Acta Agronómica
ISSN: 0120-2812
ISSN: 2323-0118
Universidad Nacional de Colombia

Zin Battisti, Luiz Fernando; Schmitt, Abdon Luiz;
Loss, Arcángelo; Sinisgalli, Paulo Antonio de Almeida
Soil chemical attributes in a high biodiversity silvopastoral system
Acta Agronómica, vol. 67, no. 4, 2018, October-December, pp. 486-493
Universidad Nacional de Colombia

DOI: https://doi.org/10.15446/acag.v67n4.70180

Acta Agron. (2018) 67 (4) p 486-493 ISSN 0120-2812 | e-ISSN 2323-0118 *https://doi.org/10.15446/acag.v67n4.70180*

Soil chemical attributes in a high biodiversity silvopastoral system

Atributos químicos del suelo en un sistema silvopastoril de alta biodiversidad

Luiz Fernando Zin Battisti[1,5], Abdon Luiz Schmitt Filho[2,4,5*], Arcângelo Loss[2,5], Paulo Antonio de Almeida Sinisgalli[3,5]*

1-Master's Degree Program in Agroecosystem, University of Santa Catarina (PGA/UFSC), Florianópolis, Brazil. 2-Professor at Master's and Doctoral Degree Program in Agroecosystem, University of Santa Catarina (PGA/UFSC), Florianópolis, Brazil. 3-Professor at Master's and Doctoral Degree Program in Environmental Science, University of Sao Paulo (PROCAM/USP), Brazil. 4-Gund Institute for the Environment, University of Vermont (GUND/UVM). 5-Silvopastoral Systems and Ecological Restoration Lab (LASSre/UFSC). *Author for correspondence: abdonfilho@hotmail.com, lfernandobattisti@hotmail.com

Rec.: 01.02.2018 Acep.: 28.09.2018

Abstract

The use of conservation managements such as the silvopastoral system, and the Voisin rational grazing system have been excellent alternatives to increase animal welfare and production efficiency and improve soil chemical attributes of degraded pastures. Therefore, the objective of this work was to evaluatethe effect of a High Biodiversity Silvopastoral System (SPSNUCLEUS) on the soil chemical attributes through comparisons with soils of a Intensive Grazing Management without trees (IGM), primary forest, and secondary forest areas. Total organic carbon, total nitrogen, pH, Al, H+Al, Ca, Mg, K, and P were evaluated after four years of implementation of SPSNUCLEUS. Soil samples from the layers 0-5, 5-10, 10-20, 20-30, and 30-40 cm were collected in all areas—SPSNUCLEUS, MIG, primary forest, and secondary forest. SPSNUCLEUS had better soil quality, with increased P and K contents (0-30 cm), compared to the other areas, and higher total organic carbon,and total nitrogen contents (5-30 cm) when compared to the MIG and secondary forest areas. The soil carbon accumulation capacity in the SPSNUCLEUS area in the layers of 5-10 cm and 20-40 cm was similar to that of the primary forest area, and higher to those of the other areas. SPSNUCLEUS proved to be a promising system to improve the soil chemical attributes of pastures.

Keywords: Organic carbon; Nitrogen; Tree component; Voisin rational grazing; Soil fertility.

Resumen

La utilización de sistemas de manejo conservacionistas como los sistemas silvopastoriles y el pastoreo racional Voisin se han mostrado óptimas alternativas para promover mayor bienestar animal, aumentar la eficiencia del sistema de producción y mejorar los atributos químicos de los suelos de pastoreo degradados. En este sentido, este trabajo evaluó el efecto del Sistema Silvopastoril con Núcleos arbóreos de alta biodiversidad (SSPNÚCLEOS) en la dinámica de los atributos químicos del suelo, comparando con pastoreo racional Voisin sin árboles (PRV), áreas de bosque primario y bosque secundario adyacentes. En el presente estudio se evaluaron los niveles de carbono orgánico total, nitrógeno total, pH, Al, H + Al, Ca, Mg, K y P. Se muestrearon en las capas de 0-5, 5-10, 10- 20, 20-30 y 30-40 cm el suelo de las áreas con SSPNÚCLEOS, PRV, bosque primario y bosque secundario. El SSPNÚCLEOS presentó mejoras de la calidad del suelo, aumentando los niveles de P y K (0-30 cm) en relación a los demás tratamientos, así como mayores niveles de carbono orgánico y nitrógeno (5-30 cm) en relación al PRV y bosque secundario. En cuanto a la capacidad de acumulación de carbono, en las capas de 5-10 cm y 20-40 cm, el SSPNÚCLEOS se igualó el área de bosque primario, pero fue superior a los demás tratamientos. El SSPNÚCLEOS se mostró prometedor para mejorar los atributos químicos de los suelos de pastoreo.

