Dynamics of the soil fertility in *quilombola* shifting cultivation communities of the Atlantic Rainforest, Brazil

Dinâmica da fertilidade do solo na agricultura itinerante de comunidades quilombolas na Mata Atlântica, Brasil

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Abstract: Shifting cultivation systems (SCS) are currently restricted to tropical areas. The classical nutrient flow model for SCS considers increasing soil fertility from the conversion phase, with the addition of nutrients contained in the biomass that was slashed and burned, and made available through ash. This study assessed the impacts of the conversion and cultivation phases on soils subjected to an SCS practiced *quilombola* populations of the Atlantic Forest, Brazil. We used a diachronic method in six experimental plots divided into two fallow age classes (10-15 and 25-30 years). The results showed that fire does not have a primary role in the cycling and maintenance of the stock of nutrients in the soil/vegetation complex. Furthermore, the soil fertility *status* was not significantly altered during the conversion and cultivation phases. Thus, the *quilombola* SCS shows specificity and that soil fertilization does not necessarily occur during the conversion and cultivation phases of SCS. The soils from fallow areas between ten and 30 years have eutrophic fertility conditions in relation to the mature forests, and are therefore viable from an agronomic standpoint. Therefore, the data on the impact of the *quilombola* SCS on soils concur as proscribed by law.

Keywords: Shifting cultivation. Swidden. Soil chemistry. Fire. Nutrient cycling.

Resumo: Os sistemas de agricultura itinerante (SAI) estão restritos, atualmente, às áreas tropicais. O modelo clássico de fluxo de nutrientes do SAI considera o aumento da fertilidade do solo durante a fase de conversão. Esse estudo avaliou os impactos das fases de conversão e de cultivo sobre os solos manejados por comunidades quilombolas que praticam a agricultura itinerante na Mata Atlântica, Brasil. Utilizamos o método diacrônico em seis áreas experimentais, divididas em duas classes de pousio (10-15 e 25-30 anos). Os resultados mostraram que o fogo não tem papel primário na ciclagem e na manutenção dos nutrientes do complexo solo/vegetação. Além disso, o *status* da fertilidade do solo não foi alterado significativamente durante as fases de conversão e de cultivo. Concluímos que o SAI quilombola mostra especificidades e que a fertilização do solo não ocorre necessariamente durante as fases de conversão e de cultivo. Os solos das áreas de pousio entre dez e 30 anos apresentam condições eutróficas com relação aos solos da floresta madura, sendo viáveis do ponto de vista agronômico. Portanto, os dados sobre os impactos do SAI quilombola sobre os solos estão de acordo com o previsto por lei.

Palavras-chave: Agricultura itinerante. Corte-e-queima. Química do solo. Fogo. Ciclagem de nutrientes.

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INTRODUCTION

Shifting cultivation is an agricultural system that depends on the slashing and burning of forest cover to open cultivation plots, which are used temporally and left to fallow for several years to allow for the recovery of forest cover and soil fertility[1] (van Vliet *et al*., 2012, 2013). However, shifting cultivation systems (SCS) have been considered as one of the main causes of tropical deforestation (FAO, 1985; Myers, 1993; Bandy *et al*., 1993; Brady, 1996), implicated for 30 to 35% of the Amazon forest loss (Serrão *et al*., 1996) and 50% of the rainforest in Indonesia (Jong, 1997). In addition, it is believed that the effects of SCS on tropical soils may compromise forests' biodiversity (FAO, 1985; Myers, 1993; Bandy *et al*., 1993; Brady, 1996), and act as an important source anthropogenic global warming (Fearnside, 2005). The negative perceptions about the impacts of SCS on tropical forests have directed public policies in many countries in an attempt to eradicate this cultivation system (Ziegler *et al*., 2009; Adams *et al*., 2013; Heinimann *et al*., 2017).

