, however, that trees grow, absorb from the soil, and accumulate nutrients in their biomass. Until the closure of the canopy and the formation of the canopies, there is a greater contribution of nutrients from the soil to the biomass of the trees, but the following years are characterized by the efficient internal recycling of nutrients in the trees, which implies a faster return of nutrients to the soil stock, that is, in the medium and long term the biogeochemical cycle of nutrients tends to increase fertility under agrosilvopastoral systems and the sustainability of the nutrients of the site (Onyekwelu et al., 2011).

A study carried out in Itatinga, in southern Brazil, in a stand of *E. grandis* 3 x 2 m (1,667 trees ha^{-1}), observed a higher flow of soil nutrients directed to the formation of the canopy in the first two years, and to total biomass production from then on, and the requirements of N, P, K, Ca and Mg were maximum in the second year after planting. The study highlighted the primary role of the biogeochemical nutrient cycle in highly weathered and very deep tropical soils (>12 m) in maintaining and sustaining site fertility (Laclau et al., 2010).

The cycling of nutrients in the agrosilvopastoral systems is potentiated by the exploitation of a greater volume of soil and by the depth of fine roots of the trees, up to 10 m deep in the soil profile, reducing nutrient losses by leaching and contributing to maximize the exploitation of the nutrients available at the site via weathering (Laclau et al., 2013). The exploitation of deeper layers in the soil profile by the root system of the trees and the deposition of litter, it gradually incorporates nutrients into the soil and can provide sustainable fertility over time (Nair, 1993). This fact was not verified in the present study, due to the short interval (11 years) of evaluation, but only the P and Ca levels increased, due to fertilization with natural phosphate in the eucalyptus planting lines. On the other hand, the presence of trees did not promote a reduction in the availability of nutrients to forage, as reported by other authors, such as Freitas et al. (2019) and Veloso et al. (2016).

However, although no statistically significant differences were detected in soil chemical attributes between the two agrosilvopastoral systems studied. SAF2 (833 trees ha^{-1}) tended to present higher levels of K and Mg in relation to SAF1 (500 trees ha^{-1}) and pasture without trees (Table 1). These trends point to a possible better performance of SAF2, with double lines and higher density of trees, in relation to SAF1 with single lines, due to the greater litter deposition and nutrient cycling over the years (Freitas et al., 2013; Silva et al., 2018).

Additional relevant information refers to wood production by the studied agroforestry systems. Braga et al. (2022) estimated that SAF1 accumulated 365.60 m^3 ha^{-1} of commercial wood (diameter $<$ 5 cm), 300.00 for sawmills and 65.60 for posts, while SAF2 produced 548.83 m^3 ha^{-1}, being 422.40 for the sawmill and 116.43 for fence posts.

Considering that OM is an efficient indicator in the evaluation of soil quality and sustainability, as it affects its physical, chemical and biological properties (Parron et al., 2015), the present research shows that the tree component in the agrosilvopastoral systems is important, as it provides the addition of OM and promotes the cycling of nutrients, associated with the continuous deposition of litter (SILVA et al., 2018) and the continuous enrichment of the soil, reducing dependence on external inputs and making the system more self-sustaining (Laclau et al., 2010).

3. Conclusion

In comparison with conventional pasture without trees, sum of bases promoted the elevation of OM contents and nutrient cycling and the elevation of P and Ca contents in the soil of pasture, due to the application of natural phosphate in the eucalyptus planting lines. There was also an increase in sum of bases (SB), effective CTC (t) and potential acidity (H + Al). The other chemical attributes of the soil studied remained unchanged.

No significant differences were observed between soil chemical attributes between sum of bases with single lines or double lines.

It is suggested to continue monitoring the chemical attributes of the soil to evaluate possible future changes in soil fertility resulting from the cycling of OM and nutrients in the long term, including at different depths in the soil profile.

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