Palabras claves: Carbono orgánico; Nitrógeno; Componente arbóreo; Pastoreo racional Voisin; Fertilidad del suelo.

Introduction

The Atlantic Forest biome was severely deforested, mainly to enable the establishment of agriculture, since planted pasture areas cover 20% of the area of this biome (Mapbiomas, 2017). Most of these pastoral areas have low production due to conventional soil management, which is inadequate due to the dependence on soluble fertilizers, annual soil turning for pasture replanting, and grain monocultures, such as maize, for silage production (Alvez et al., 2013).

A solution to these problems generated because of the use of conventional soil management in pastoral areas is the use of rotational pasture managements, such as the Voisin rational grazing system. It is a pastoral system based on the division of the pasture into paddocks (Hanson et al; 2013). Although rotating grazing systems have several benefits, paddocks impede the free access of the herd to shaded areas; this is an intrinsic limitation of rotational managements.

A rotational management combined with silvopastoral systems is an interesting alternative for pasture-based milk production; this system was responsible for the growth of the dairy industry in the South region of Brazil (EPAGRI/CEPA, 2017). The thermal comfort of the animals promoted by the arboreal vegetation promotes a more stable milk production, since thermal stress caused by sun exposure causes reductions in milk production of up to 25%, and reproductive and health problems in the animals (Fisher et al; 2008).

In this context, the Laboratory of Silvicultural Systems and Ecological Restoration of the Federal University of Santa Catarina (LASSre/UFSC) has been developing a High Biodiversity Silvopastoral System (SPSNUCLEUS). This system was developed by combining the patching theory for the restoration of forest areas with principles of rotational pasture managements and silvopastoral systems that recommend the planting of forest species in pasture areas. SPSNUCLEUS has been implemented in a participative way with family farmers of milk farms that used Management Intensive Grazing without trees (MIG) since 2011.

This system makes the production more complex by diversifying the landscape, which affects ecological processes and, consequently, the soil quality at temporal and spatial scales (Ghaley et al; 2014).This diversification, obtained by adding the tree component to the landscape, has improving physical, chemical, and biological attributes of soils of pastures (Ghaley at al; 2014, Casals et al; 2014).Therefore, the objective of this work was to evaluate the effect of SPSNUCLEUS on the soil chemical attributes of pastures implemented in the Atlantic Forest biome through comparisons with soils of MIG, primary forest, and secondary forest areas.

Material and methods

Study area

The study was conducted in the municipality of Santa Rosa de Lima, southern state of Santa Catarina, Brazil (28°02'27"S, 49°07'4"W), which has an average altitude of 235 m (200 m to 1200 m). The climate of the region is subtropical humid with hot summer (Cfa),according to the Köeppen classification, with temperatures above 22°C in the summer, and precipitation greater than 30 mm in the driest month. Its total annual precipitation is 1400 to 1600 mm (Alvarez et al; 2013). The native vegetation consisted of a dense ombrophilous forest and some points of mixed ombrophilous forest (IBGE, 2015).

Four different pasture systems were evaluated: a High Biodiversity Silvopastoral System (SPSNUCLEUS), a Management Intensive Grazing without trees (MIG), a primary forest (F1), and a secondary forest (F2). All areas had undulating relief (slopes of 12% to 15%) and altitude of approximately 240 meters.The soils of the experimental area were formed from weathered granite and was classified as Inceptisol (Cambissolo Háplico) (EMBRAPA, 2013), and has silt loam texture (500 g/kg silt, 192 g/kg clay and 261 g/kg sand) in the 0-40 cm layer.

The experiment was conducted in a dairy family farm that represents well most farms of the South region of Brazil (EPAGRI/CEPA, 2017; Alvez et al; 2013).The pasture area had *Axonopus catharinensis* and *Hemarthria altíssima* grasses rotated in MIG since 1999—16 years before the experiment. This area had been seeded with *Avena sativa, Lolium multiflorum*, *Trifolium pretense*, and *Trifolium repens*every beginning of autumn to minimize the effects of low forage production during autumn and winter. These winter grasses and legumes had been seeded over the pastures systematically since the division of the area into paddocks (MIG). Before this division, the pasture soil had been subjected to liming to raise its pH in water to 5.5. Nitrogen fertilizer (urea; 50 kg/ha) was applied annually from 2009 to 2015. In 2012, SPSNUCLEUS was implemented in two hectares of the area that was under MIG (Figure 1).