A review of the effects of SCS on soils (Ribeiro Filho *et al*., 2013) showed that there is no consensus whether they are beneficial or detrimental. Some authors point to degenerative results (Borggaard *et al*., 2003; Rasul *et al*., 2004), while others disagree based on a chronic lack of evidence (Mertz, 2002; Mertz *et al*., 2009; Bruun *et al*., 2009; Mukul & Herbohn, 2016). Evidence supporting SCS include reduced soil erosion when compared to other systems (Ziegler *et al*., 2009; Thomaz, 2013), as well as the maintenance of several ecosystem services: hydrological (Ziegler *et al*., 2009), biodiversity protection (Rerkasem *et al*., 2009) and potential carbon sequestration (Bruun *et al*., 2009).

However, a recent meta-analysis that synthetized the literature on the overall effects of SCS on soil chemical properties (Ribeiro Filho *et al*., 2015) showed that pH values increase under shifting cultivation, while Total N and C content are significantly reduced, and no significant impacts are observed on cation exchange capacity (CEC). These results support the position of those who argue for the sustainability of SCS, and highlight the importance of evaluating the soil system as a soil-vegetation complex (Ribeiro Filho *et al*., 2015).

The Atlantic Forest has only 11.7% of its original cover (Ribeiro *et al*., 2009) and is considered one of the world's top biodiversity hotspots (Myers *et al*., 2000) as well as a World Heritage Site by the United Nations. Present forest cover encompasses protected areas, private properties and indigenous people's lands, including 375 *quilombola* communities (SOS Mata Atlântica, 2011); 88 of them are located in the region of the Ribeira Valley, São Paulo state (Andrade & Tatto, 2013). The *quilombolas* are descendants of former Maroon colonies, and are among the poorest and most marginalized rural communities in Brazil (Penna-Firme & Brondizio, 2007; Adams *et al*., 2013).

Since 1964, there has been a history of implementation of environmental laws and policies that have restricted agricultural practices and extraction of timber and non-timber forest products in the Atlantic Forest, affecting *quilombolas* livelihoods (Adams *et al*., 2013). In 2006, the Atlantic Forest Law (Federal Law 11.428, Federal Decree 6.600/2008) (Brasil, 2006, 2008) tried to correct previous restrictions allowing traditional populations, through the request of a license, to suppress forest in initial stages of succession for subsistence agriculture (Varjabedian, 2010). Resolution 27/2010 (São Paulo, 2010) regulated this license in the state of São Paulo but forbade the use of fire, which is being disputed by the *quilombolas* (Adams *et al*., 2013).

The *quilombola* shifting cultivation follows the classic phases of this forest cultivation system, which has been practiced for millennia in tropical areas (Nye & Greenland, 1960; Adams, 2000; Pedroso-Junior *et al*., 2008, 2009; Mazoyer & Roudart, 2010; Heinimann *et al*., 2017).

[1] The concept of soil fertility used here refers to the ability of the soil to provide nutrients in quantities and proportions suitable for cultivation (Lepsch, 2011).

Although there is a basic pattern that characterizes SCS in tropical areas – conversion of the forest through slash-and-burn of the vegetation, cultivation and fallow (Nye & Greenland, 1960; Mertz *et al*., 2009; Pedroso-Junior *et al*., 2009; Mazoyer & Roudart, 2010) – the practices vary depending on the community considered. The main function of the fallow, from an ecosystem standpoint, is to transfer nutrients from the soil back to vegetation biomass (Aweto, 2013).

This investigation was carried out in a traditional shifting cultivation system in the Atlantic Rainforest (Brazil), practiced by *quilombola* Afro-Brazilian populations. Three research questions guided this study: (1) what is the role of biomass in soil fertility?; (2) does the *quilombola* SCS alter soil properties, as measured by changes in soil fertility?; (3) what are the impacts of fire on the soil compartment, and how are they influenced by the availability of biomass?

Here we present the first investigation of the impacts of *quilombola* SCS on Atlantic Forest soils, aiming specifically at assessing its effects on fertility.

MATERIAL AND METHODS

STUDY AREA

The study was conducted in an area of approximately 11,000 ha, in the *quilombola* communities of São Pedro (SP) and Pedro Cubas de Cima (PCC), in the municipalities of Eldorado and Iporanga, in the Ribeira Valley (São Paulo, Brazil) (Figure 1) (Santos & Tatto, 2008).

