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Short communication

Evaluation of soil fertility in smallholder agroforestry systems and pastures in western Amazonia

Sonia S. Alfaia[a,*], Gilberto A. Ribeiro[a], Antônio D. Nobre[b], Regina C. Luizão[c], Flávio J. Luizão[c]

[a] *Instituto Nacional de Pesquisas da Amazônia, Coordenação de Pesquisas em Ciências Agronômicas, Avenida André Araújo, 2936-Petrópolis, Caixa Postal 478, 69011-970 Manaus, Amazonas, Brazil*
[b] *Instituto Nacional de Pesquisas da Amazônia, Coordenação de Pesquisas em Botânica, Avenida André Araújo, 2936-Petrópolis, Caixa Postal 478, 69011-970 Manaus, Amazonas, Brazil*
[c] *Instituto Nacional de Pesquisas da Amazônia, Coordenação de Pesquisas em Ecologia, Avenida André Araújo, 2936-Petrópolis, Caixa Postal 478, 69011-970 Manaus, Amazonas, Brazil*

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Abstract

Agroforestry systems are often mentioned as a type of sustainable agriculture that is appropriate for the edapho-climatic conditions of Amazonia. However, long-term studies on the sustainability of this land use do not exist. This study evaluates the soil fertility in smallholder agroforestry systems in Western Amazonia, and compares the fertility of land under agroforestry with the fertility of neighboring land under pasture and native forest. Smallholdings located in Nova California, Rondônia, Brazil, were selected, with two different soil types. Soil pH, organic C, P, K, Ca, Mg and Al were determined. The soils of the agroforestry system maintained their improved chemical characteristics that originated in the burn, especially with respect to increased levels of exchangeable Ca and Mg and reduction of exchangeable Al, while maintaining stable levels of organic C, even when compared to adjacent primary forest soils. However, in the agroforestry system K and P fell to extremely low levels, below those considered to be critical for Amazonian soils. This reduction can reasonably be attributed to nutrient exports by consecutive harvests of cupuassu (*Theobroma grandiflorum*, Sterculiaceae) and pejibaye (*Bactris gasipaes*, Palmae) fruits. These nutrients can limit sustainable fruit yields in the agroforestry systems.
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Keywords: Soil nutrients; Land use systems; Sustainable agriculture; Tree crops

1. Introduction

Although agroforestry systems (AFS) are often mentioned as a type of sustainable agriculture that is more appropriate for the edapho-climatic conditions of Amazonia, long-term studies regarding the sustainability of these land use systems do not exist. There is an ample literature on the productive potential and ecological functions of agroforestry systems (Smith et al., 1995; Dubois et al., 1996), among which soil conservation is often the most important. Maintenance of soil fertility requires preservation of its organic matter, physical properties and nutrient levels. Various studies in Amazonia have shown that

* Corresponding author. Tel.: +55-92-6431853; fax: +55-92-6421845.
E-mail address: sonia@inpa.gov.br (S.S. Alfaia).

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soils do not support intensive annual plant cultivation without fertilizer applications (Sanchez et al., 1983; Alfaia et al., 1988), and even these may not maintain sustainability. Due to the fragility of these soils, all agricultural projects in the region must consider soil fertility and its maintenance as a priority. One parameter to evaluate the sustainability of production systems is soil quality, which includes organic matter, acidity and/or alkalinity, availability and balance of nutrients, structure and aggregation, water infiltration and storage, as well as plant productivity.

The RECA Project (Economic Mixed and Dense Reforestation) is an association of smallholders created in 1987 in New California, Rondônia, on the frontier with Acre, Brazil. They felt a need to create a social, economic and environmental alternative project. The AFS were planted in 1988/1989. The project adopted agroforestry systems as their main model of land use and soil management. Approximately 300 families participated in the project, each with 1–3 ha of agroforestry system based on three regionally important fruits: cupuassu (*Theobroma grandiflorum*, Sterculiaceae), peach palm (*Bactris gasipaes*, Palmae) and Brazil nut (*Bertholletia excelsa*, Lecythidaceae). This project is one of the best-known AFS experiences in Amazonia and is generally considered to be successful, although it's success is relatively recent.

Initially the RECA AFS plantations presented high productivity, however, smallholders are currently worried about their sustainability because a decline in system productivity has been observed in the last few years. Because the RECA AFS model is being rapidly adopted by other communities in Amazonia it is important to determine if the system is an ecologically sustainable alternative to swidden/fallow and other land use options.

This study is part of a larger research project, financed by the Pilot Program to Protect the Tropical Forests of Brazil (under the aegis of G-7), in which various groups of specialists are simultaneously studying changes in the physical, chemical and biological aspects of soils in agroforestry systems and pastures of the RECA smallholders. These studies will develop base-line information to guide the selection of soil management practices aiming to maintain and restore the soil's productive potential for these agroforestry plantations. The objective of this study was to evaluate soil fertility in RECA agroforestry systems, as well as to compare the fertility of the AFS with that in adjacent pastures and native forests.