SPSNUCLEUS is a silvopastoral system in which the tree element is added in 5 m x 5 m patches and arranged in the pasture paddocks. These tree patches are properly fenced and distributed equidistantly in the area and contain only native species of the local biome. The summed area of the tree patches is equivalent to 10% of the paddock total area. This system increases the biodiversity of the area, since 50 different native tree species —40 climaxes and 10 pioneers—is added per hectare, besides the naturalized forage grasses and legumes and native Melipona bees (Schmitt Filho et al., 2013).

Each SPSNUCLEUS paddock had, on average, six 25 m^2 tree patches (40 tree patches per hectare).Each tree patch consisted of four *Mimosa scabrella* seedlings, four seedlings of honey or fruit species, eight *Euterpe edulis* seedlings, and a distinct climax species. The MIG and SPSNUCLEUS areas were side by side (Figure 1). The areas with native primary and secondary forests that were used as comparative parameters were adjacent to the MIG and SPSNUCLEUS areas. F1 consisted of a primary dense ombrophilous forest of 6 hectares, predominantly composed of trees of the species *Alsophila setosa, Cyathea phalerata, Sloanea spp;* and *Ocotea spp*. This area represented the original soil condition of all areas (control). F2 consisted of a 15-years old secondary dense ombrophilous forest, predominantly composed of trees of the species *Alchornea triplinervia, Nectandra spp;*and *Byrsonima ligustrifolia*. The F2 area was previously used for plantations of successive maize (*Zea mays*) crops with conventional soil tillage—plowing and harrowing.

Soil sampling and analyses

Soil samples were collected in February 2016 to evaluate the total organic carbon (TOC), total nitrogen (TN) and soil fertility (pH, Al, H + Al, Ca, Mg, K, and P). Deformed soil samples were collected from the layers 0-5, 5-10, 10-20, 20-30, and 30-40 cm.Three simple soil samples to form a composite sample were collected in each area, with six replications.A simple soil sample was collectedat the North, South, East, and West side of the tree patches in the SPSNUCLEUS area, at 2 m from the fence of the tree patches, and in the center of the tree patches, with six replications.

These five samples collected in each tree patch formed a composite sample of the SPSNUCLEUS soil. The soil sampling in the MIG area were performed following the same positions used in SPSNUCLEUS. In the forest areas (F1 and F2), samples were collected randomly at 500 meters from the forest border of each area (Figure 1).

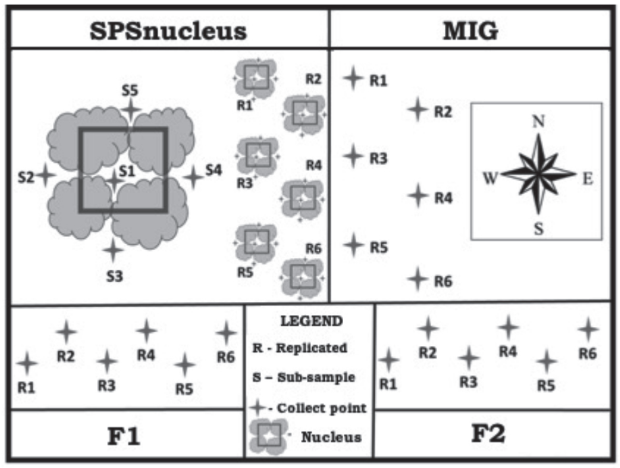

Figure 1. Schematic diagram of the soil sampling, with emphasis on the arrangement of collection points. Source: Luiz Fernando ZinBattisti (2016).

The samples were then taken to the laboratory, air dried, disaggregated, and sieved in a 2-mm mesh sieve, obtaining the air-dried fine earth, according methodology of Embrapa (1997). The pH in water, exchangeable Ca^{+2}, Mg^{+2}, Al^{+3}, H+Al, and available K^+ and P were determined in samples of air-dried fine earth from the 0-30 cm layer, according to EMBRAPA (1997).The TOC and TN contents of the soil (0-40 cm) were determined by the dry combustion method in a C and N auto analyzer at 900ºC (CHN-1000; Leco).

Statistical analysis

The data were analyzed for normality and homogeneity by the Lilliefors and Barttlet tests, respectively. Then, they were analyzed in a completely randomized design since the evaluated management systems were in the same topographic and edaphoclimatic conditions. The results were subjected to analysis of variance by the F test and the significant means were compared by the Tukey's test at 5% significance.

Results

TOC and TN contents in the soil

The highest TOC contents were found in the surface layers, decreasing with depth. SPSNUCLEUS and primary forest (F1) had the highest TOC contents in the 5-10, 20-30, and 30-40 cm layers.MIG had the highest TOC mean, and F2 had the lowest TOC mean in the first 5 cm of the soil (Figure 2).

