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Soil Fertility in Agroforestry System with Introduction of Green Manure

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Abstract: Green manuring is an alternative practice of agricultural production capable of not only reestablishing but also increasing soil fertility levels in addition to allowing a better utilization of agricultural inputs. These characteristics make green manuring an interesting alternative agricultural system for regions in which soils are degraded with low water retention capacity and high nutrients leaching. The objective of this study was to evaluate chemical attributes of a soil submitted to an agroforestry exploitation system. That fertility evaluation took place during three years in which the soil was exposed to the following conditions, spontaneous vegetation, leguminous plants and cultivation upon leguminous plants residues. The introduction of leguminous plants as a green manure practice in these tropical agroforestry system favors the reduction of aluminum saturation, the increment of the CEC and the organic matter content and also the amount of P in the soil. In this system, the needs in nutrients of the plants in consortium have to be satisfied by external supply of those elements (mainly with the help of soil liming) so as to avoid the gradual impoverishment of the soil.

Key words: Soil fertility · Agroecology · Sustainability ·Soil conservation

INTRODUCTION

Agroforestry systems (SAF's) have been recommended for tropical regions due to their social, economic and environmental benefits. Is an alternative agricultural production that seeks to minimize the effect of human intervention in natural systems [1]. Such benefits are usually related to their capacity to sequester carbon dioxide from the atmosphere, the adequate cycling of water and nutrients and the improvement of soil quality when in comparison with monoculture agricultural systems using either annual or perennial agricultural species [2].

The SAF's represent one of the forms of land use more adequate to the soil and climatic conditions of the region, although studies concerned with the sustainability of those systems are scarce [3]. Due to their promoting a higher production of aerial and root biomasses and a larger covering of the soil surface in comparison with other agro systems, the SAF's favor the accumulation of carbon in the system, the keeping of soil fertility through a more efficient cycling of nutrients and the reduction of losses due to leaching and erosion and the deposition of plants litter.

The integration of trees into agricultural systems may dramatically affect soil nutrient cycling by altering soil structure, microbial biomass and microclimate and by increasing the quantity and diversity of plant residues and rhizodeposition products [4]. Some recent studies demonstrate the reduction of carbon stocks in microbial systems less stable, as pasture and conventional tillage compared to areas of native or similar environments, such as agroforestry [5, 6].

The high costs of agricultural inputs, specially soil fertilizers and correctives and the growing demand for technologies less aggressive to the environment, make

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the ecological management of soil fertility a promising agricultural practice capable of increasing the sustainability of agricultural systems. Thus, the knowledge of the diversity and dynamics of agroecological practices viewing the improvement of soil chemical characteristics is important for the development of more efficient management systems.

Maintaining the productivity of agricultural and forestry systems is essentially dependent on the organic matter transformation process and thus on the microbial biomass [7].

The success of a SAF's is related with the amount of nutrients made available by the decomposing plant residues and how those nutrients meet the demands of the growing crop [8]. The decomposing plant residues covering the soil surface result in more beneficial effects such as a larger covering of the soil, a larger amount of organic matter delivered to the soil, biological fixation of atmospheric nitrogen, reduction of soil and nutrients losses [9], erosion and leaching control and increment of biodiversity [10].

Among the agroecological technologies and processes which can be considered as alternative agricultural models, the use of leguminous plants is of significant importance due to their potential for the biological fixation of atmospheric nitrogen and the diversity of crop and animal species which they can be associated with.

Green manure is an alternative agricultural production system which minimizes the effects of factors leading to soil degradation, mainly soils of the Cerrado biome, located more to the North of the country, a region displaying high proportions of sand and low proportions of organic matter due to intense and generalized weathering. Cover crops, by virtue its root system, which, when decomposed and release nutrients also contributes to the formation of soil organic matter, intensely favor the physical state of the soil [11, 12].

Different crop species being cultivated in succession contribute for the equilibrium of nutrients in the soil and to increase soil fertility in addition to allowing a better utilization of agricultural inputs [13].

According to scientific studies and practical evidences, green manuring is a practice that protects the soil against rain drop impact and also against the incidence of solar rays, the breaking of compacted soil layer, increases the soil organic matter content, increases the soil capacity to absorb and retain water, decreases soil acidity, promotes the rescuing and recycling of easily leachable nutrients, increases the extraction and mobilization of nutrients from deep soil layers such as Ca^{+2}, Mg^{+2}, K^{+} and micronutrients, increases the extraction of fixed P, increases the amount of atmospheric N_2 fixed by symbiosis by the leguminous plants, inhibits the germination and growth of weeds either by allelopathy or just by competition for light [14].

