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SOIL CHEMICAL PROPERTIES IN AN INTEGRATED CROP-LIVESTOCK-FORESTRY SYSTEM

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Keywords:
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ABSTRACT

The experiment was conducted in Eutrophic Red-Yellow Ultisol, and aimed to evaluate soil chemical properties in Integrated Crop-Livestock-Forestry Systems (ICLF) in comparison to other types of soil use. The study assessed ICLF systems, monocultures of acacia (*Acacia mangium*), eucalyptus (*Eucalyptus urophylla* x *E. grandis*), *Urochloa brizantha*, *Urochloa decumbens*, *Sorghum bicolor* and *Panicum maximum*, with crop variations in three agricultural cycles in a 2 year period, in comparison to native vegetation, 8-year-old *U. brizantha* pasture and degraded pasture of *P. maximum* with exposed soil areas. In contrast to native forest and well-managed pastures and ICLF systems, contents of organic matter and calcium in the soil were lower in monocultures of eucalyptus, acacia and forage. The good fertility of the soil contributed to the total CEC, pH, K and Mg variables evaluated and these did not show any distinction between the environments analyzed. Soil organic matter and Ca contents were higher in native vegetation and managed pasture environments. These can be used in the evaluation of implemented systems ICLF few years before, in order to determine the feasibility of systems.

Palavras-chave:
Sistema agroflorestal
Conservação do solo
Áreas degradadas e recuperação ambiental

PROPRIEDADES QUÍMICAS DO SOLO EM UM SISTEMA DE INTEGRAÇÃO LAVOURA- PECUÁRIA-FLORESTA

RESUMO

O experimento foi conduzido em Argissolo Vermelho Amarelo Eutrófico, e teve como objetivo avaliar os atributos químicos do solo em sistemas de ILPF em comparação com outros usos do solo. No estudo foram avaliados sistemas de ILPF, os monocultivos de acácia (*Acacia mangium*), eucalipto (*Eucalyptus urophylla* x *E. grandis*), *Urochloa brizantha, Urochloa decumbens, Sorghum bicolor* e *Panicum maximum*, com variações de cultivo em três ciclos agrícolas em período de 2 anos, em comparação à mata nativa, pastagem de *U. brizantha* com mais de 8 anos de atividade e pastagem degradada de *P. maximum* com áreas de solo exposto. Comparados à mata nativa e a sistemas bem conduzidos de pastagens e de ILPF, os teores de matéria orgânica e de cálcio do solo foram menores em monocultivos de eucalipto, acácia e forrageiras. O fato de o solo apresentar boa fertilidade contribuiu para que as variáveis CTC total, pH, potássio e magnésio avaliadas não apresentassem distinção entre os ambientes analisados. A matéria orgânica do solo e os teores de Ca foram superiores em ambientes de mata nativa e de pastagem conservada, e podem ser considerados em avaliações em ILPF com poucos anos de implantação para distinção da sustentabilidade dos sistemas.

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INTRODUCTION

Agricultural research is an important strategy to increase food production and consumer goods in order to achieve demands from growing populations with minimal impact to the environment. This will require bigger yields, increase in fertilization efficiency, ecological practices, and changes in cattle production. According to Blum (2013), based on the current distribution of land and quality soil, future global food and fiber production and sustainable land use are compromised and threatened by the increase and spatial changes of the world population, as well as expected changes in lifestyle and growing demands for food and bioenergy. Also, production is impacted by changes in the world economy, climate change and a global decline in freshwater supply. To Pimentel (2006), soil erosion is one of the most serious environmental and public health problems facing human society. Humans obtain more than 99.7% of their food (calories) from land and less than 0.3% from the oceans and other aquatic ecosystems, thus preservation of the soil, the most important component in production, is vital to protect the environment and guarantee that actual and future populations are healthy and well nourished.

The integrated agroforestry systems, crop-livestock-forestry among them, stand out because they combine maintenance of economic gains during long periods, wide product variety market, and environment conservation (PACIULLO *et al*., 2011). The environmental benefits observed when the crop-livestock-forestry system is applied can be used for restoration of degraded pastures, which is considered as one of the biggest problems in pasture in the tropics, turning this system more attractive to the cattle breeder (SANFORD, SUDMEYER, 2007).