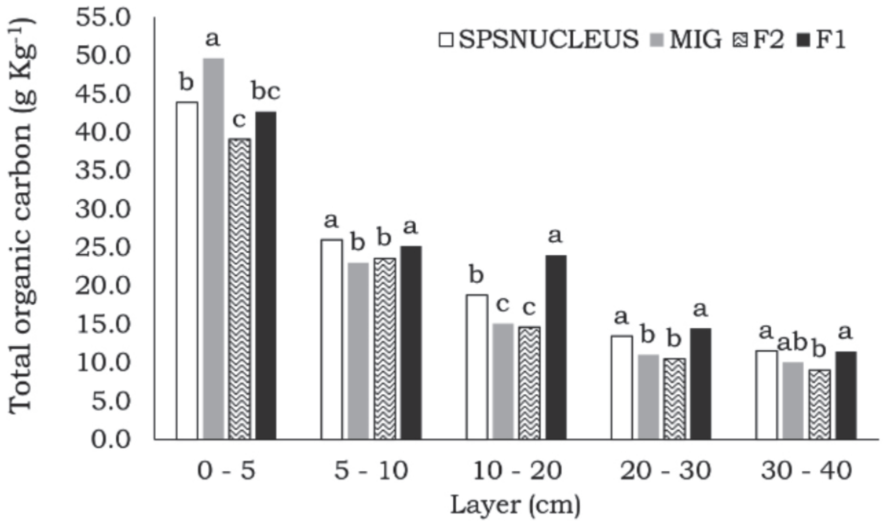

Figure 2. Total organic carbon contents in soils of different pasture management systems in Santa Rosa de Lima SC, Brazil. Means followed by the same letter in the bars are similar by the Tukey's test at 5% significance. SPSNUCLEUS = High Biodiversity Silvopastoral System, MIG = Management Intensive Grazing without trees, F1 = Primary forest, F2 = Secondary forest.

SPSNUCLEUS, MIG, and F1 had the highest TN contents in the first 5 cm of soil (Figure 3). F2 had the lowest TN contents, differing from the other areas. F1 had the highest TN contents from the depth of 5 cm, followed by SPSNUCLEUS, MIG, and F2. MIG had lower TN contents than F2 only in the 20-30 cm layer.

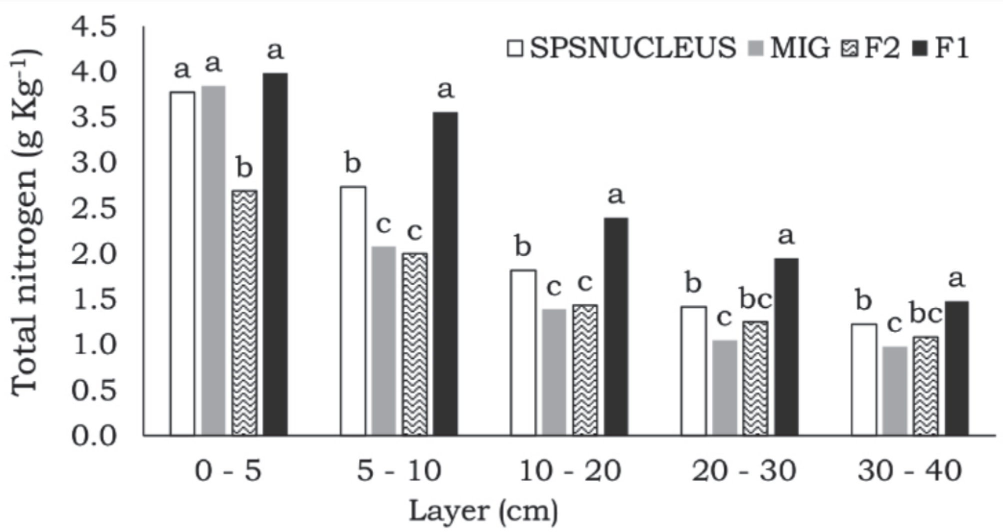

Figure 3. Total nitrogen contents in soils of different pasture management systems in Santa Rosa de Lima SC, Brazil. Means followed by the same letter in the bars are similar by the Tukey's test at 5% significance. SPSNUCLEUS = High Biodiversity Silvopastoral System, MIG = Management Intensive Grazing without trees, F1 = Primary forest, F2 = Secondary forest.

