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Evaluation and comparison of soil under integrated crop-livestock-forest system in the southeast of Goiás, Brazil

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The integrated crop-livestock-forest (ICLF) has been indicated as an important alternative of agricultural production, in economic and environmental terms. This study aimed to evaluate and compare the chemical properties of soil under the system on integrated crop-livestock-forest in the Santa Brígida Farm, Ipameri City, southeast of Goiás State, Brazil. It was used a completely randomized design in a 4 × 2, with four replications. The analyzed factors consisted of four land uses (SS2 = *Eucalyptus sp.* 2 years age + *Urochloa brizantha* grass, SS6 = *Eucalyptus* sp. 6 years age + *U. brizantha* grass, ILF = corn + *U. brizantha* grass and RF = remaining forest - control) combined with two different depths of the soil (0-20 and 20-40 cm). Data from soil analyzes were used to generate the cluster analysis and principal component analysis (PCA) using the R program. In both depths was checked the grouping of sampled areas in three groups: One containing the ILF and SS2 areas samples of, which were the most similar to each other; a second group containing SS6 area samples; and a third group containing the remaining forest samples. A gradual variation in organic matter, Ca + Mg, H + Al, K and pH, CEC and V% can be observed in the samples of 0-20 cm layer, where in the remaining forest area was with the highest values of these variables, follow by the areas SS6, ILF and SS2 respectively. In the layer soil 20-40 cm depth, SS6 area stood out in relation to Ca + Mg, pH, CEC and V%. It can be concluded that the ICLF is a promising production system to be deployed, especially in areas with the purpose of recovering degraded pastures.

Key words: Soil quality, agroforestry systems, sustainability, biodiversity.

INTRODUCTION

The Cerrado biome constitutes the second largest Brazilian vegetal formation, occupying 2 million km^2 (approximately 23% of the country), with vegetation types which include forest formation, savanna and campestral (Ribeiro and Walter, 1998). This biome was included among the 34 hotspots of the planet due to its high degree of endemism being rich biologically and a threatened region (Mittermeier et al., 2005). In the last

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few years, the Cerrado has experienced a quickly reduction of its original cover vegetation, due to the expansion of the agriculture in Brazil central.

Estimates indicate that about half of the original Cerrado coverage has been transformed into cultivated pastures, annual crops and other types of land use (Ratter et al., 1997; Klink and Machado, 2005). Currently, most of the Cerrado presents highly fragmented native vegetation (Carvalho et al., 2009) and in many areas where there was a change of land use for the development of livestock farming pastures are degraded (Dias-Filho, 2007). In this sense, Macedo (2009) explains that degraded pastures are those that decreased productivity, lost vigor and are unable to recover naturally to adequately sustain the animals that consume it.

The removal of natural vegetation to agricultural operating systems causes profound changes in soil properties. Its management affects their biological, physical and chemical characteristics. Inadequate practices result in depletion of soil nutrients, reducing its fertility. Thus, information on dynamics of soil nutrients in the long term is important to assess the sustainability of practices (Ferreira et al., 2009).

The ICLF which originally received the name of Agroforestry Systems (AFS) was developed with the purpose of renovation and restoration of degraded pastures (Zimmer, 1999). The ICLF has been widely adopted in Brazil in the last few years, in which the introduction of crops is not obligatory, but is part of integration between grains production, cattle and trees where there is a use interaction, nutrition, physical and biological of the soil, in order to increase the income of producers and environmental protection (Macedo, 2009). Interactions between animals, pastures, crops and trees can interfere with the quality of the soil for several reasons.

Pastures may change the availability of nutrients according to their capacity and cycling, or remove them from the deeper layers and release them on the surface of the soil, promoting greater availability to subsequent culture (Ferreira et al., 2009). Soil compaction by animals and machines or reduce water infiltration and insufficient coverage encourage loss of nutrients and soil erosion (Cardoso et al., 2012).

Livestock in the pasture presence alters the distribution of the nutrients. Partitioning of nutrients between feces and urine also reduces the uniformity of nutrient return through excreta. Cattle grazing a given patch consume forage containing different nutrients; however, the return does not occur uniformly at a given site (Vendramini et al., 2007).