The implementation of trees in agricultural production systems and in pastures increases the energy capture efficiency by exploration of different strata in the environment (BALIEIRO *et al.,* 2004), the supply of organic matter on the soil and the nutrient cycling (BARRETO *et al.,* 2006), which promotes biota development and significant improvement on chemical and physical soil characteristics in short, medium and long term. Furthermore, the addition of trees to these systems prevents continuous deforestation of native forests (BALBINO *et al*., 2011; BONAUDO *et al*., 2014)

Studies performed in crop-livestock-forestry systems in which leguminous tree were introduced in consortium with fodder plants revealed improvement in organic matter quality and C/N ratio in leaf litter, while environments dominated by grass presented high values of this ratio, leading to temporary unavailability of nitrogen in the soil (BALIEIRO *et al*., 2004). A favorable C/N ratio promotes an increase of mineralization rates and nutrient release (RANDOMSKI; RIBASKI, 2012). Additionally, a favorable ratio can guarantee a sustainable intensification in agriculture, promoting increase in production of foods, fibers and energy, associated with the promotion of ecosystem services (MORAES *et al*., 2014). Thus, the recovery of these degraded areas stimulates the development of operational and rentable alternatives with potential to modify positively the productive capacity and sustainability of the property.

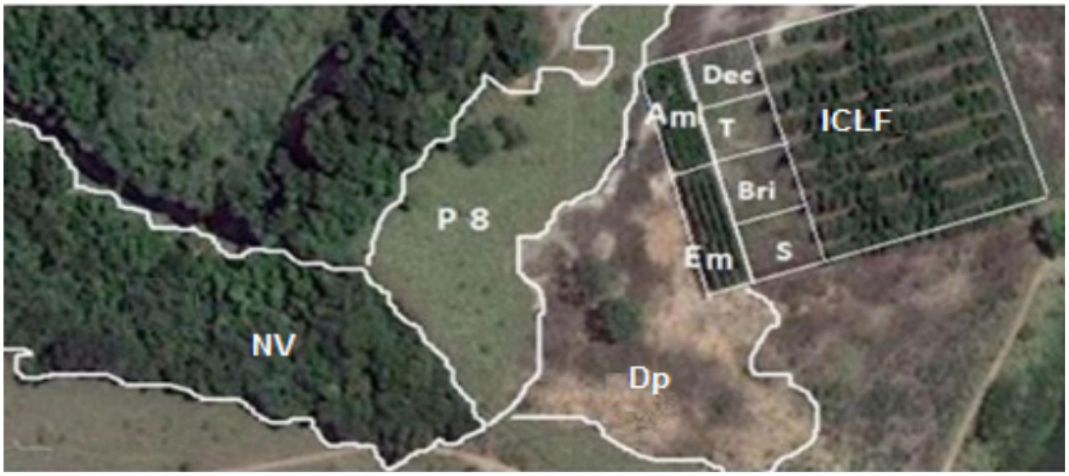
This study aimed to evaluate chemical attributes of the soil in consortium systems of crop-livestock-forestry and monocultures implanted on degraded pastures.

MATERIALS AND METHODS

The research was conducted in an area of Eutrophic Red-Yellow Ultisol between the coordinates 16°40'3.17" S and 43°50'40.97" W, at 598 meters of altitude. According to the Köppen classification, the regional climate is classified as tropical savanna (Aw), characterized by high annual temperatures and two distinct seasons, rainy summers and dry winters. The soil types evaluated are shown in figure 1 and described in Table 1.

The treatments tested with forage species *Sorghum bicolor*, *Urochloa decumbens*, *Urochloa brizantha* and *Panicum maximum* were implemented in three distinct cycles: from 2008 to 2009 (1st cycle), 2009 to 2010 (2nd cycle), and 2010 to 2011 (3rd cycle). Each treatment was replicated four times.

Sorghum and the forage species were planted using the no-till system on straw. Forage seeds were broadcast on the soil surface in all crop



NV=native vegetation; P8=*B. Brizantha* pasture with over 8 years of implementation; Dp = degraded pasture of *P. maximum*; Em = monoculture of eucalyptus; Am = monoculture of acacia; S=*Sorghum bicolor*[1]; Bri=*Urochloa brizantha;* T=*Panicum maximum cv;* Dec=*Urochloa decumbens;* ICLF = area of implantation of 7 different systems of crop-livestock-forestry described in table 1

Figure 1. Satellite picture of the experimental area. Source: Adapted from "Google Maps".

Table 1. Description of systems for use, occupancy and cultivation of soil in the experiment. Each plot of ICLF-E contains 5 eucalyptus trees + Forage and ICLF-AE contains 3 acacia trees and 2 interleaved eucalyptus + Forage.