Soil fertility

The soil of the SPSNUCLEUS and MIG areas had the highest pH in all layers evaluated. F1 and F2 had the highest Al and Al+H, contents in all layers. MIG and SPSNUCLEUS had the highest Ca and Mg contents. SPSNUCLEUS had the highest K and P contents (Table 1).

continuous contribution and accumulation of plant residues to the soil as litter fall (leaves, fruits, branches) and roots; plant residues are the main contributors of organic C to the soil (Caldeira et al., 2008) the litter production represents the first stage of nutrients and energy transfer from the vegetation to the soil, because most of the nutrients absorbed by the plants comes back to the forest ground through the fall of the litter or leaves wash and for the collections of the accumulated litter five rectangular samples units (SU). This denotes the effect of the tree component on soil TOC content, and its importance in pastoral systems, since the highest TOC contents were found in areas containing trees. Soils of primary forest (F1) have high C contents and are not subjected to disturbances that degrade organic matter, thus, the input of C via litterfall, and root decomposition is continuous. The higher TOC contents of SPSNUCLEUS confirms the results of other studies that found higher C contents in soils near trees in silvopastoral

Table 1. Chemical attributes of soils of different pasture management systems in Santa Rosa de Lima SC, Brazil.

System	pH	Al	Al+H	Ca	Mg	K	P
		-------------- $cmol_c\ kg^{-1}$ --------------				-- $mg\ dm^{-3}$ --	
			0 – 5 cm soil layer				
SPSNUCLEUS	4.85 a	0.40 c	6.70 b	4.40 b	2.33 a	186.88 a	13.60 a
MIG	4.95 a	0.13 c	4.23 b	5.60 a	2.38 a	108.67 b	6.70 b
F2	3.98 b	2.85 b	21.33 a	0.78 c	0.90 b	47.50 c	3.25 b
F1	3.60 b	6.68 a	25.15 a	0.28 c	0.65 b	114.33 b	6.87 b
CV (%)	4.80	24.13	34.28	16.12	16.83	14.39	27.86
			5 - 10 cm soil layer				
SPSNUCLEUS	4.76 a	0.79 c	7.44 b	2.93 a	1.56 a	103.13 a	6.01 a
MIG	4.85 a	0.53 c	4.18 b	3.35 a	1.28 a	50.75 b	3.57 b
F2	3.88 b	3.65 b	20.73 a	0.33 b	0.43 b	29.25 c	2.35 b
F1	3.65 b	6.70 a	23.13 a	0.13 b	0.23 b	36.50 bc	3.67 b
CV (%)	6.14	19.13	14.41	34.22	21.95	15.94	17.03
			10 – 20 cm soil layer				
SPSNUCLEUS	4.38 a	1.34 c	7.84 b	1.46 a	0.95 a	61.34 a	2.52 a
MIG	4.73 ab	1.95 c	5.30 b	1.18 a	1.08 a	32.75 b	1.72 b
F2	4.05 bc	3.85 b	17.28 a	0.3 b	0.30 b	21.50 b	1.45 b
F1	3.78 c	6.48 a	18.18 a	0.10 b	0.15 b	25.00 b	1.85 b
CV (%)	7.50	21.09	15.50	36.84	29.23	20.86	26.18
			20 – 30 cm soil layer				
SPSNUCLEUS	4.68 a	2.13 b	8.49 b	0.93 a	0.64 a	45.46 a	1.30 a
MIG	4.65 a	2.00 b	6.50 b	0.80 a	0.58 a	17.33 b	0.78 b
F2	4.03 b	3.73 b	14.13 a	0.10 b	0.13 b	12.50 b	0.93 b
F1	3.90 b	5.85 a	16.25 a	0.10 b	0.13 b	17.75 b	1.65 a
CV (%)	5.68	24.28	13.00	48.08	29.48	12.57	31.21

Means followed by the same letter in the columns are similar by the Tukey's test at 5% significance. SPSNUCLEUS = High Biodiversity Silvopastoral System, MIG = Management Intensive Grazing without trees, F1 = Primary forest, F2 = Secondary forest. CV = coefficient of variation.

Discussion

Soil TOC and TN contents

The higher TOC content found in MIG in the first 5 cm of the soil may be due to the more homogeneous development of the grass roots in this system (Machado, 2004). MIG promotes root biomass production, which decomposes continuously, increasing C content in the first 5 cm of the soil (Corazza et al; 1999).

SPSNUCLEUS and F1 had the highest TOC contents from the depth of 5 cm due to the system compared to open pastures (Hoosbeek, et al., 2016).

The lowest TOC contents of F2 in the 0-5 cm layer may be connected to the soil management used before the natural vegetation reestablishing, which altered the soil fertility due to soil turning through plowing and harrowing, and planting of annual crops. According to Cardoso et al. (2010) the conversion of native forest to planted pastures, using soil turning, and continuous grazing, reducesthe organic C stocks of the soil.