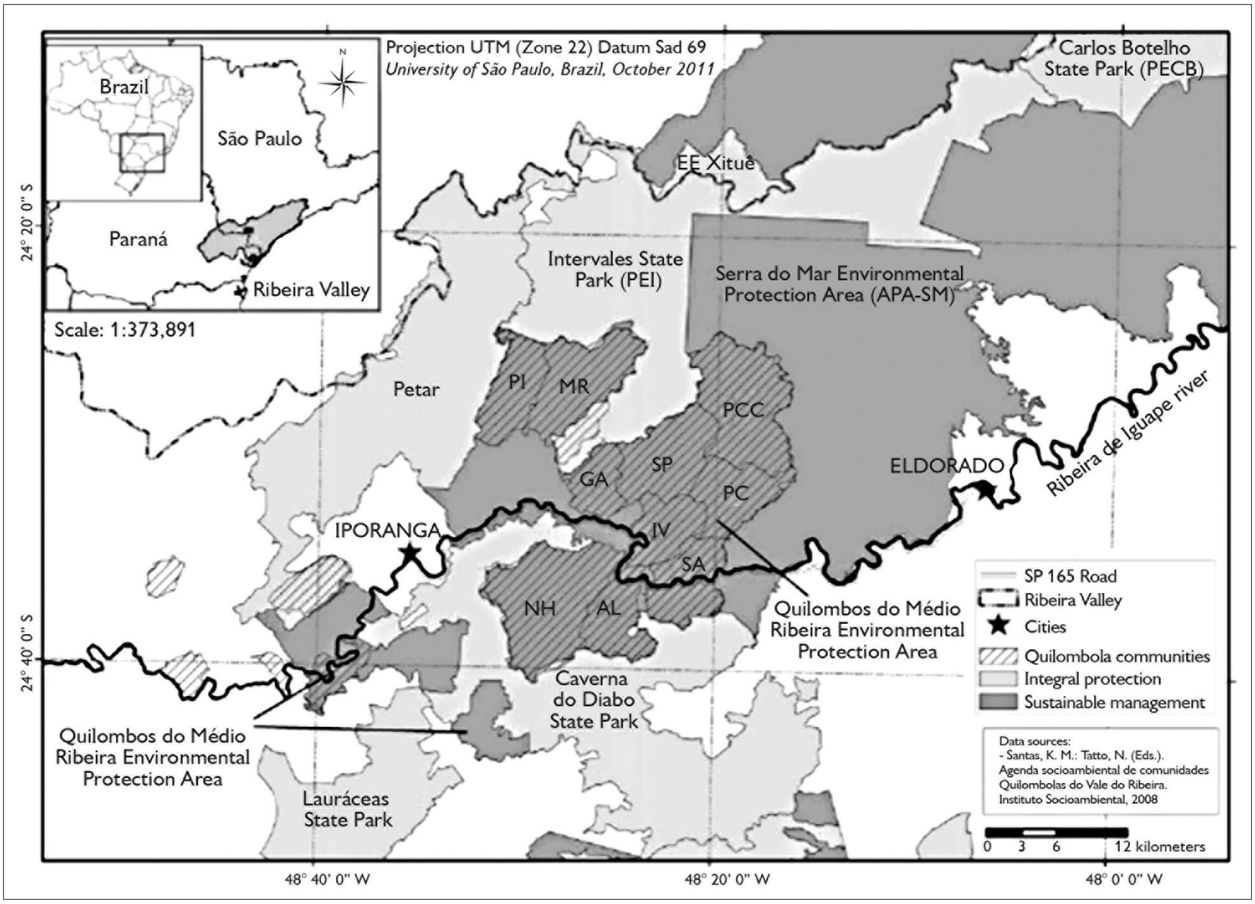

Figure 1. *Quilombola* communities and preservation units. Legends: SP = *quilombo* descendant community of São Pedro; PCC = *quilombo* descendant community of Pedro Cubas de Cima. Source: Santos & Tatto (2008).

The two communities are located at altitudes between 100 and 600 m that feature a monsoon climate (Am Köppen), with annual averages of 22 °C (varying between 17 °C and 30 °C) at lower altitudes. Rainfall is concentrated from October to March (69.4% of the total), with an annual average of 1,500 mm of rain (Gomes *et al*., 2013). The relief has two distinctive patterns, according to Theodorovicz & Theodorovicz (2007): (1) mountainous, with a declivity of hillsides that are generally over 30% with amplitudes of over 300 m; (2) predominantly undulated, with a predominance of declivities of between 20 and 30%, with amplitudes similar to the previous pattern.