Plot	SOIL MANGEMENT
T1	ICLF-E_1 = *Eucalipto urophylla* + *Sorghum bicolor*[1] + *Urochloa decumbens* (1st and 2nd cycles) and *Vigna unguiculata* and *Canavalia ensiformis* + *U. decumbens* (3rd cycle).
T2	ICLF-E_2= *E. urophylla* + *S. bicolor* [1] and *Urochloa brizantha* (1st and 2nd cycles) and *V. unguiculata* + *C. ensiformis* + *U. brizantha* (3rd cycle)
T3	ICLF-E_3= *E. urophylla* + *S. bicolor* [1] + *Panicum maximum* cv (1st and 2nd cycles) and *V. unguiculata* + *C. ensiformis* + *P. maximum* cv (3rd cycle).
T4	ICLF-E_4= *E. urophylla* + *Sorghum bicolor* [1] (three cycles)
T5	ICLF-AE_1= *Acacia mangium* + *E. urophylla* + *S. bicolor*[1] + *U. decumbens* (1st and 2nd cycles) and *V. unguiculata* and *Canavalia ensiformis* + *U. decumbens* (3rd cycle).
T6	ICLF-AE_2= *A. mangium* + *E. urophylla* + *S. bicolor* [1] and *U. brizantha* (1st and 2nd cycles) and *V. unguiculata* + *C. ensiformis* + *U. brizantha* (3rd cycle)
T7	ICLF-AE_3= *A. mangium* + *E. urophylla* + *S. bicolor* [1] + *P. maximum* cv (1st and 2nd cycles) and *V. unguiculata* + *C. ensiformis* + *P. maximum* cv (3rd cycle).
T8	S = *Sorghum bicolor*[1] (three cycles)
T9	Dec = *Urochloa decumbens* (three cycles)
T10	Bri = *Urochloa brizantha* (three cycles)
T11	T = *Panicum maximum cv* (three cycles)
T12	Em[2] = Clonal eucalyptus (*E. urophylla* x *E. grandis*), planted at a 3 x 2 m spacing
T13	Am[3] = *Acacia mangium*, planted at a 3 x 2 m spacing.
T14	P8 = *Urochloa Brizantha* pasture with over 8 years of implementation

T15	Dp = Degraded pasture
T16	NV = Native vegetation

(1) cultivar BRS 610, fertilization by 06-30-06 (NPK) at 300 kg ha^{-1} and topdressing $(NH_4)_2SO_4$ at 80 kg ha^{-1}

(2) (3) Seedlings were planted in December 2008 in 40 cm diameter holes, previously fertilized with 100 g superphosphate. 15 days after, were fertilized with 18 g boron and 100 g of formula 4-30-10 (NPK) per plant. At 90 and 150 days after transplantation (DAT), topdressing fertilization was performed with 150 g of KCl per plant and, at 270 DAT, 100 g of formula 10-30-10 (NPK) was used per plant as additional fertilization.

From planting until harvest for silage of sorghum, the entire experimental area received sprinkler irrigation, whenever necessary, with daily water depth of 5.0 mm.

cycles, using 6 kg ha^{-1} of pure and viable seeds immediately before planting sorghum. Sorghum was sown by broadcasting eight seeds per linear meter spaced at 0.5 m between rows, keeping a distance of 1.0 m away from the tree rows.

Assessments took place in April 2011, 27 months after the intercropping of the first cycle had been implemented. Four simple collections were performed in each plot at a depth of 0-20 cm to extract composite soil samples, which were air-dried, grounded and passed through 2 mm sieves to obtain TFSA. The following chemical properties were assessed: pH, organic matter (OM), calcium (Ca), potassium (K), magnesium (Mg), aluminum (Al), nitrogen (N), phosphorus (P), sum of bases (SB): effective acidity (H+Al), potential (T) and effective (t) cation exchange capacity and base saturation (V).

Mean confidence intervals were calculated for comparisons between treatments, considering the probability level of 5% by the t-test.