The use of leguminous species as soil covering plants is an important strategy to increase the sustainability of agroecosystems since it increases soil fertility. Among the advantages of their use it may be highlighted the input of biomass to the cultivated land [15], the increment of N by means of the fixation process [16], protection of the soil against erosion [17] and also the recycling of nutrients from the deeper soil layers.

The objectives of this study were to accompany soil fertility during three years as influenced by the adopted management and compare the increment in fertility of the soil as a result of the types of plant present mainly that due to the introduction of leguminous plants in the system.

MATERIALS AND METHODS

The study was developed in the experimental area from Federal University of Tocantins, at Gurupi-TO, 11° 43' S and 49°04'W and 280m height. The according to Köppen classification, the weather is type B1wA'a" humid with moderated water deficiency (April to September) and the annual average temperature is 26.7°C. The data of monthly and annual rainfall during the three years of evaluation are shown in Figure 1. The soil was characterized as Dystrophic Haplic Plinthosol [18].

The experimental area was a agroflorestry system six year old, with an area of approximately 3000 m^2 having more than twenty arboreal species, the trees planted at a spacing of 4 x 4 m. Among the species, the following ones were arboreal leguminous: acácia (*Acacia mangium* Wild), ingá (*Inga edulis* Mart), tamboril (*Enteolobium contortisiliquum*), candeia (*Gochnatia polimorpha*), pau-ferro (*Caesalpinia ferrea*), paricá (*Schizolobium amazonicum* Huber), jacarandá (*Jacaranda mimosaefolia*), caroba (*Jacaranda cuspidifolia*); natives species; ipê (*Tabebuia chysotricaha*), baru (*Dypterix alata* Vog.), jatobá (*Hymenaea courbaril* L.), angico (*Albizia polycephala*), copaíba (*Copaifera langsdorffii* Desf.), caju (*Anacardium occidentale* L.), bacaba (*Oenocarpus bacaba* Mart.), fava de bolota (*Parkia multijuga* Benth) and exotic species for wood and other purposes neem (*Azadirachta indica*), seringueira (*Hevea brasiliensis*), urucum (*Bixa orellana* L.), jambo (*Syzygium malaccense* L.), jaca (*Artocarpus integrifólia* L.), teca (*Tectona grandis*).

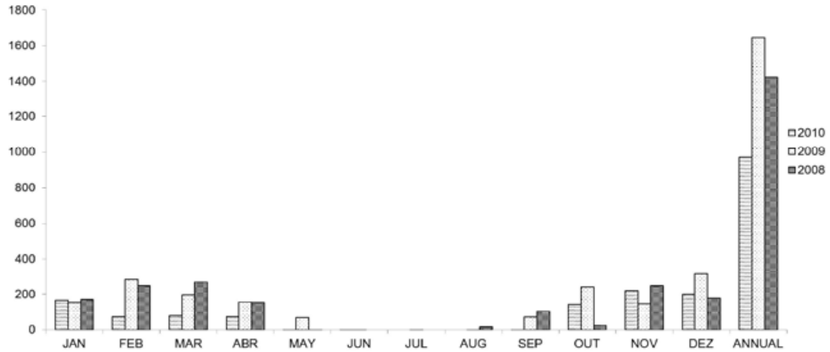

Fig. 1: Pluviometric indexes related to the period during from 2008 to 2010 in Gurupi - TO.

Soil fertility was evaluated during the three year period as influenced by the management procedure adopted in the previous year. The first year (2008) was a fallow year in which the predominant species were: *Diodiateres*, *Euphorbia heterophylla*, *Cyperus rotundus, Cenchrus echinatus, Commelina benghalensis andropogon* sp., *Mimosa pudica*, *Ageratum conyzoides* and *Brachiaria decumbens*. Samples has being collected in 24 plots of 10 m long by 4 m wide.

In the second year the following species were cultivated as green manure: *Crotalaria juncea, Crotalaria spectabilis, Canavalia ensiformes* and *Stizolobium aterrimum*. For the introduction of the leguminous plants, at the beginning of 2009, the space between plant species was of 0.45 m and in the consortium treatments there was an alternation of species. Each experimental unit was 10 m long with four lines, totalizing 24 plots samples collected. In the planting row, 22 kg P ha^{-1} in the form reactive phosphate natural arad was applied.