Due to the complexity of the formation of bedrock, which originated from a sequence of tectonic environments with significant geological age, there are different types of soil in the Ribeira Valley: Acrisol, Cambisol, Latosol, Neosoil and Gleysols (Santos & Tatto, 2008). The studied areas have a predominance of Cambisols (EMBRAPA, 2006; Ribeiro Filho, 2015). The predominant vegetation is dense ombrophilous forest (Brazilian Institute of Geography and Statistics - IBGE), covering 95% of the landscape with a mosaic of different successional stages (Ivanauskas *et al*., 2012). The experimental plots are located between 24° 31.173' and 24° 30.405' S and 48° 22.369' and 48° 17.987' W.

São Pedro (SP) has borders with the communities of Ivaporunduva, Galvão, Pedro Cubas de Cima and with the Intervales State Park (Figure 1). The population in 2008 included 135 people and São Pedro's official area is 4,688 hectares (Santos & Tatto, 2008), partially located in municipalities of Iporanga and Eldorado (SP). All agricultural land uses, with the exception of pastures, occupied less than 1% of the community's land. The largest portion São Pedro's territory was occupied by secondary natural vegetation of different ages in addition to more mature forest (Munari, 2009). The community received the deed to the land in 2001 (Santos & Tatto, 2008; Adams *et al*., 2013).

Pedro Cubas de Cima (PCC) is bordered by the communities of São Pedro, Ivaporunduva and Sapatu, and the Intervales State Park, and is within the Serra do Mar Environmental Protected Area (Santos & Tatto, 2008) (Figure 1). In 2008, the community was composed of 69 people (Santos & Tatto, 2008), covering a total area of 6,875 hectares. The pasture, opened by farmers who were not part of the community, constituted around 5% of the total area. This is the dominant form of land use, followed by rice plantation (Santos & Tatto, 2008). Secondary vegetation in different regeneration stages and mature forest covered 6,050 ha. Pedro Cubas de Cima was recognized as a *quilombola* community in 2003, but they are still waiting for the deed to the land (Santos & Tatto, 2008; Adams *et al*., 2013).

DEFINING THE EXPERIMENTAL PLOTS

The research design used to study the dynamics of the fertility of the soil subjected to the SCS was diachronic monitoring (Yemefack *et al*., 2006), which was defined by Green (1979) as the ideal impact study design. The basic idea of this experimental design refers to the soil sampling of study areas before and after potential impacts (SCS practice), together with control areas adjacent to the plots (Manly, 2009).

The SCS farming phases (conversion of the forest and cultivation) were monitored *in loco* by obtaining soil samples (see section "Sampling soil fertility") before and during the conversion phase: phase 1, pre-conversion (before the beginning of the activities in the area); phase 2, post-fire (one week after the use of fire to clear the plot); phase 3, post-harvest (one week after the harvest). The areas were pre-defined in mutual agreement with the local informants. The declivity, exposure of the hillside, fallow age, history of use (proportion between years of cultivation and years of fallow), and the type of culture planted in each area were annotated for each plot (Table 1).

With the purpose of addressing what is established by Resolution SMA/027 with the ideal fallowing period according to the farmers' local ecologic knowledge (Nazarea, 1999), these areas were divided in two blocks/groups: 10-15 (legal) and 25-30 (local knowledge) years of fallow. Initially, 13 areas were licensed, however, for

Table 1. Independent variables for the six experimental plots. Legend: * = relation between: left number means quantity of agricultural crops; number right its time fallow.