2. Materials and methods

2.1. Study location

The RECA project is located near the city of New California, Rondônia, Brazil, between 9°24′45″S and 9°54′54″S and 65°27′28″W and 65°51′52″W. For this study, smallholdings located on three side-roads of the RECA project, called Pioneiro, Cascalho and Linha-5, were selected to examine different Ferralsol and Cambisol groups of soils, representative of the project as a whole. Three small holders on each side-road were sampled in 1997 (each farmer's area is considered as a repetition for the statistical analysis), with the following land use systems in each:

Agroforestry systems. Land preparation followed the traditional system of slash and burn of primary forest during the dry season of 1988. In early 1989, the AFS plantations were established with cupuassu, pejibaye and Brazil nut seedlings in an uniform design on a 4 m × 7 m grid to complete stocking densities of 240, 65 and 32 plants ha^{-1}, respectively. From initial planting until crown shading set in, after about 1 year, short cycle crops, such as rice (*Oryza sativa* L.), maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.), were planted in the strips between the perennials. In the under-story of the established system the farmers planted leguminous cover crops to fix nitrogen and control weeds. The farmers do not use fertilizers to increase system productivity. Each family has 1–2 ha of agroforestry system.

Pasture. The pastures were slashed and burnt at the same time as the AFS areas and in the first year were planted with annual crops, before being planted to pasture of *Brachiaria humidicola*. No chemical fertilizers were applied at any time.

Primary upland forest. Each small holder has preserved areas of native forest adjacent to the AFS plantations and pasture. These areas are used for extraction of non-timber forest products, but no management is practised.

2.2. Sampling and soil chemical analysis

Along the Pioneiro side-road the soils are classified as Red Oxisols (Ferralsol); along the Cascalho and Linha-5 side-roads the predominant soils are classified as deep and shallow Yellow-Red Inceptsols (Cambisol), respectively. The soil sampling was carried out in an area of approximately 1 ha in each land use system, after subdivision into three plots (replicates). In each plot, 10 sub-samples were collected in the 0–20 cm layer to form a composite sample. In the 20–40 cm layer, which presented greater uniformity, five sub-samples per plot were collected to form a composite sample. Soil sampling was carried out with a 10 cm OD open auger. The samples were air dried and sieved in a 2 mm sieve.

Soil pH, P, K, Ca, Mg and Al were determined following the methods used by EMBRAPA (Silva, 1999): soil pH was determined in H_2O in a soil:water ratio of 1:2.5; Ca^{2+}, Mg^{2+} and Al^{3+} were extracted with KCl 1 N; P and K were extracted with double acid (0.0125 M H_2SO_4 + 0.05 M HCl). Organic C were determined with a carbon, hydrogen and nitrogen auto-analyzer (Carlo Erba, Italy).

2.3. Statistical analysis

The experimental design used was a randomized block, with three treatments (land use systems) and three replicates (small holdings). Each side-road was treated as a separate entity. Means were compared with the Tukey test, at 5% of probability.

3. Results and discussion

The soil chemical analyses in the three land use systems showed that even after 10 years the slashing and burning of the primary forest for establishment of the agroforestry systems and pastures yielded the expected increment in soil pH, with a reduction in the level of exchangeable Al and increases in the level of exchangeable Ca and Mg (Fig. 1). These changes were generally highly significant. Higher levels of Ca and Mg occurred more often in the AFS, followed by the pasture and primary forest. That those higher levels of soil fertility in AFS and pasture soils were still apparent after 10 years is remarkable.

In Amazonia, numerous studies have shown an increase in nutrients incorporated into the soil by the ashes from forest burning (Seubert et al., 1977; Sanchez et al., 1983; Desjardins et al., 2000). Seubert et al. (1977) calculated that the burning of the primary vegetation on an Ultisol incorporated 67 kg ha^{-1} of N, 6 kg ha^{-1} of P, 38 kg ha^{-1} of K, 75 kg ha^{-1} of Ca and 16 kg ha^{-1} of Mg. While this resulted in high annual crop productivity in the first year, it was a transitory soil fertility improvement. In a short period low soil pH, high Al level and low exchangeable base levels returned. The present study showed the comparative advantage of agroforestry systems versus pasture in relation to these four soil characteristics.

Many factors may contribute to maintenance of nutrient levels after burning the forest for agroforestry systems. Like upland primary forests, agroforestry systems have a dense, deep and permanent network of roots, contributing to more efficient nutrient cycling and preventing losses due to leaching, which is often the main cause of soil fertility loss in annual crop land use systems. Tree canopies and leaf litter also protect the soil against erosion and high temperatures.