RESULTS AND DISCUSSION

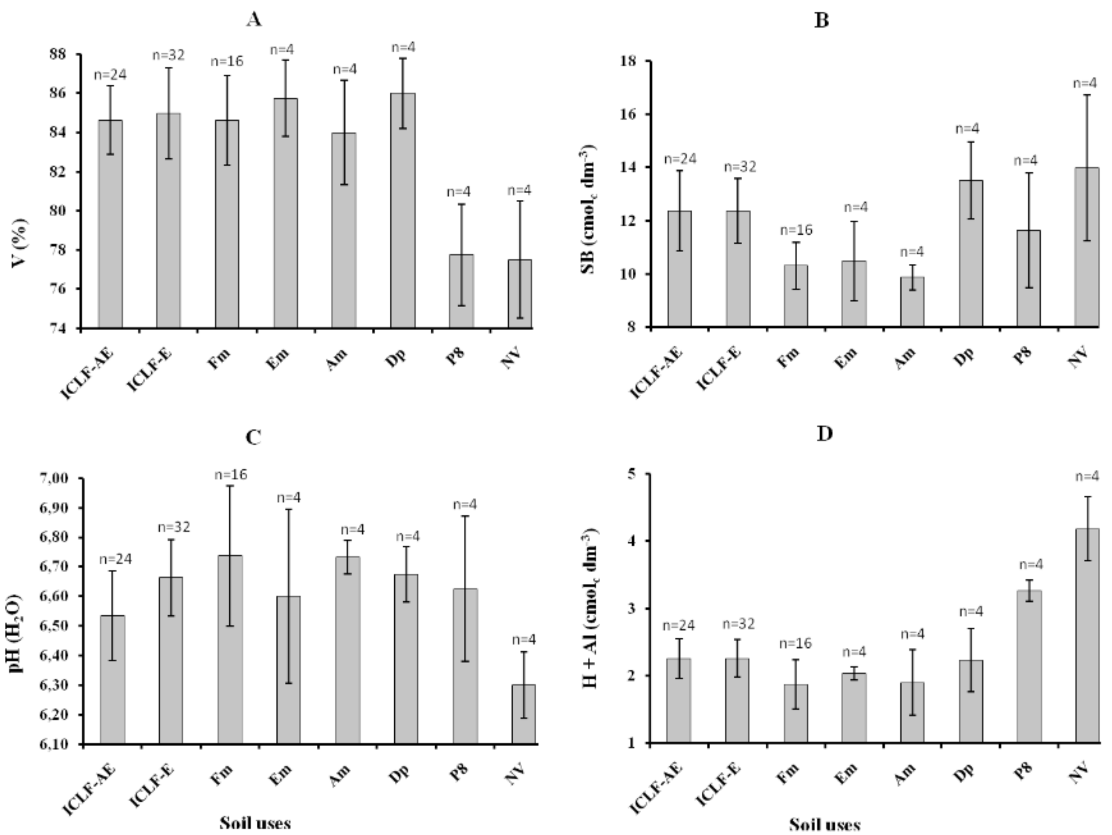
ICLF arrangements and forage monocultures showed no statistical differences among their subsystems. Total averages were calculated for the following systems: arrangements T1, T2, T3 and T4, with new identification (ICLF-E); arrangements T5, T6 and T7, with new identification (ICLF-AE); and for monocultures of sorghum (T8), *Urochloa decumbens* (T9) and *Urochloa brizantha* (T10) and Tanzania (T11), with new identification (Fm).

Soil pH values were above 6.1 (Figure 2) in all studied agricultural systems, which corresponds to a rating of "high" for pH values, or "weak acidity" (ALVAREZ *et al.,* 1999). The comparison between systems showed the potential acidity (H + Al) as higher in the native vegetation (NV) and in *Urochloa brizantha* pasture in use for more than 8 years (P8) when compared to other types of land.

This high pH value is probably associated with the mineralization of organic matter, because pH was highly correlated to such property (Table 2), and with the production of root exudates, common in areas of forests and soils with high organic matter content (BARRETO *et al*. 2006).

The values obtained for SB were classified as "very good", as established by Alvarez *et al.* (1999), because they achieved values above 6 $cmol_c$ dm^{-3}. Furthermore, the absence of exchangeable aluminum, together with high contents of Ca, K and organic matter, contributed to good $CEC_{(T)}$ (Figure 3), which, associated with low levels of potential acidity (H+Al), showed high base saturation (V), above 50%, characterizing the soil as eutrophic (Figure 2). According to Silva *et al*. (2007), CEC is used as a measure of nutrient retention capacity, favoring the maintenance of fertility for an extended period of time, and the eutrophic nature of the soil reflects good chemical reservoir, helping to efficiently keep ecosystem balance. In low-fertility soils, the influence of organic matter on $CEC_{(T)}$ was more evident, taking into account the low levels of exchangeable bases. Maia (2006) and Iwata (2012) observed increased levels of soil exchangeable bases under agroforestry systems and related this increase to the contribution in nutrient cycling by the tree roots.