	SP2	SP5	SP6	PCC2	PCC6	PCC7
Community	São Pedro	São Pedro	São Pedro	Pedro Cubas de Cima	Pedro Cubas de Cima	Pedro Cubas de Cima
Fallow time	10	12	30	30	15	30
Number of cultivations	2	3	2	3	3	2
History of use*	1:15; 1:15	1:12; 1:10; 1:15	1:30; 1:15	1:30; 2:30	1:15; 1:30; 1:10	1:30; 1:150
Declivity	20	35	30	30	0	35
Exposure of the hillside	Southeast	South	Northeast	Southeast	Plane	Northwest
Cultivation area (ha)	0,381	0,334	0,183	0,689	0,704	0,785
Culture planted	Maize	Rice	Maize	Maize	Rice	Maize
Coordinates (GPS)	22-J0766051/ 7287856	22-J0763401/ 7285743	22-J0764995/ 7287798	22-J0775693/ 7288199	22-J773390/ 7291819	22-J773785/ 7291198

several reasons related to the household dynamics (e.g. lack of labor), only six areas remained in the study (Table 1). Thus, six plots were monitored with the diachronic method, distributed between the communities of São Pedro (3) and Pedro Cubas de Cima (3). In total, three plots had been fallowed for 10-15 years, and three for 25-30 years (Table 1).

The selection of the six experimental plots (EP) by the farmers was performed using previous knowledge of the history of land use, either experienced by the informant or informed by previous generations. Thus, areas that had produced abundant rice or maize crops, or both, were chosen if they had a fallow period of at least ten years. For the farmers, this is the minimum period needed for the recovery of soil fertility. The size of the plots varied from 0.2 to 0.8 ha (Table 1). Licenses from Environmental Company of the State of São Paulo (CETESB) were obtained for opening the EP.

ESTIMATING BIOMASS

To quantify the differences in stages of vegetation regeneration in the experimental plots (in addition to the fallow period obtained from the informants), an estimate of the epigeal phytomass was conducted before the conversion phase. Initially, a structural study of the vegetation was conducted, in which three square portions of 10 x 10 m (total of 300 m^2/area, adding up to 18 portions) were used to sample the biomass. All wooden individuals with height ≥ 1.5m had their diameter at breast height (DBH) and height measured (adapted from Mueller-Dombois & Ellenberg, 1974).

Epigeal phytomass was initially estimated using the two existing models specific for the Atlantic Forest (Burger & Delitti, 2008). Other models used in the literature for this purpose have a pan-tropical scope and were discarded (Brown *et al*., 1989; Scatena *et al*., 1993; Chave *et al*., 2005; Barbosa *et al*., 2014). Subsequently, with the purpose of obtaining a more precise estimate of the epigeal phytomass, a new allometric equation was developed. The SP6 and PCC7 areas were chosen for sampling, since they were among the ones used for a previous phytosociological study, and represented the average structure of secondary forests in the *quilombola* territories (Gomes *et al*., 2013; Barbosa *et al*., 2014).

In each area, the epigeal phytomass of two 100 m^2 plots was weighed, using the destructive method (Whittaker *et al*., 1974; Chapman, 1976; Burger & Delitti, 2008). Therefore, 66 trees were cut down at the base with the aid of chainsaws and axes. The leaves were manually separated from the twigs and branches, and the wet weights for all of these components were measured with a dynamometer in the field. Samples of the base of the trunk, of the twigs, branches and the leaves of each tree were separated in bags and identified. All of the sub-samples collected in the field were sent to the laboratory and dried at 80 ºC until they maintained a constant weight to determine the dry weight (kg) of each tree.

MEASURING THE IMPACT OF FIRE

Regarding the preparation for the fire, three components were considered to compose the evaluation of the efficiency of the fire (low, medium and high) over the soils of the experimental plots: the care and the quantity of work dedicated to the slash and chopping of the vegetation, which is responsible for producing a larger or smaller layer of *facho* (local term for the material of the slashed vegetation), which will serve as fuel to increase the efficiency of the fire; the drying period of the slashed vegetation; and the climate conditions prior to and on the day of the fire. Areas with a greater work investment were considered to potentially burn more efficiently. All of the information was written down in the plots' spreadsheets.

The temperature reached by the soil at the moment the epigeal phytomass was burnt was measured with the aid of thermocouples resistant to high temperatures connected to a "Fieldlogger Logger" (datalogger). The thermocouples were buried in five points of the studied area at three different depths, totaling 15 points in each experimental plot: 1 cm, 5 cm and 10 cm. The data was collected every three seconds starting 15 minutes before the beginning of the fire and ending 60 minutes after the end of the fire (Mamede & Araújo, 2008).