The ICLF systems can be classified according Balbino et al. (2012), in four categories: (1) Integrated Crop-Livestock (ICL) or Agropastoril System - integrates agricultural and livestock components; (2) Integrated Livestock-Forest (ILF) or Silvopastoral System - integrates forestry and livestock components; (3) Integration Agriculture-Forest (IAF) or agroforestry systems - integrates agricultural and forestry components; (4) Integrated crop-livestock-forest (ICLF) or agrosilvopastoral System - integrates agricultural components, livestock and forestry.

The main advantages arising from the use of ICLF system are: a reduction in the use of chemical inputs in the soil, herbicides and pesticides; decrease in pasture recovery costs; economic and social benefits; and reducing environmental degradation, improved chemical, physical and biological soil properties (Prado et al., 2010; Balbino et al., 2012).

Although ICLF present as a production system capable of promoting the conservation and improvement of soil quality (Tonucci et al., 2011). Evaluation of soil quality provides subsidies for the diagnosis of the degree of environmental degradation. However his analysis is complex and must be performed jointly the key attributes and their interrelationships, for in isolation is not enough to explain the loss or potential gain of crops of particular soil (Carneiro et al., 2009).

The ICLF system has been insufficiently researched, especially in central Brazil. Accordingly, this study aimed to evaluate and compare, through joint analysis, the chemical properties of soil under of integrated crop-livestock-forest system in Santa Brígida Farm in Brazil southeastern.

MATERIALS AND METHODS

Study field

The study was conducted in the Santa Brígida Farm (geographical coordinates: 17° 39' S / 48° 12' W), large area with 922 ha, located in Ipameri city, southeastern Goiás State. The climate is classified as Aw (tropical seasonal) with annual rainfall of about 1600 mm, temperature average about 23°C and is characterized by two well-defined seasons, a dry winter and a rainy summer (Alvares et al., 2014). The farm land is gently rolling relief, with an altitude of 800 m, and the soil area is classified as dark-red latosol with good drainage and sandy clay texture, content approximately 45% of clay (Oliveira et al., 2013).

ICLF system is developed on Santa Brígida Farm since 2006. In this property developed the a new production system, it's called "Santa Brígida system", consisting in corn intercropping with leguminous crops (green manure), specifically the pigeon pea cultivars (*Cajanus cajan*) or sun hemp (*Crotalaria spectabilis*), the objective is insert the green manure into the production system, to allow an increased supply of nitrogen into the soil by biological nitrogen fixation (Oliveira et al., 2010).

The total area of *Eucalyptus* sp. on the farm is 60 ha intercropping with grass, divided into *Eucalyptus* sp. (GG100) 6 years with grass *Urochloa brizantha* (syn. *Brachiaria brizantha*) and *Eucalyptus* sp. (I144 and Super Clone) 2 years with *U. brizantha*. The area allocated to the legal reserve is 184 ha and permanent preservation areas totaling 27 ha (Oliveira et al., 2010). In the areas of legal reserve and permanent vegetation the vegetation includes types predominate the Cerrado and seasonal forests, which have dynamic linked with the climate (Oliveira-Filho and Ratter, 2002), and arboreal vegetation that occur along watercourses called gallery forests or riparian forests.