Soil organic matter contents were higher in NV and *Brachiara brizantha* systems with over 8 years of use (P8) (Figure 3), demonstrating that an 8-year period of good land management keeps the levels of soil organic matter similar to those of native vegetation soil. However, when pasture land is poorly managed, there may be rapid degradation of the system even if soil chemical conditions are preserved (Figure 3). In this case, excessive trampling produces a thin sealing layer on the soil surface, which affects infiltration and water



Source: From the author.

Notes: ICLF-AE = total mean of intercropping system eucalyptus + acacia +forage; ICLF -E = total mean of intercropping system eucalyptus + forage; Fm = total mean of monocultures of forage Dec (*B. decubens*), Bri (*B. brizantha*), T (*Panicum maximum*) and S (*Sorghum bicolor*); Em = monoculture of eucalyptus; Am = monoculture of acacia; Dp = degraded pasture of *P. maximum*; P8 = *B. brizantha* pasture with over 8 years of implementation; NV = native vegetation, SB = sum of bases; $CEC_{(T)}$ = total cation exchange capacity, V = base saturation; H + Al = potential acidity.

Figure 2. Soil chemical properties: base saturation (A), sum of bases (B), pH (C) and potential acidity (D), and mean confidence intervals tested at 5% probability by the t-test, depending on cultivation system.

storage, hindering seed germination and seedling establishment and degrading the environment (SOUZA *et al.,* 2007), as was the case of the Dp system. Under these unfavorable conditions, the soil can be tilled and the physical conditions restored; however, if the type of management adopted does not take into consideration a good land cover, the problem will persist, especially in soils with properties similar to the Ultisol used in this study.

Under the conditions presented above for Dp, difficulty in gas exchange between soil and atmosphere, and greater difficulty in water infiltration can preserve soil organic matter (CHAUDHARI, 2013), thus keeping the levels in this system equal to those of ICLF systems (Figure 3). When this system occurred, if trees were intercropped with grasses, input of organic matter was high; however, as a result of better physical conditions, the processes of mineralization may have been more intense, while maintaining similar levels to that of Dp. In contrast, monocultures increased biological activity in the soil, just like ICLFs, but with much lower input of organic matter. For this reason, monocultures showed the lowest values of soil organic matter (Figure 3). In such systems, there was an increase in soil organic matter over time, as noted by Pignataro-Netto, Kato and Goedert (2009), who found similar organic matter content for both pasture lands established for over 15 years and native “cerrado” (savanna). This similarity was attributed to excellent incorporation of organic matter into the soil by grasses.

In the case of forage monocultures (Fm), figure 3, the site was used for animal grazing, which caused the removal of a large portion of plant shoots. As for sorghum, all shoots were removed to make silage. In an experiment done by Braz *et al*. (2004) with forage production systems free from livestock grazing, the accumulation of material on the soil surface (litter) reached 414 and 311 kg ha^{-1} for *B. brizantha* and *B. decumbens*, respectively, in a deposition period of only 28 days. Cecato *et al*. (2001) found in pastures of *Panicum maximum* an average litter production of 2,179 kg ha^{-1} of dry matter over a period of 56 days. Therefore, as stated by Miranda (2002), the system is deficient if there is a complete removal of shoots for silage and forage relies only on roots for increasing soil organic matter.

As for the monocultures of eucalyptus and acacia, the lowest organic matter content (Figure 3) can be associated with the woody nature of the waste used and the lack of forage that can contribute to moisture retention and improvement of the C/N

Table 2. Coefficient of correlation between contents of soil organic matter and Ca, Mg, H + Al, nitrogen in Red-Yellow Ultisol.

Variables		Correlation	Significance
OM	Ca	0.5725	0.069^{ns}
	Mg	0.3305	0.212^{ns}
	H + Al	0.9317	0.0004***
	$CEC_{(T)}$	0.8085	0.0076***
	N	0.8326	0.0052***
Ca	Mg	0.1904	0.3257^{ns}
	SB	0.9901	0.0000***
	$CEC_{(T)}$	0.9249	0.0005***

Source: Author.

OM = organic matter (%), Ca, Mg, SB, H + Al, and $CEC_{(T)}$= = calcium, magnesium, sum of bases, potential acidity and cation exchange capacity in (cmol dm^{-3}); *** significant at 0.1% by the t-test; ns = not significant at 5% probability.