SAMPLING SOIL FERTILITY

Sub-samples of the soil were collected from the experimental plots (Table 1) with the use of parallel transects according to the contour lines of the terrain, in top, middle and bottom portions of the areas. Each sub-sample was handled independently, totaling three (3) points inside and two (2) outside, per transect, in each area. For each point, samples were collected at three depths (0-1 cm, 1-5 cm and 5-10 cm), totaling, 45 sub-samples of soil per experimental plot.

The fertility analysis was conducted using the following parameters at the Laboratory of Soil, College of Agriculture, University of São Paulo (ESALQ/USP): pH in water and KCl (1:2,5), available phosphorus (P), potassium (K), exchangeable calcium (Ca), magnesium (Mg), and aluminum (Al), H +Al, sum of bases (SB%), cation exchange capacity (CEC), saturation of the CEC per base (V%) and saturation per aluminum (m%). The organic analysis used the following parameters: organic matter (O.M.) and organic carbon (O.C.). The physical analysis corresponded to the parameters: physical analysis of the texture, total sand, silt and clay (with dispersant) for the determination of the class of texture. The Department of Soils at the Federal University of Viçosa (UFV) conducted the total N analyses. All soil analyses were performed according to the methodology used for Donagema *et al*. (2011).

The determination of the stability of the aggregates was conducted at Laboratory of Pedology of the Faculty of Philosophy, Letters and Human Sciences of the University of São Paulo. The methodology used was adapted from Grohmann (1960), and enabled the evaluation of the stability of soil aggregates by sifting with water.

STATISTICAL ANALYSIS

To identify the experimental plots' pedological patterns, descriptive statistical tests were conducted for the variables that composed the soil fertility dynamics during the cultivation cycle. This same set of variables was subjected to a variance analysis (ANOVA), with the General Linear Model (GLM), which is commonly used in environmental analysis since it can process data with a variance structure that can be non-linear and not very constant (Bolker, 2008; Barbosa *et al*., 2014). With the GLM procedure, the averages for the different phases were compared with the multiple comparison test of Tukey (with a significance of < 5%).

RESULTS

THE *QUILOMBOLA* SCS

The groundcover (secondary vegetation) in the six EP was converted into agricultural plots in August 2013. Initially, the vegetation of the undergrowth (herbaceous plants, vines, shrubs and saplings) was cut (*roçada*, a local term) with the use of machetes and sickles to facilitate the large caliber wooden vegetation slash phase. The slash was performed in a joint effort system, that is, a group of up to ten farmers worked in a labor exchange system. Both the cutting and the clearing started from the lowest point of the plot (bottom) towards the higher areas (top).

After two weeks, the wooden vegetation was cut with the use of axes and, eventually, chainsaws. The phytomass was left drying for 20 to 30 days. During this period, the cut branches and trunks were chopped (*picar*, local term). The chopped material, together with the leaves and branches that fell to the ground during the *roçada* and the decomposing wood, enables the spread of fire and is locally called *facho* (fuel material).

According to our informants, a successfull burning depends on a period of little rain between the slash and the fire; a five day drought before the fire; a clear sky; low air humidity on the day of the fire, which occurs between 12 and 15 o'clock; existence of enough dry *facho* (biomass of the litter), not too decomposed; and a mild wind. An efficient fire results in bare soil, free of litter and eventual spontaneous plants that grow after the slash, enabling the farmers to use direct plantation techniques.

In the EP the fire did not burn the thick branches and trunks, which are left in the plot, and sowing was performed right after the fire in a random way, in the free spaces between the unburned slashed vegetation. The points of the EP where the fire was not efficient were not sowed. Rice was planted in PCC6 and SP5, and maize in the remaining plots (SP2, SP6, PCC2 and PCC7, Table 1). The harvest was performed six to eight months later, after 3-5 days of drought, between February and June 2014. The 2013-2014 summer season was exceptionally dry, what compromised the productivity of the study's EP (Ianovali, 2015).