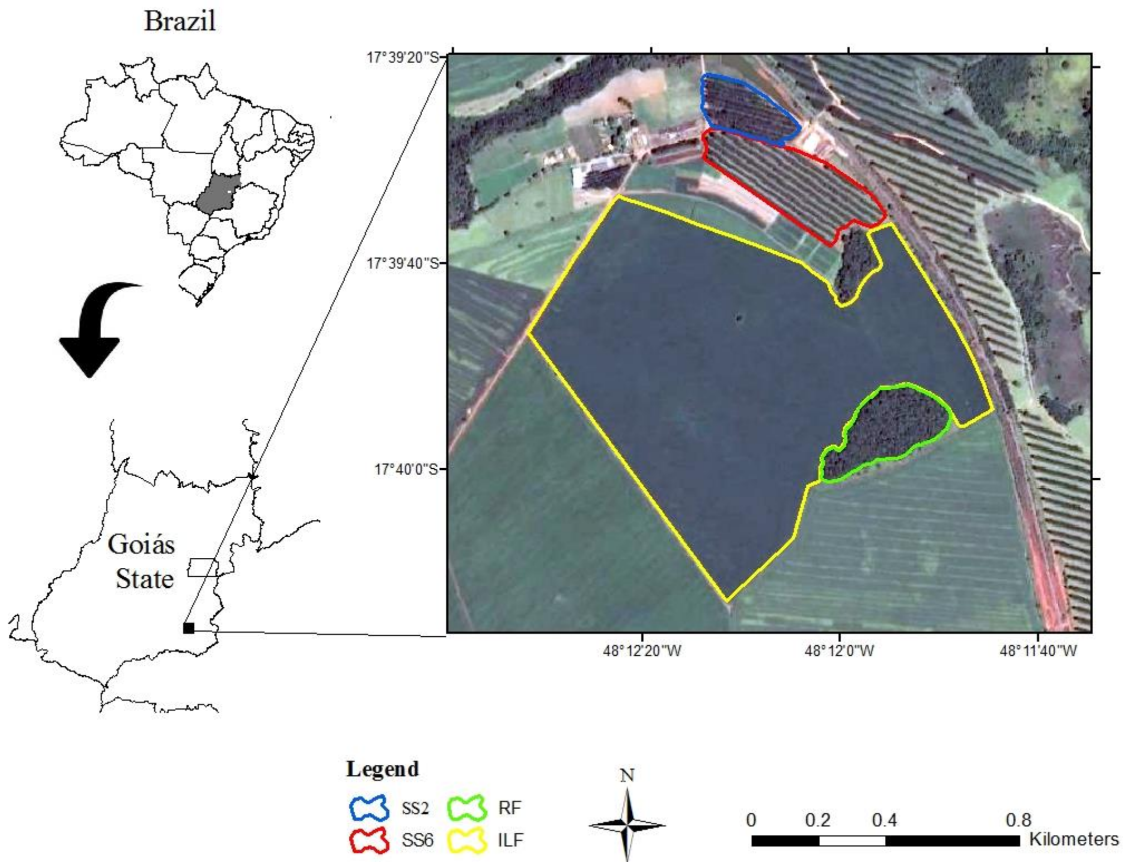

Figure 1. Areas sampled in the Santa Brígida Farm, in Ipameri city, southeastern Goiás State, Brazil. SS2 = *Eucalyptus* sp. 2 years + *U. brizantha* grass; SS6 = *Eucalyptus* sp. 6 years age + *U. brizantha* grass; ILF = Integration corn +*U. brizantha* grass; RF = remaining forest - control.

The maize area +*U. brizantha* grass cultivated in 2013 was 200 ha with yield average of 10800 kg.ha^{-1} of maize. The number of cattle on the farm is variable because it is the time of year that most of the area is used for farming, but on average are 1600 head of cattle a year in the finishing phase. The harvest of 2006/2007 to 2011/2012 the average stocking rate increased from 0.5 to 2.5 AU (animal unit).ha^{-1} and the weight gain of 2 to 16 kg.ha^{-1} (Oliveira et al., 2013).

Soil collection and analysis of data

Sampling was conducted in the period from 15 to 26 July 2013, in four sites in the Santa Brígida Farm, namely: SS2 = *Eucalyptus* sp. 2 years age + *Urochloa brizantha* grass, SS6 = *Eucalyptus* sp. 6 years age + *U. brizantha* grass, ILF = corn + *U. brizantha* grass and RF = remaining forest - control. The remaining forest consists of 6 ha forest fragment, located next to the other sampling sites (Figure 1).

It was used a 4 × 2 completely randomized design in factorial. The factors analyzed were constituted by the four land use systems sampled and two soil depths (0-20 and 20-40 cm). For each use of the studied soil, were randomly selected four sample plots, which were collected 20 single samples, taken by zigzag pathway, at 0-20 and 20-40 cm. Finally, the single samples were combined to form a composite sample for each plot and each depth. Thus, four composite samples were obtained from each treatment at each depth, which were sent to the laboratory for analysis. The size of the area of solo collection varied as a function of land use, ranging from 2 to 5 ha.

Additionally, the results of a soil analysis from the area SS6 of 2006, at 0-20 cm, were used to represent the situation of soil area before the implantation of the ICLF system, when this local had relatively degraded pastures.