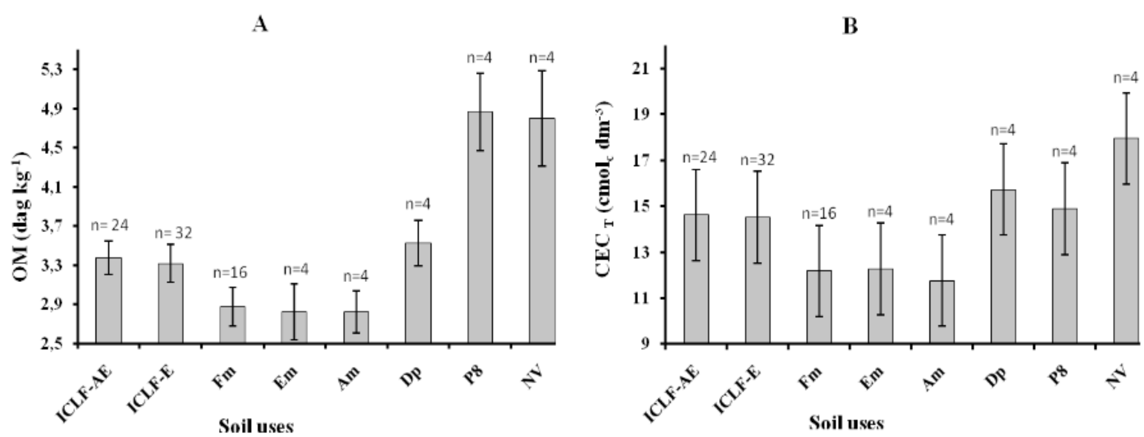


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Figure 3. Organic matter content (A) and $CEC_{(T)}$ (B) in different types of land use with a mean confidence interval at 5% probability by the t-test.

ratio of litter. Additionally, ideal conditions, such as moisture retention and warmer temperatures, were formed in the soil for the development of organisms responsible for decomposing deposited material. However, larger amounts of deposited crop residues do not always result in higher accumulation of organic matter in the soil.

Nitrogen balance in the system is crucial to accumulate organic matter under no-tillage system, and to accumulate 1 Mg C ha^{-1} as organic matter requires at least 80 kg ha^{-1} of N (ALVES *et al.*, 2002; SISTI *et al.*, 2004). Radomski and Ribaski (2012) report, in the vicinity of tree rows, the prevalence of the nutrient amount in the litter, where shading is increased, because of the amount of wood and low light intensity, which hinders the decomposition process.

With regards to sites where ICLF was implemented, as mentioned above, organic matter replacement was more efficient because of the integration between trees and forage, despite the reduced time for implementing the system, i.e., only two years. Some researchers observed an increase in the levels of soil organic matter in integrated systems in five-year periods (SILVA *et al.*, 2011). Braz et al. (2004) analyzed soil organic carbon in pastures of *Brachiaria* in systems with 5 and 18 years of continuous use. These researchers found the amount of organic carbon there was larger than in native vegetation of the *cerrado*, while Menezes *et al*. (2008) observed that soil organic matter did not differ in 5-year agroforestry systems, compared to native vegetation.

As for nitrogen, there was no statistical difference between the different types of land use in the implemented systems and in the area of degraded pasture; however, these values were lower than those found in the well-managed pasture with over 8 years of implementation (P8), and in those with native vegetation area (NV) (Figure 4). Nitrogen contents, however, were strongly correlated with the content of soil organic matter present in the soil (Table 2). According to Sacramento (2013), under the conditions of the Brazilian semi-arid region, losses of N were the lowest in the agrosilvopastoral system than in silvopastoral system after 13 years of implementation, showing that agrosilvopastoral system seems promising to promote soil sequestration of C and N. The short time elapsed from the implementation of ICLF systems until the soil sampling may explain the lower values of nitrogen concentration, even with crop fertilization and cultivation of tree and herbaceous legumes, when compared to native vegetation (NV) and pasture formed more than 8 years before (P8). Changes in soils under agroforestry systems have been reported in literature to occur only after the fourth year of implementation (SILVA *et al*., 2011).