According to the results,organic C tends to translocate to deeper depths in tropical forests. However, this deeply stored carbon is metabolized by the microorganisms when the system changes from forest to pasture, with eventual soil turning. C is concentrated on the soil surface after the pasture implantation, where the metabolization rate is very high; this results in a dynamic flow of organic C with constant input from the root decomposition. Contrastingly, C is reallocated to greater depths in SPSNUCLEUS, showing the potential of this system to store carbon. Moreover, C tends to be more stable in deeper layers because of lower disturbances.

F1 had the highest TN in all layers due to the absence of anthropogenic intervention, and the continuous input of litterfall in this area. This result is confirmed by the TN contents in depths lower than 5 cm, and TOC in the 10-40 cm layer in SPSNUCLEUS, MIG and F2, whichwere lower than those found in F1.These results were due to the C and N loss processes triggered by the deforestation occurred in these areas (SPSNUCLEUS, MI Gand F2) for agriculture purposes, with consequent soil turning and exposure of deeper soil layers, since these cultural practices cause oxidation of organic matter and decrease TOC and TN contents (Tivet, et al., 2013).

After the pasture formation, and reestablishment of the biocenosis in the soil, C and N accumulate in the soil surface layers, since TOC and TN contents in SPSNUCLEUS and MIGwere similar to those of the F1 in the 0-5 cm layer. Moreover, the soils of SPSNUCLEUS and MIG were covered with diversified pastures, with presence of N-fixing legumes. This C and N accumulation in the first centimeters of the soil was due to the contribution of fasciculate roots, and dead grass stems due to low light intensity (Loss et al;2014).

The tree patches had great effect on the soil TN content in layers deeper that 5 cm. SPSNUCLEU Shad higher TN contents than MIG in all layers, although the difference between these two areas was only the presence of tree patches. This result was probably due to the biodiversity of the areas, especially related to native N-fixing legume trees, such as *Mimosa scabrella* present in the tree patches (Coelho, et al., 2007). SPSNUCLEUS had higher TOC and TN contents in layers deeper than 5 cm when compared to MIG. Thus, the SPSNUCLEUS environment favors the accumulation of TOC due to the input of N, either by biological fixation or fertilizers; in addition, TOC does not increases when the amount of N is limiting for biological synthesis (Urquiaga, et al., 2005).

Soil fertility

SPSNUCLEUS and MIG had the highest pH, Ca, and Mg, and lowest Al, and H+Alcontents (Table 1) probably due to the liming at the MIG implementation to correct the soil acidity.The lower pH and higher H+Al contents of F1 and F2 may be due to the continuous litterfall deposition, which increases soil organic matter. This material is decomposed by the soil biota and can acidify the soil by releasing H^+ions through the release of low molecular weight organic acids, and specific reactions (Gonçalves, et al., 2012).

The higher Ca and lower Al, and H+Alcontents of SPSNUCLEUS and MIG was due to the liming and may also be connected to the input of cattle manure, which is composed of more than 0.5% of CaO. When the manure is evenly distributed in the soil, as in MIG and SPSNUCLEUS, it contributes more efficiently to the increaseof the soil pH. This occurs due to the H^+ consumption when it is dissolved in the soil solution, which increases the pH and reduces Al and H+ Alcontents (Whalen, et al., 2000).Galvão, et al., (2008) evaluated the effects of continuous application of cattle manure in different systems for 6, 15, and 40 years and found higher increases of Ca in the soil, and higher Ca contents in cattle manures when compared to Mg. The similarity between the Ca and Mg contents of SPSNUCLEUS and MIG was due to the similar fertilization and liming performed in these areas.

The highest phosphorus (P) contents were found in SPSNUCLEUS in all depths (Table 1) due to the input of P via litterfall. The roots absorb phosphorus from greater depths, and return to the soil when the leaves fall in the soil surface forming the litterfall, as observed by Casals et al. (2014) and Hoosbeek et al. (2016).

Moreover, the animal waste around the tree patches adds Pto the soil.Casals et al. (2014) evaluated parameters related to soil fertility in a silvo pastoral system in Nicaragua and found that the presence of 10-year-oldtrees in the system increased P, K^+, Ca^{+2}, TOC, and TN in the first 10 cm of the soil under the canopy when compared to open pasture. Hoosbeek, et al., (2016) evaluated the soil fertility of the 0-20 and 20-40 cm layers of areas below the tree canopy, adjacent to the tree canopy, and at open pasture, in asilvopastoral system with sparse trees over 50 years old in Nicaragua. Their results showed greater P content at the 0-20 cm layer in the area adjacent to the canopy compared to the open pasture and below the canopy of the trees; the presence of trees also increased C and N contents, and availability of nutrients to plants due to the litterfall produced, confirming the results found in the present study.