Potassium concentrations were significantly lower in AFS soils than under pasture, in both the 0–20 cm layer and the 20–40 cm layer (Fig. 2). High levels of K in soils under pasture have been mentioned by various authors (Tomé, 1997; Tornquist et al., 1999). According to Tomé (1997), high levels of K may occur in acid soils under older pastures due to the capacity of many grass species to extract K from the upper soil and, through recycling, promote the availability of this nutrient in the soil.

In the AFS soils the K levels were extremely low, even below levels considered to be critical by Cochrane et al. (1984) criteria for Amazonian soils. This reduction can reasonably be attributed to nutrient exports by consecutive harvests of cupuassu and pejibaye fruits, since K is one of the most important nutrients for cupuassu and pejibaye yields. According to Cravo and Souza (1996), the export of this macronutrient in cupuassu fruits is about 5 kg Mg^{-1}; therefore the annual harvest of cupuassu fruits exports approximately 20 kg of K ha^{-1} per year. These results show that the majority of the AFS plantations at RECA require K replacements and would probably show a positive response to K fertilization.

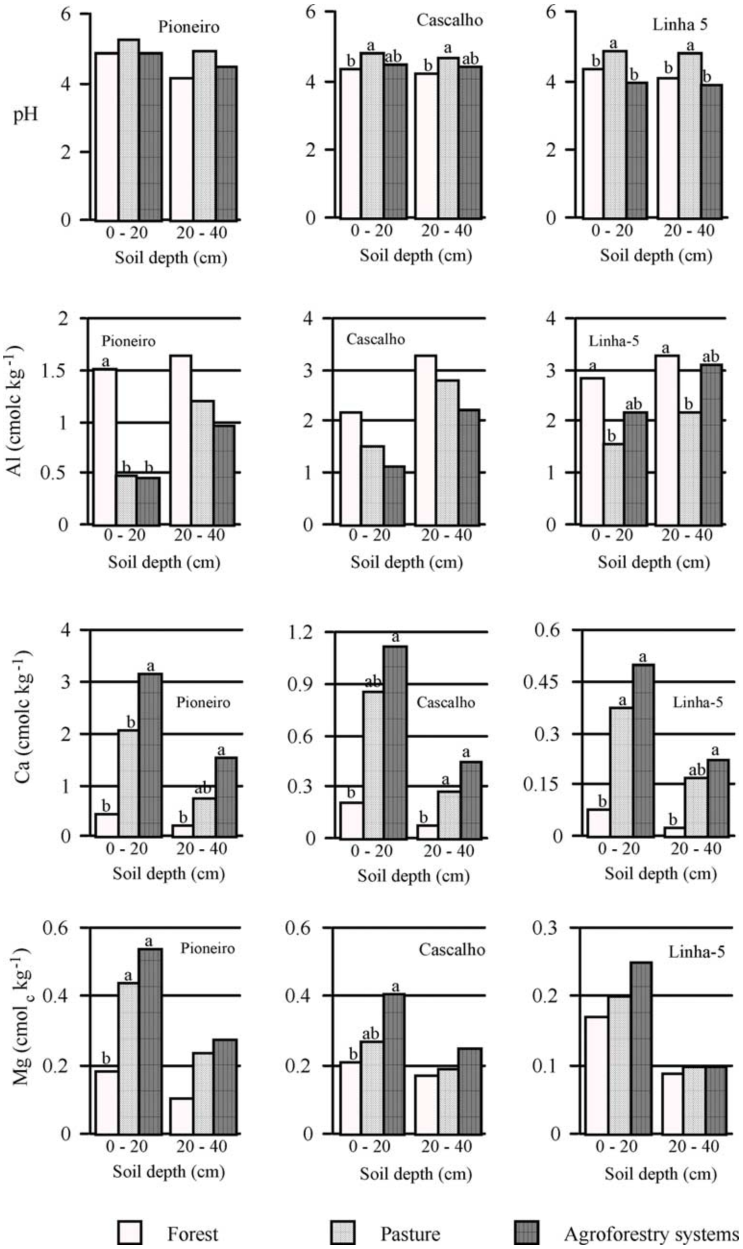

Fig. 1. Mean soil pH, aluminum, calcium and magnesium concentrations, at two depths in three land use systems along three side-roads of the RECA project, Nova California, Rondônia, Brazil. Each mean represents three smallholder properties on the side-road. Values flagged by same letter are not different by Tukey test at 5% probability.