Except for NV and Dp, which, respectively, showed low and high values (Figure 3), the values of C/N ratio in the various types of land use were close to the healthy range needed by soil microorganisms, which is 10: 1 in average (MOREIRA; SIQUEIRA, 2006). In degraded pasture (Dp), a process of intense mineralization, coupled with greater exposure of soil and certainly a higher temperature, could have caused the decomposition rate of organic matter to increase over time. This may have contributed to the increase in C/N ratio, thus decreasing the value of N over C and, consequently, reducing the rate of decomposition (BERG; MEENTEMEYER, 2002). Under these conditions, there might occur loss of nitrogen through volatilization or leaching (PANDEY, SHARMA, 2003), reducing N levels in the soil.

In contrast, the physical conditions of degraded pasture could have contributed to the persistence of residual stocks of organic matter in these environments, especially because the rate of organic matter decomposition is delayed when nutritional relationships (C/N) are altered (Figure 4).

In the case of native forests, the figures for OM, N and C/N ratio may be associated with greater plant diversity, which is typical of these sites. This provides larger amount and quality of litter deposited over time. Additionally, the smaller variation in temperature and humidity, and the absence of soil disturbance, which preserves fungal hyphae, favor the microbial activity that mineralizes and provides nutrients for vegetation in a balanced and dynamic manner. For well-managed pasture (P8), the results for OM, N and C/N ratio is associated with the root system of fine roots, root exudates and preservation

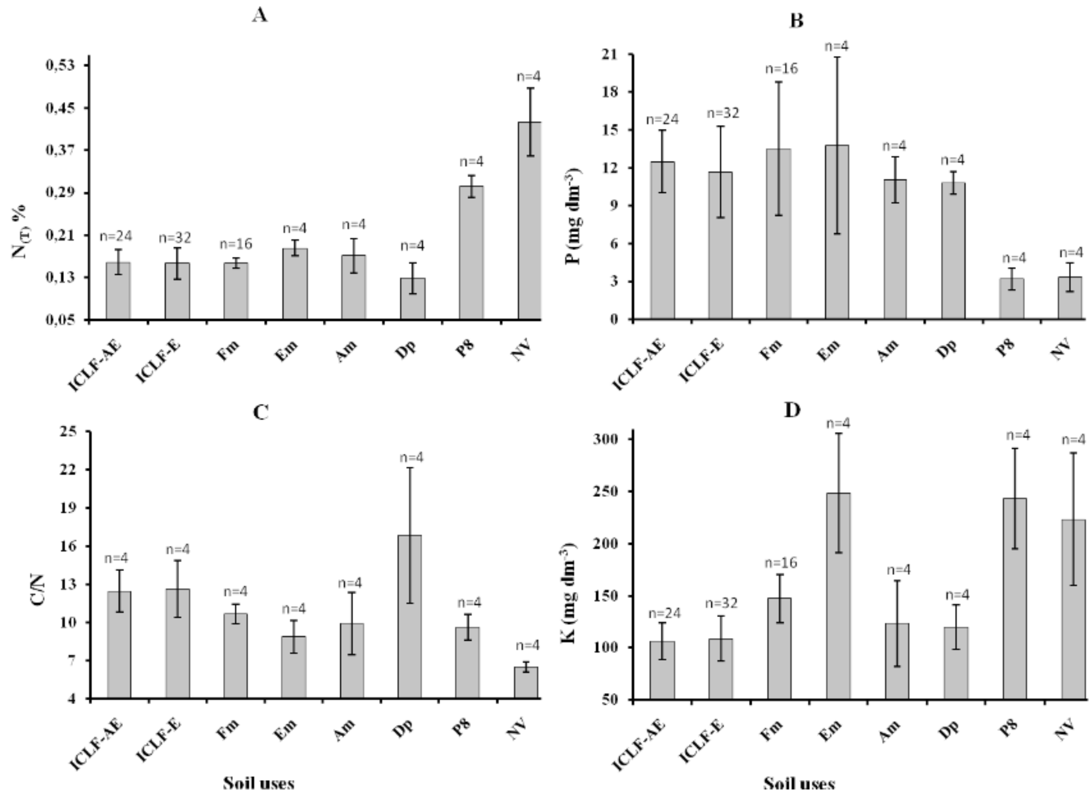

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Figure 4. Total nitrogen (A), phosphorus (B), C/N ratio (C) and potassium (D) in different types of land use and mean confidence intervals at 5% probability by the t-test.

of soil structure (REIS-JUNIOR AND MENDES, 2007), which can be seen from the best values of OM and N (Figure 3 and 4).