The chemical properties determined were: Ca, Mg, Al H +, P, K, Zn, Fe, Mn, Cu, pH and texture analysis (clay, sand and silt). The contents of Ca, Mg and Al, were extracted with neutral potassium chloride (KCl) 1 mol L^{-1}. The determination of Ca and Mg was obtained by atomic absorption spectrophotometry and neutralization titration by Al with NaOH solution and phenolphthalein indicator, base (NaOH) 45 with standardized potassium biphthalate solution ($KHC_8H_4O_4$ or C_8H_5KO) 2 mol. The determination of extractable P was achieved by Mehlich1 method, with the transmittance reading colorimeter with wavelength set to 660 nm. The K contents were extracted with Mehlich1 solution and quantified by flame photometry. The pH was determined in water using a soil / solution ratio of 1:1 and read by potentiometry (Tedesco et al., 1995).

Available nutrient contents Zn, Cu, Mn and Fe were extracted with extraction solution Mehlich 1 (HCl 0.05 mol L^{-1}H2SO4 + 0.025 mol L^{-1}) in soil: solution 1: 5, with 5 min stirring (Mehlich, 1978), with two hours of stirring (Lindsay and Norvell, 1978) and analyzed by

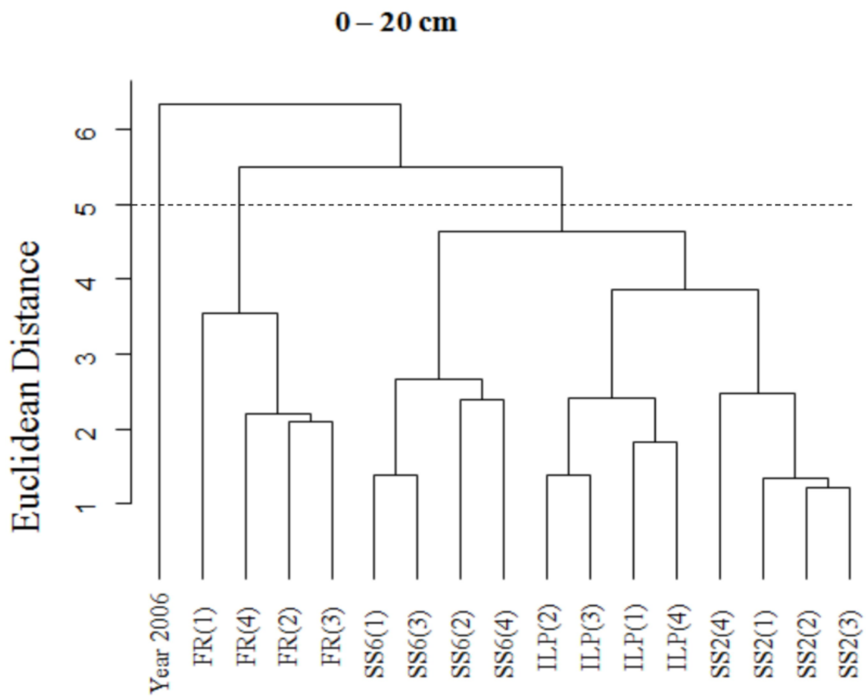

Figure 2. Dendrogram resulting from cluster analysis related to soil properties, 0-20 cm depth, areas sampled in the Santa Brígida Farm: SS2 = *Eucalyptus* sp. 2 years + *U. brizantha* grass; SS6 = *Eucalyptus* sp. 6 years age + *U. brizantha* grass; ILF = Integration corn +*U. brizantha* grass; RF = remaining forest -control; Year 2006 = Before SS6 "end point": implementation.

atomic absorption spectrophotometry.

Data from soil analyzes were used to generate the multivariate analysis, the Euclidean distance is used as a measure of similarity between the samples and the connection method for unweight averages (UPGMA) as hierarchical clustering criterion. In addition, data were submitted to principal component analysis (PCA) to reduce the dimensionality of soil variables analyzed by eliminating overlaps, and provide a more concise view of the differences between the types of production systems evaluated. The broken-stick criterion was used to designate the number of axes used in ordering and were inserted into the graphics variables with loadings higher than 0.6 in absolute values. Statistical analyzes were done in the R program (R Development Core Team, 2012).