THE BIOMASS IN THE EXPERIMENTAL PLOTS

The dry weight of the epigeal phytomass was composed by 81% of trunks and thick branches (or twigs), 9% of thin branches and 8% of leaf. Table 2 shows the results obtained for the epigeal phytomass in each EP: DBH (diameter at breast height), height and number (N) of the

Table 2. Epigeal phytomass in each experimental plot diameter at breast height (DBH), height and number (N) of the tree individuals sampled from the EP areas (N/ha = individuals per hectare), and the estimates of biomass using model obtained in this study.

Area	Fallow (years)	Mean height	Mean (DBH)	Standard deviation (DBH)	N (total)	N/ha	Biomassa (mg/ha)
PCC6	10-15	4,17	3,51	0,35	178,00	5933	25,37
SP5	10-15	4,36	3,59	0,24	232,00	7733	30,58
SP2	10-15	5,23	4,84	0,42	190,00	6333	86,22
PCC7	25-30	4,09	4,15	0,43	270,00	9000	114,71
PCC2	25-30	4,71	4,84	0,61	195,00	6500	116,65
SP6	25-30	5,20	5,76	0,27	244,00	8133	161,91
Mature forest	+150	6,49	7,73	1,01	161,00	5367	272,85

sampled trees, and the number of individuals per hectare (N/ha). The estimated biomass for the six EP plot areas had a positive correlation with the fallow age informed by the farmers (pearson correlation of 0.8 with a significance level of < 0.01%). Table 2 shows the epigeal phytomass estimates using the allometric model obtained in this study (ln = Napierian logarithm; PS = dry weight [kg]; d = diameter; h = height):

Eq. 1 $\ln PS = -3.04992 + 0.92198 \ln(d^2h)$

In the areas used to calculate the allometric model (200 m^2), the diameter of the weighed trees ranged between 3.18 and 34.5 cm, and the total dry weight of the slashed biomass was 3,544.2 kg.

THE EFFECTS OF FIRE ON THE SOIL

The average preparation time for burning the plots was 18 hours (Ianovali, 2015) (Table 3). The drying period of the slashed vegetation varied between 22 and 30 days, and a 4-to-6 day period with no rain was observed before the biomass was burned. The plots were burned for around one hour. The fire efficiency means areas with a greater work investment were considered to potentially burn. It was low in SP6 and high in PCC7, being average for the other studied areas. Despite these variations, in the 1 cm soil layer the maximum temperature remained under 60 °C and the average increase in temperature after the fire, for all plots, was 10 °C (Table 3).

Table 3. Fire characteristics and effects in each experimental plot. Legend: * = source Ianovali (2015).

	Soil depth (cm)	PCC6	SP5	SP2	PCC7	PCC2	SP6	Mean (SD)
Long fallow		10	10	15	25	30	30	
Estimate of the biomass (mg/ha)		25,37	30,58	86,22	114,71	116,65	161,91	
Preparation for the burn (hours)*		12	15	8	36	24	12	18 (10,4)
Efficiency of the fire		Mid	Medium for high	Mid	High	Mid	Low	
Time measured (minutes)		203	109	98	118	122	66	119,33 (41,66)
Total burning time (minutes)		57	55	45	84	48	40	54,83 (14,25)
Maximal soil temperature (°C) under fire	1	24,8	56,6	28,8	41,4	23,6	42,9	36,35 (11,77)
	5	22,2	28,9	26,5	31,8	24,3	29,6	27,22 (3,26)
	10	21,3	24,0	26,4	24,9	23,1	24,4	24,02 (1,57)
Temperature (°C) difference before and after the fire	1	2,0	2,6	2,1	20,3	2,6	6,9	9,98 (9,60)
	5	2,8	4,9	2,0	10,3	2,7	0,7	3,90 (3,12)
	10	1,6	2,0	2,0	3,3	1,4	2,1	2,07 (0,60)

EFFECTS OF THE *QUILOMBOLA* SCS ON SOIL FERTILITY DYNAMICS (ANOVA)

The results of the multiple comparisons with ANOVA adjusted using Tukey with the GLM procedure between the stages of the SCS in the experimental plots showed that, in general, there were no significant changes in the soil's fertility condition between the beginning (pre-conversion) and the end (post-harvest) of the agricultural period of the EP areas (Appendix).