The phosphorus contents varied according to soil use, with the lowest values being observed for NV and P8 (Figure 4). These results could be attributed to mineral fertilization with phosphorus, used when implementing integrated systems and monocultures. In degraded pastures, there are residual phosphorus contents from previous fertilization in which occurred pasture cultivation as in the conventional production system. Low levels of phosphorus in the pasture area P8 are well-managed according to Baker *et al*. (2007), who observed a reduction of available phosphorus in soil under pasture (Figure 4). For these researchers, phosphorus reduction cannot be explained by soil organic matter content, because property assessed showed no significant difference in their study on native vegetation, pasture, and agroforestry. Their results also agree with those of Alfaia *et al*. (2004), who found that levels of phosphorus did not vary significantly across the systems evaluated; the levels were low in all systems, with critical concentrations of 10 mg kg^{-1}, as a result of nutrient export by fruits, since the type of land use had little influence on the concentration of phosphorus in the soil.

According to Oberson and Joner (2005), soil microorganisms act as sinks and sources of phosphorus (P) and mediate in the mineralization and immobilization processes of P cycle in the soil. However, their development as a function of higher P availability in the soil occurs more sharply under the canopy than outside the trees (GNANKAMBARY *et al*., 2008).

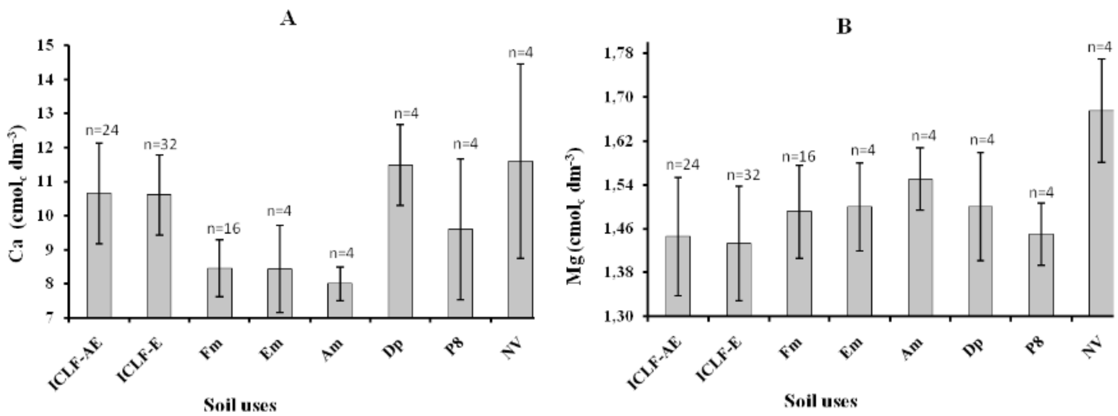

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Figure 5. Macronutrients in soil: calcium (A) and magnesium (B), and mean confidence intervals of depending on cultivation systems at 5% probability by the t-test.

Ca contents were influenced by different types of land use (Figure 5), with a significant decrease of Ca values in areas of monoculture, Fm, and Am when compared to degraded pasture (Dp). These results differ from the observations of Alfaia *et al*. (2004), in which systems with 8 years of implementation wereevaluated. In 22-year-old systems, Randomski and Ribaski (2012) found increased K and Ca contents near the trees at the sites of intercropping between *Grevilia robusta* and *Cynodom plectostachyus*. These researchers reported that such contribution is due to the disposal of waste from trees and animals that use places with the most shade during grazing, thus contributing to the production of Ca and P at a greater extent. The highest levels of Ca and Mg occurred more frequently in agroforestry systems followed by pastures and native vegetation, and remained so even after 8 years (ALFAIA *et al*., 2004).

In this study, the good natural fertility of the soil is due to the fact that it is in a karst area, and this is evidenced by the wealth of the soil in exchangeable bases, especially calcium. It should be noted, however, that calcium is in high concentration when compared to magnesium, i.e. greater than 4:1, and this could cause plant imbalance.

CONCLUSION

- Compared to systems with native vegetation, managed pastures and ICLF, levels of soil organic matter and soil calcium are lower in monocultures of eucalyptus, acacia and forage.
- In a short period of time, organic matter and calcium content of the soil are good indicators for the assessment of ICLF systems.
- Native vegetation and well-managed pasture of *Urochloa Brizantha* had higher contents of nitrogen and organic matter in the soil when compared to 27-month-old ICLF systems and to degraded pasture areas.

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