Phosphorus levels did not vary much between land use systems, being low in all of them (Fig. 2), as occurs in 90% of Amazonian soils (Sanchez et al., 1982). Although not significant, a trend of lower levels of P in AFS soils was observed, suggesting nutrient exports by cupuassu and pejibaye harvests, as occurred for K. These results confirm that land use systems have little influence on soil P concentrations,

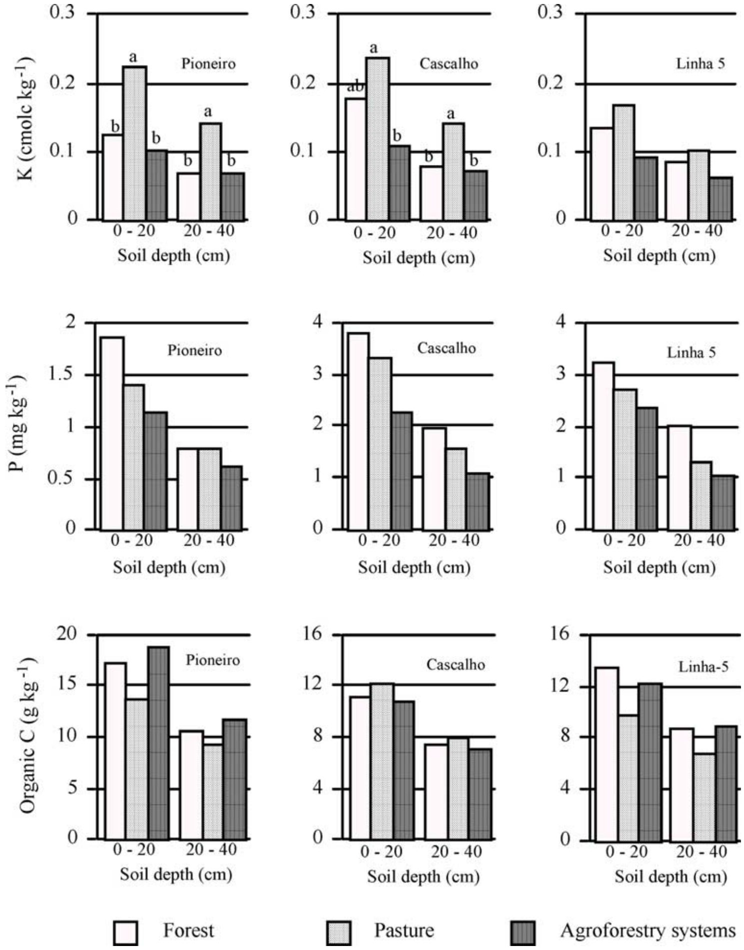

Fig. 2. Mean soil potassium, phosphorus and organic carbon concentrations at two depths in three land use systems along three side-roads of the RECA project, Nova California, Rondônia, Brazil. Each mean is from three smallholder properties on the side-road. Values flagged by same letter are not different by Tukey test at 5% probability.

as frequently reported for Amazonian pastures (Eden et al., 1991; Desjardins et al., 2000) and AFS plantations (McGrath et al., 2001). Assuming a critical P level of 10 mg kg^{-1}, this nutrient can limit fruit yields in the AFS areas studies, as can K. Any technology recommended to recuperate soil productivity must be economically viable because most smallholders do not have the economic means to practise high input agriculture. The addition and mineralization of organic matter rich in K, such as cupuassu fruit rinds, which is also rich in N and P, or pejibaye leaves, which are rich in N, can be alternative sources of organic manure.

In this study, organic C varied according to soil type, with higher concentrations in the Oxisol than in the Inceptsol (Fig. 2). In the Oxisol, C was significantly higher in areas with forest and AFS than in pastures, while no significant differences among land use systems were observed in the Inceptsol. Changes in soil organic C after conversion of primary forest to agricultural systems in Amazonia are after contrasted (Desjardins et al., 2000). With the change of forest to pasture, a gradual increase in C in the soil after burning has been observed (Koutika et al., 1977), while others report relative stability (Eden et al.,

1991) or a pronounced decrease (Falesi and Veiga, 1986). Isotopic tracer studies revealed that the amount of forest-derived C remaining in the soil decreases quickly in the first years after pasture establishment, and slows as the supply of pasture-derived organic matter decomposition increases (Desjardins et al., 1994). The effect of AFS on changes in soil C in comparison with pasture or primary forest is not as well known. McGrath et al. (2001) did not find significant differences in C concentration between AFS and primary forest in the RECA project. Recco et al. (2000) observed that older AFS showed a trend of recovery and maintenance of organic C similar to that in primary forest in western Amazonia.

4. Conclusions

In this study, the soils of the agroforestry system maintained the improvements of their chemical characteristics that originated in the burn, especially with respect to increased levels of exchangeable Ca and Mg, while maintaining stable levels of organic C, even when compared to adjacent primary forest soils. However, K and P fell to extremely low levels. This reduction can reasonably be attributed to nutrient exports by consecutive harvests of cupuassu and pejibaye fruits. These nutrients can limit fruit yields in the agroforestry systems.

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