RESULTS

Cluster analysis for the data of the 0-20 cm depth shows the formation of two distant groups (less similar), which are very different compared to the sample of 2006. The soil samples of the remaining forest (RF) are separated in a group and sample from other areas another group (Figure 2). In this second group, remodeling the formation of two subgroups, in which observed that the samples of corn areas Integration + *U. brizantha* grass (ILF) and *Eucalyptus* sp. 2 years age + *U. brizantha* grass (SS2) are more similar to each other than between them and the *Eucalyptus* sp. area 6 years age + *U. brizantha* grass (SS6).

The broken-stick criterion indicated the selection of two axes for the principal component analysis (PCA) data in 0-20 cm depth (Figure 3). The first axis explained 44% of the variation in the data, which is positively correlated with the Ca + Mg variables, H + Al, K, organic matter, CEC and V%, with the highest values of these variables were found in the samples the remaining forest, followed by samples of SS6, SS2, ILFand 2006 sample. One can also notice a greater dispersion of the samples relating to the remaining forest when compared to samples from other areas (Figure 3). In turn, the second axis explained 27% of the data variation, indicating increased levels of P and sand in the samples SS6 area.

For the 20-40 cm depth, the cluster analysis reveals the formation of two distant groups, in which a group is formed by samples from the area SS6 and the other group consisted of samples from other areas (RF, SS2 and ILF). This second group can be further subdivided into two similar subgroups, one of containing the remaining forest samples and the other consisting of ILF and SS2 areas samples, which were the most similar areas to each other (Figure 4).

The PCA results to the data of 20 to 40 cm depth are shown in Figure 4, were selected three axes by broken-stick method, being that the variation of percentage in the

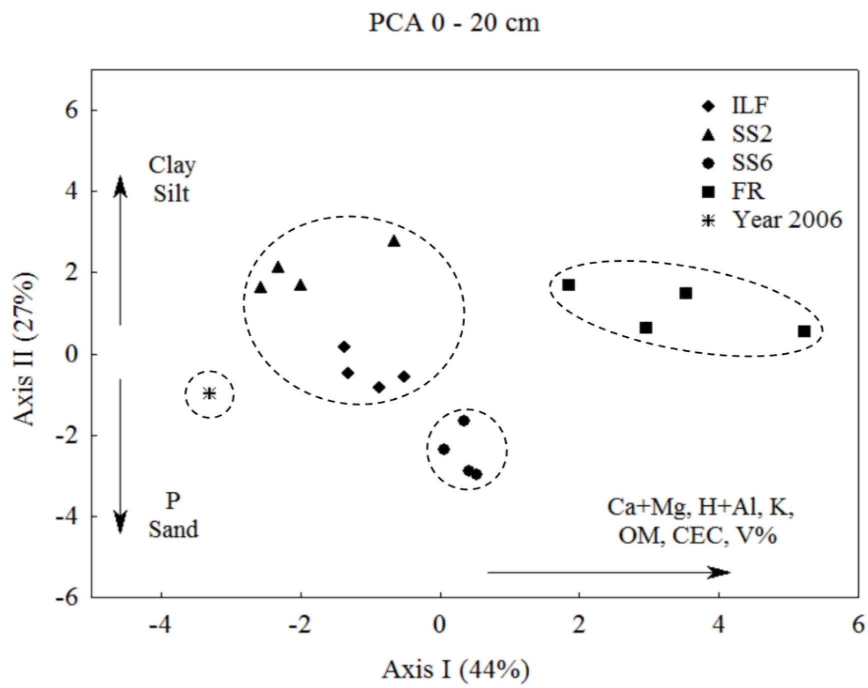

Figure 3. Principal component analysis (PCA) on the soil properties, 0-20 cm depth, the areas sampled in the Santa Brígida Farm: SS2 = *Eucalyptus* sp. 2 years age + *U. brizantha* grass; SS6 = *Eucalyptus* sp. 6 years age + *U. brizantha* grass; ILF = Integration corn +*U. brizantha* grass; RF = remaining forest –control; Year 2006 = Before SS6 implementation.