In the third year (2010) the soil was covered with the plant residues of the leguminous of the second year. At the beginning of 2010, the treatments consisted in the cropping of cassava (Manihot esculenta Crantz), cowpea (*Vigna unguiculata* (L.) Walp) and in the consortium of both species in the subplots over the residue of the previously cultivated green manures, totaling collecting samples under the same 24 plots of 2009. In the planting soon followed and due to treatments already performed soil analysis and current nitrogen fertilization was not, but was performed phosphorus and potassium planting at a dose of 40 kg ha^{-1}. This is the fertilization recommended for cassava before the P and K levels currently obtained.

The discussion of the results refers to three moments when the soil was sampled for fertility evaluations: November of 2008 (after the fallow period), June of 2009 (after the cultivation of the leguminous plants) and August of 2010 (after the soil had been covered with the leguminous plants residues).

A composite soil sample was taken from each plot, consisting of four sub-samples at a depth of 0 – 0.20 m. In laboratory the pH (H_2O) and the levels of Ca, Mg, K, Al, H + Al (potential acidity) and available P were determined by both procedures of Embrapa [19].

The statistical analysis of the data consisted in submitting them to the analysis of variance and the comparison of means by the Tukey´s test ($p = 0.05$) with the help of the SISVAR software [20].

RESULTS AND DISCUSSION

Significant effects were observed (Table 1) for Mg, Al, T (CEC potential), K, organic matter, pH at the depth of 0-0.20 m, these results being understood as indicating the occurrence of differentiated values of the evaluated treatments for the analyzed variables.

There were significant differences for Mg and pH. The increments in pH values and in the contents of Ca and Mg in the year 2010 are due, probably, to the nutrients being released into the soil by the leguminous plants residue. It is verified in 2010 that the soil Ca content went up between 25 to 44% larger than those of the previous two years (Table 1). Menezes *et al*. [21] in a study with SAF's in Rondônia verified the contents of Ca and Mg to reach the mean values of 1.7 and 0.5 cmol$_c$ dm^{-3}, respectively, these being results very close to those verified in the present work.

Potassium content in the various systems differed significantly one from the other, with the fallow system having the highest K content. This may be explained by the fact that those plants are of spontaneous occurrence thus being more adapted to adverse climatic conditions [22]. If it rains after the plants senesce, a large amount of

Table 1: Chemical attributes of the soil in the agroforestal system during three years of agricultural management

System	Ca	Mg	Al	H+Al	t	T	SB
	---------- $\text{cmol}_c\ \text{dm}^{-3}$ ----------						
SAF 2008	1.28a	0.5ab	0.19a	2.35a	2.28a	4.45b	2.10a
SAF 2009	1.69a	0.22b	0.02b	5.48a	1.94a	7.40ab	1.92a
SAF 2010	2.28a	0.57a	0.03b	6.10a	3.01a	9.11a	2.98a
CV (%)	60.88	36.25	49.04	40.90	36.36	25.54	42.87

Means in the same line followed by the same letter, do not differ significantly at the level of 5% of probability according to Tukey´s test. t: CEC effective; T: CEC; SB: sum of bases.

Table 2: Chemical attributes of the soil in the agroforestal system during three years of agricultural management

System	V(%)	P mg dm^{-3}	K $\text{cmol}_c\ \text{dm}^{-3}$	O.M. (g dm^{-3})	m (%)	pH (H_2O)
SAF 2008	47.19a	8.17a	0.32a	11.77b	8.20a	5.56b
SAF 2009	28.37a	14.85a	0.01c	21.94a	1.03b	5.58b
SAF 2010	32.55a	44.57a	0.13b	21.29a	0.99b	6.02a
CV (%)	30.96	80.52	36.57	25.52	22.01	1.79

Means in the same line followed by the same letter, do not differ significantly at the level of 5% of probability according to Tukey´s test. V: saturation bases; m: saturation by aluminium; O.M. organic matter.

K is washed away from the dead tissues and return to the soil. This nutrient may have been exported together with the agricultural products obtained at the local of each system or absorbed by the trees of the SAF's.

According to Cunha *et al*. [23], it is possible to infer that the recycling of that element by the cover plants is not being sufficient to supply the amounts which are removed with the harvest of corn in a Cerrado region. This hypothesis is supported by Alfaia *et al*. [24], who mention the possible exportation of those nutrients by succeeding crops in SAF's evaluated in Rondônia. It is also possible that part of the liberated K was lost by leaching, mainly during the 2009 and 2010 years due to the more intense rains taking place in those years (Fig. 1).

According to Miyazawa *et al*. [25], the monovalent cations are easily leachable mainly when they are found in their ionic form. That is the reason why in agricultural mineral soils cation leaching takes place in the following order: Na^+, K^+, Mg^{+2}, Ca^{+2} and Al^{+3}.