SPSNUCLEUS had the highest K contents in all layers probably due to the cattle urine around the tree patches. K is eliminated in greater proportion by urine, unlike P, Ca and Mg, which are excreted in larger proportions in the feces, and N,which is excreted in urine and feces (Haynesand Williams, 1993). K contents was also affected by the litterfall, since K is the macronutrient that is more easily released from leaves and plant tissues because it is not part of the cellular constitution (Aberand Melillo, 2001). This may explain the K contents of F1 in the 0-5 cm layer, which were lower than the K content of SPSNUCLEUS because F1 had no animal urine input.

In general, SPSNUCLEUS mitigated the effects of soil degradation caused by non-conservationist agricultural uses, such as the conventional soil management previously used in the areas. SPSNUCLEUS generates shades (animal welfare), produces non-timber forest products, and increases the biodiversity of anthropogenic rural landscapes (Schmitt Filho, et al., 2013). Moreover, it is a production system that improves the soil chemical attributes, making it reach similar rates to primary forest areas,especially regarding carbon, nitrogen, phosphorus, and potassium contents.

Conclusions

The High Biodiversity Silvopastoral System (SPSNUCLEUS) 1 improved the soil chemical attributes after four years of implementation. The soil carbon accumulation capacity in the 5-10 cm and 20-40 cm soil layers in the SPSNUCLEUS area was similar to that of the primary forest area, and higher than those of the other areas. Increased the soil total organic carbon content in the 5-40 cm layer, and total nitrogen content in the layer 5-30 cm, compared to the pasture management systems without tree patches. Increased the soil fertility regarding phosphorus and potassium contents in all evaluated layers,compared to the other systems. Proved to be a promising production system to improve soil chemical attributes, making it reach the carbon, nitrogen, phosphorus, and potassium accumulation potential of primary forests.

References

Aber, J. A;and Melillo, J. M. (2001). *Terrestrial Ecosystems.* Saunders College Publishers: New York, NY. doi.org/10.2307/1311684.

Alvez, J. P; Schmitt, A. L; Farley, J. C; Erickson, J. D;and Méndez, V. E. (2014). Transition from semi-confinement to pasture-based dairy in Brazil: farmers' view of economic and environmental performances. *Agroecology and sustainable food systems,* 38(9):995-1014. doi.org/10.1080/21683565.2013.859222.

Alvares Ca; Stape Jl; Sentelhas Pc; Gonçalves Jlm; Sparovek G. (2013). Köppen›s climate classification map for Brazil. *Meteorologische Zeitschrift.* 22: 711-728. doi.org/10.1127/0941-2948/2013/0507.

Caldeira, M. V. W; Vitorino, M. D; Schaadt, S. S; Moraes, E;and Balbinot, R. (2008). Quantificação de serapilheira e de nutrientes em uma Floresta Ombrófila Densa. Semina: *Ci. Agr. 29*(1):53-68. doi.org/10.5433/1679-0359.2008v29n1p53.

Cardoso, E. L; Silva, M. L. N; Silva, C. A; Curi, N;and de Freitas, D. A. F. (2011). Estoques de carbono e nitrogênio em solo sob florestas nativas e pastagens no bioma Pantanal. *Pesq.Agropec. Bras.* 45(9):1028-1035. doi.org/10.1590/s0100-204x2010000900013.

Casals, P; Romero, J; Rusch, G. M;and Ibrahim, M. (2014). Soil organic C and nutrient contents under trees with different functional characteristics in seasonally dry tropical silvopastures. *Plant Soil* 374(1-2), 643-659. doi.org/10.1007/s11104-013-1884-9.

Coelho, S. R; de Moraes Gonçalves, J. L; de Miranda Mello, S. L; Moreira, R. M; Da Silva, E. V;and Laclau, J. P. (2007). Crescimento, nutrição e fixação biológica de nitrogênio em plantios mistos de eucalipto e leguminosas arbóreas. *Pesquisa Agropecuária Brasileira,* 42(6), 759-768. doi.org/10.1590/s0100-204x2007000600001.

Corazza, E. J;Silva, J. D; Resck, D. V. S;and Gomes, A. C. (1999). Comportamento de diferentes sistemas de manejo como fonte ou depósito de carbono em relação à vegetação de cerrado. *Rev. Bras. Ci. Solo* (*23*):2. doi.org/10.1590/s0100-06831999000200025.

Embrapa. (1997). *Manual de métodos de análise de solo.* Rio de Janeiro: Embrapa Solos. https://www.agencia.cnptia.embrapa.br/Repositorio/Manual+de+Metodos_000fzvhotqk02wx5ok0q43a0ram31wtr.pdf.