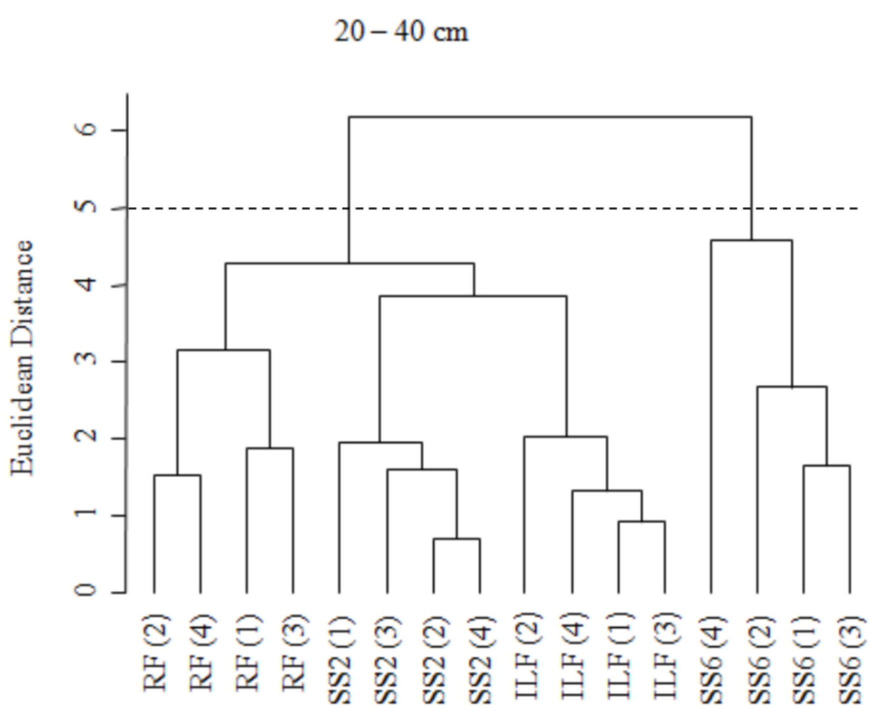

Figure 4. Dendrogram resulting from cluster analysis related to soil properties, 20 to 40 cm depth, the areas sampled in the Santa Brígida Farm: SS2 = *Eucalyptus* sp. 2 years age + *U. brizantha* grass; SS6 = *Eucalyptus* sp. 6 years age + *U. brizantha* grass; ILF = Integration corn +*U. brizantha* grass; RF = remaining forest - control.