No significant differences were found for potential acidity ($H^+ + Al^{+3}$) whose values increased yearly together with total CEC and the amount of organic matter. Aluminum saturation was smaller with the introduction of green manures, going down from 8.20 % in the first year to 0.99 % in the second one. Considering that the area of the experiment was not submitted to any liming, it is probable that in those treatments aluminum complexation reactions by organic compounds might have occurred, such as superficial adsorption processes or chelation due to the use of leguminous plants.

The effects brought about by the organic compounds of cover plant residues on soil chemical characteristics are transient. They may mitigate the acidifying effects caused by carboxylic and phenolic groups resulting from the decomposition of plant residues by the reaction of the amidic and ammoniacal nitrogenous fertilizers (nitrification process) and the exportation of bases by the harvests [26].

Working on the relation between acidity and other attributes in a soil with high levels of organic matter, Ebiling *et al*. [27] verified that the amount of organic matter showed a positive correlation with the amount of extractable hydrogen and with the potential acidity, that is, the higher the soil content of organic matter, the higher its acidity.

No significant difference in P level was found when the different years were compared (Table 2). It is possible to observe a difference of the treatment with spontaneous vegetation in comparison with the other treatments. This result may be the consequence of the application of natural phosphate for the introduction of the leguminous in 2009 or possibly part of the cycled P in the leguminous litter would remain as organic compounds protected in some way from the competition by the mineral phase in the soil. Thus, it is likely that the higher amounts of organic matter in 2009 and 2010 were the causing factor of the higher amounts of P in organic forms when in comparison with 2008.

According to Pavinato and Rosolem [28], it is normal the occurrence of higher availabilities of P in soils covered with plant residues not only because of the P present in the residues but also because of the competition of the organic compounds from residues for the exchange sites in the soil.

It is worthy of note that the amount of extracted P, in some cases, does not necessarily mean efficiency such as, for example, the diluted solutions of strong acids such as is the case of the extractor Mehlich-1, which, in soils that were fertilized with natural non reactive phosphates of apatitic origin (natural phosphate from Catalão, natural phosphate from Patos of Minas, among others) overestimate the amount of available P [29]. The information about the amount of available P in the soil as determined by Mehlich-1 extractor is just a qualitative measure and, even so, subject to considerable errors in some cases mainly in soils with too high levels of P-Ca resulting of the application of natural phosphate of apatite origin in the year 2009.

Statistically significant differences were found for organic matter the smallest amounts were found for the fallow condition and the highest during the second and third year with the management of leguminous. This is probably due to the higher amount of litter accumulated on the soil surface considering that the system of management may affect the carbon content of the soil due to the amount of added plant residues as well as by the change in the rate of organic matter decomposition [30].

Under the conditions of the soil of this experiment (a Plintosoil, usually an acidic soil), increments in the anionic adsorption, reductions of the bases saturation and a low contribution of minerals by weathering are likely to occur. The development of an organic cover of the soil in systems managed under the agroforestry focus, immobilizes a great deal of nutrients which are of great importance to maintain the equilibrium between cycled nutrients and the plant and to reduce the losses resulting from the exportation needed for the agricultural productions, thus resulting in more sustainable systems [31].

Bases saturation was not significantly modified by the introduction of leguminous plants in the SAF when in comparison with the spontaneous vegetation system. Nascimento *et al.* [32] observed that pigeon pea, crotalaria and velvet bean, although with higher absolute values, didn't result in values of saturation bases significantly higher than that observed in a fallow area. As to the cation exchange capacity (CEC), a similar behavior was observed with a significant difference between the result of the SAF with leguminous plants in comparison with the other systems, this, probably, being consequence of the greater addition of organic matter.

Differences among soil fertility variables have been observed in long lasting experiments, attributable to the effects of leguminous species in comparison with non leguminous species like as to pH, exchangeable aluminum, aluminum saturation and anion adsorption [33]. Several works report similar results [34-36] showing that changes in soil variables (mainly in those of chemical nature), under SAF conditions, do not take place in short periods of time.

CONCLUSIONS

The introduction of leguminous plants as a green manure practice in these tropical agroforestry system favors the reduction of aluminum saturation, the increment of the CEC and the organic matter content and also the amount of P in the soil.

In this system, the needs in nutrients of the plants in consortium have to be satisfied by external supply of those elements (mainly with the help of soil liming) so as to avoid the gradual impoverishment of the soil.

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