Embrapa. (1999). Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. Rio de Janeiro. https://www.embrapa.br/solos/sibcs/classificacao-de-solos.

Epagri/CEPA (2017). *Sintese Anual da Agricultura de Santa Catarina 2016-2017.* Centro de Socioeconomia e Planejamento Agricola, 203. http://docweb.epagri.sc.gov.br/website_epagri/Sintese-Anual-da-Agricultura-SC_2016_17.pdf.

Fisher, A. D; Roberts, N; Bluett, S. J; Verkerk, G. A;and Matthews, L. R. (2008). Effects of shade provision on the behaviour, body temperature and milk production of grazing dairy cows during a New Zealand summer. *N. Z. J. Agric. Res.* 51(2):99-105. doi.org/10.1080/00288230809510439.

Galvão, S. R; Salcedo, I. H;and de Oliveira, F. F. (2008). Acumulação de nutrientes em solos arenosos adubados com esterco bovino. *Pesq. Agrop. Bras*. 43(1):99-105. doi.org/10.1590/s0100-204x2008000100013.

Gonçalves, G. K; Bortolon, L; Meurer, E. J; Gonçalves, D. R. N; de Sousa, R. O;and Fagundes, S. M. (2012). Phosphorus extractors for irrigated rice on soils under reactive phosphate fertilization. *Rev. Ci. Agrovet.* (J. Agrovet. Sci. 11(3):196-204. doi.org/10.5965/223811711632017324.

Hanson, J. C; D. M. Johnson, E. Lichtemberg, and K. Minegishi (2013).Competitiveness of management-intensive grazing dairies in the mid-Atlanticregion from 1995 to 2009. *J. Dairy Sci.* 96:1–11. doi.org/10.3168/jds.2011-5234.

Haynes, R. J;and Williams, P. H. (1993). Nutrient cycling and soil fertility in the grazed pasture ecosystem. In: *Adv. Agron.* 49:119-199. doi.org/10.1016/s0065-2113(08)60794-4.

Hoosbeek, M. R; Remme, R. P;and Rusch, G. M. (2016). Trees enhance soil carbon sequestration and nutrient cycling in a silvopastoral system in south-western Nicaragua. *Agrof. Syst.* 1-11. doi.org/10.1007/s10457-016-0049-2.

Loss, A; Pereira, M. G; Bernini, T. A; Zatorre, N. P;and Wadt, P. G. S. (2014). Fertilidade do solo e matéria orgânica em Vertissolo e Argissolo sob cobertura florestal e pastagem. *Comun. Sci.* 5(1):1-10. doi.org/10.11606/d.64.2007.tde-18092007-113334.

Machado, L. (2004). *Pastoreio Racional Voisin: tecnologia agroecológica para o terceiro milênio.* 1. ed. Porto Alegre: Cinco Continentes.

MapBiomas. (2017). *Sistema de Estimativas de Emissões de Gases de Efeito Estufa do Observatório do Clima.* Retrieved February 16, 2017, from http://mapbiomas.org

Schmitt, A; Farley, J; Alvez, J; Alarcon, G;and Rebollar, P. M. (2013). Integrating agroecology with payments for ecosystem services in Santa Catarina's Atlantic Forest. In: *Gov. Prov. Ecosys. Serv.*333-355. doi.org/10.1007/978-94-007-5176-7_17.

Schmitt Filho, A. L; Fantini, A.C;Farley, J; Sinisgalli, P. (2017). Nucleation theory inspiring the design of High Biodiversity Silvopastoral System in the Atlantic Forest Biome: ecological restoration, family farm livelihood and agroecology. In: World Conference on Ecological Restoration.Foz do Iguaçu PR. p.450

Tivet, F; de Moraes Sa, J. C; Lal, R; Briedis, C; Borszowskei, P. R; dos Santos, J. B; ... and Bouzinac, S. (2013). Aggregate C depletion by plowing and its restoration by diverse biomass-C inputs under no-till in sub-tropical and tropical regions of Brazil. *Soil Till. Res.* 126:203-218. doi.org/10.1016/j.still.2012.09.004.

Urquiaga, S; Alves, B. J. R;and Boodey, R. M. (2005). Produção de biocombustíveis A questão do balanço energético. *Rev.Política Agr.* 14(1):42-46. http://www.scielo.br/pdf/pab/v48n10/v48n10a03.pdf.

Whalen, J. K. et al. (2000). Cattle manure amendments can increase the pH of acid soils. *Soil Sci. Soc. Am. J.* 64(1):962–966, 2000. doi.org/10.2136/sssaj2000.643962x.