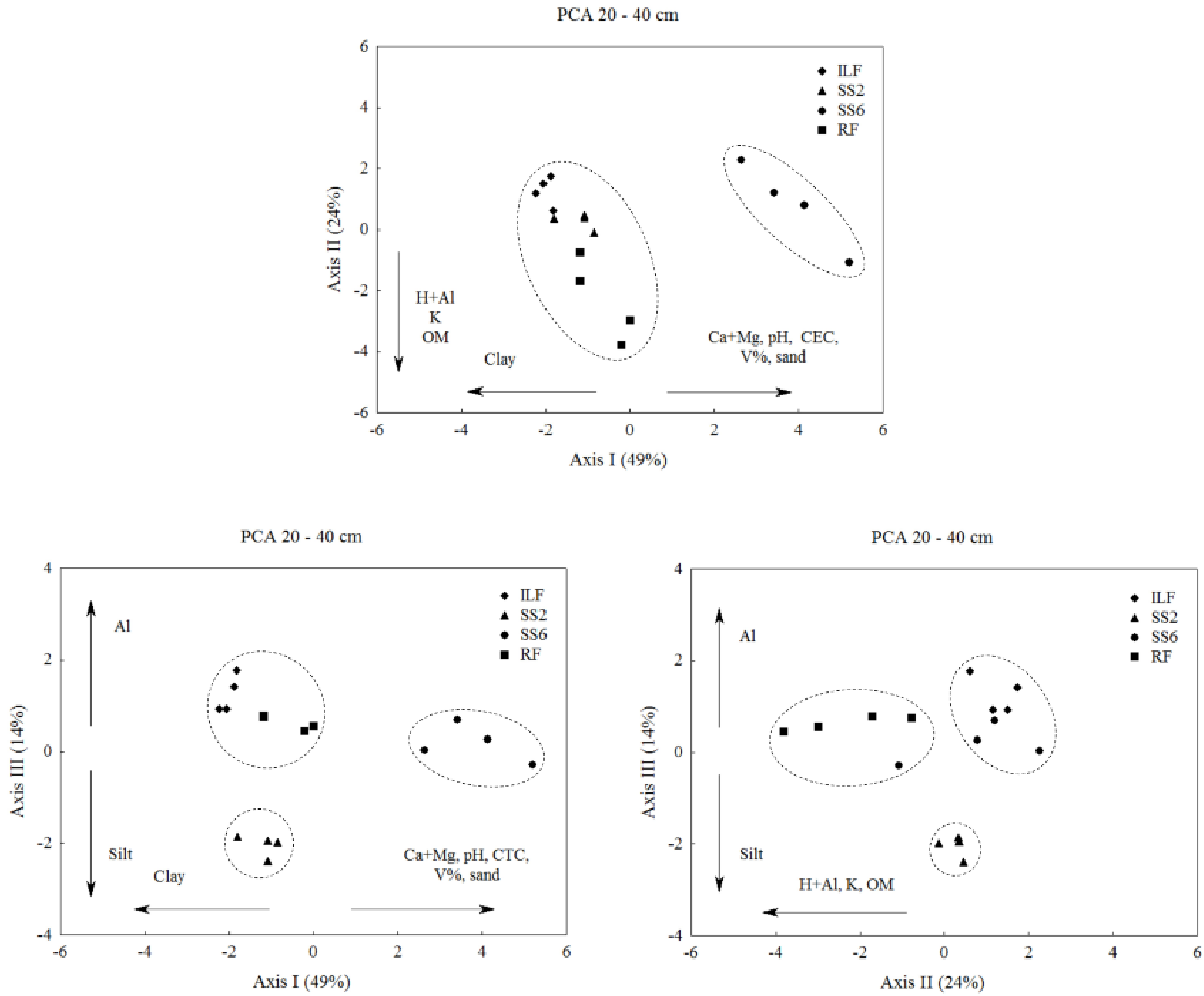

Figure 5. Principal component analysis (PCA) on the soil properties, 20 to 40 cm depth, the areas sampled in the Santa Brígida Farm: SS2 = *Eucalyptus* sp. 2 years age + *U. brizantha* grass; SS6 = *Eucalyptus* sp. 6 years age + *U. brizantha* grass; ILF = Integration corn +*U. brizantha* grass; RF = remaining forest - control.

data explained by each axis are: axis I = 49%, axis II = 24% and axis III = 14%. In 20-40 cm depth were found higher Ca + Mg, pH, CEC, V% and sand in the samples of SS6 area and higher H + Al, K and organic matter in samples of the remaining forest. For all analyzed variables, samples from areas with ILF and SS2 showed relatively similar results and their points showed little dispersion when compared with the data concerning the areas of SS6 and remaining forest (Figure 5).

DISCUSSION

When one considers all the variables in both layers (0-20 and 20-40 cm), confirms grouping the sampled areas into three groups: one containing samples of the areas with ILF and SS2, which may be considered the most similar areas together; a second group of samples containing SS6 area; and a third group containing specimens of the remaining forest (Figures 2 and 4). This gradient can be noticed by observing the distribution of the points on the graphs of principal component analysis, which are positioned so that they form two or three distinct subgroups of points (Figures 3 and 5).

A gradual change in the levels of organic matter, Ca + Mg, H + Al, K and CEC and V% can be observed in the samples of 0-20 cm layer, wherein the remaining forest area was with the highest values of these variables, then the areas SS6, ILF, SS2 and 2006 sample respectively. As the 2006 sample represents the situation of the area SS6 before the adoption of ICLF, when the area was covered by relatively degraded pasture, there is a gradual

Improvement in the soil chemical properties positioned to crop-livestock-forest systems intermediate situation between the pasture and the remaining forest.

This result is possibly due to the greater complexity of interactions and greater efficiency in cycling and use of nutrients in the remaining forest (Macedo, 2010). The organic matter in soil properties acts as an energy source for microbial mass and plant nutrients. According to Perez-Marin et al. (2004), the mineralization of organic matter releasing plant nutrients such as N, P, S, K, Ca, Mg and micronutrients, plus 15 to 80% of the total phosphorus found in the soil.

In forest ecosystems, litter is the principal route of nutrients transfer, such as C, N, P, Ca, Mg and K, plants to the soil (Cunha et al., 1993). An adaptation of plants in tropical forests is the proliferation of fine roots of the organic layer in the road surface, allowing the absorption throughout the year, the nutrients released by the decomposition of organic matter (Laclau et al., 2004).

The closeness between the samples of SS6 area and the remaining forest, at 0-20 cm depth, compared to the Ca + Mg, H + Al, K, CEC, V% and organic matter can be an indication that in the area SS6 nutrient cycling being more efficient than the SS2 and ILF areas, and benefit from the litter and cattle dung (Lang et al., 2004). According Moro (2012), the higher levels of Ca in ICLF systems can be explained by good amount of organic matter in this system, providing greater amount of negative and greater loads cation exchange capacity (CEC), since in tropical soils the fraction mineral little to the CEC and organic matter is colloidal component that more interferes with the cation exchange capacity of these soils.

The greater spread of samples relating to the remaining forest seen in Figure 3 reflects a natural condition of greater diversity and variability in this environment, unlike the other samples related areas, which were more concentrated and therefore more homogeneous.

In the 20-40 cm deep layer, SS6 area stood out in relation to Ca + Mg, pH, CEC and V%, which was due to the root system of grasses reach greater depths (Barducci et al., 2009) and as the system already has six, the decomposition of the roots allowed release of nutrients. The root system of plants *Urochloa* is fascicular, and vigorous, which allows greater tolerance to drought and increased absorption of nutrients in deeper layers (Barducci et al., 2009). Galharte and Crestana (2010) affirm that the brachiaria grass produce significant amount of dry matter and there is an increase of organic matter in soils with brachiaria pasture compared with Cerrado soils unchanged.

The introduction of trees in pasture can influence the amount and availability of nutrients in the root absorption area of companion crops. This is because the root system of the trees to be deeper intercepts the nutrients located in inaccessible soil layers to the fodder roots and makes them available on the surface as vegetative material is deposited and decomposed (Sánchez et al., 2003). The recycling of nutrients in silvopastoral systems can be more efficient than in monoculture grass, due to the exploitation of deeper layers of the soil by the roots of the shrub / tree species, compared to the components of the herb layer (Lira, 2013). In turn, in the 20-40 cm layer, the remaining forest had higher H + Al, K and organic matter, which is also due to the cycling of nutrients from the roots of dead plants and decomposition of litter.

In *Eucalyptus* spp. integration systems nutrients accumulated in the leaves return to the ecosystem through litter, becoming a way of nutrients and energy transfer, given that the plant residues have beneficial effects, including maintenance of good physical and chemical conditions soil (Ogunkunle and Awotoye, 2011). In addition, these authors add that increasing organic matter in the soil and provide nutrients, stimulate the biological activity and reduce the acidity of the soil.

The animals also influence nutrient cycling in the ecosystem, since they act in the redistribution of nutrients from the consumption via defoliation of the pasture, and his return to the soil via excretion. The retention of nutrients consumed by grazing animals is variable, from 5 to 30% of the total ingested, thus returning nutrients for the grazing animals via excreta is a principal component of its cycle (Rotz et al., 2005). Estimated that about 60 to 90% of nutrients ingested by animals return to pasture in the form of animal feces and urine (Barrow, 1967).

The rational land use has been studied and discus in function of the search for technological alternatives that enable the correct handling of the soil and therefore sustainable agriculture (Stefanoski et al., 2013). For this to occur it is necessary a safe management of natural resources with qualitative analysis, quantitative and the interpretation of physical, chemical soil attributes and major changes generated in soil quality.

The areas studied showed a wide variation in the attributes evaluated the soil, and the soil of SS6 area was the one closer to the remaining forest. Therefore, it can be inferred that the integration of crop-livestock-forest adopted in the Santa Brígida Farm is providing improved soil quality, since they were deployed in areas occupied by degraded pastures.

Conclusion

1. On the upper surface of the soil (0-20 cm), there was a gradual change in soil organic matter, Ca + Mg, H + Al, K, CEC and V%, and the remaining forest was the area with the highest values of these variables, followed by SS6, ILF, SS2 areas and 2006 samples respectively.
2. In the20-40 cm deep soil layer, SS6 area stood out in relation to Ca + Mg, pH, CEC and V%.
3. Integrated crop-livestock-forest is a promising production system to be deployed mainly in places in order to recover degraded pastures, increased and

diversifying agricultural production, and contribute to the improvement of soil quality.

Conflict of Interests

The authors have not declared any conflict of interests.

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