The soil's pH (for the H_2O and KCl methods, 1:2.5) had average values that differed among the six EP areas, however, with the exception of PCC2, the areas with a fallow of 10-15 years had less acid soils (pH $H_2O > 5.0$) than the ones with 25-30 years of fallow (pH $H_2O < 5.0$) (Appendix).

However, the soil pH did not vary significantly between the SCS phases for each of the six investigated EP's, even considering the three depths that were analyzed (Appendix). In regards to the average pH (H_2O and KCl) at different depths, calculated by adding all the samples from a same layer, the 1 cm layer differed significantly from the 5 and 10 cm layers, while these two did not have significant differences between them (Appendix).

The initial content of macronutrient P differed among each of the six plots (Figure 2 and Appendix). For P, there were significant changes from phase 1 (pre-conversion) to phase 2 (post-fire), with increased concentrations in PCC6 and PCC7 ($p < 0.001$) (Figure 2). The other areas also presented changes in the average content; however, the differences were not significant (Figure 2 and Appendix).

Despite the change in the content of P after the fire, the soil returned to the initial condition after harvest (Figure 2 and Appendix). In regards to depth, with the calculation of the averages from all of the areas, layers 1, 5 and 10 cm had decreasing differences in the content of P. In PCC6 the change in content of P after the fire occurred only at the superficial layer ($p < 0.001$), while in PCC7 the change occurred only in the 5 cm layer ($p = 0.0015$) (Appendix).

The average values for K also differed among EP's (Figure 3 and Appendix). The average values of K in the soil changed significantly in 50% of the experimental plots; in the 10-15 years old plots the differences were statistically significant (Figure 3 and Appendix). Like what happened for P, the main changes occurred after the conversion, with an average increase of 50% in the content of K. However, these soils returned to the initial condition after the harvest, with the exception of PCC6. When the variation was analyzed by depth layer, there was a variation for the 1 cm layer from P1 to P2 in PCC6, SP2 and SP5 ($p < 0.001$) and on the 5 cm layer for SP2 and SP5 ($p < 0.001$). The other areas did not have significant changes (Figure 3 and Appendix). In regards to depth, the average

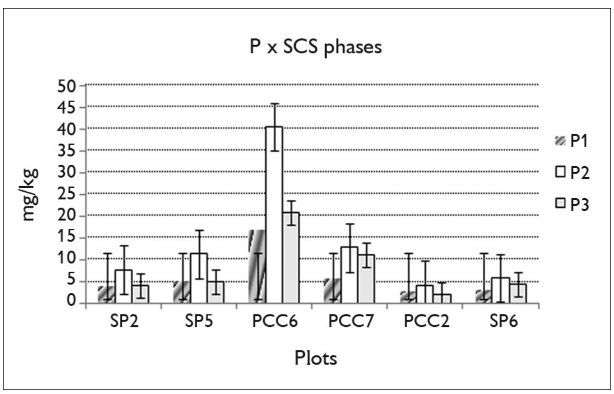

Figure 2. Average values of phosphorus (P) for P1, P2 and P3 with a standard deviation. Significant differences occurred in PCC6 and PCC7 from P1 to P2 (n = 27/phases/plot).

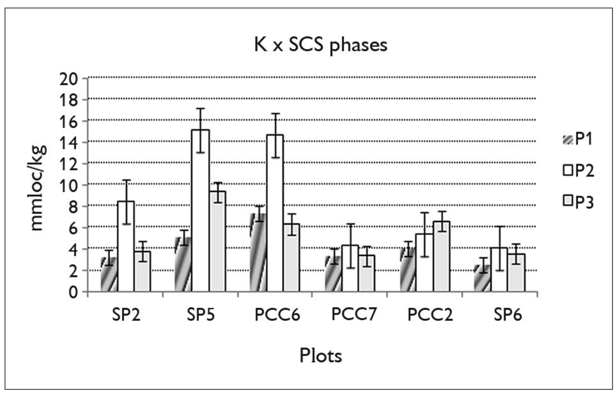

Figure 3. Average values of potassium (K) in P1, P2 and P3 with a standard deviation. Significant differences occurred in SP2, SP5 and PCC6 from P1 to P2 (n = 27/phases/plot).

value considering all of the areas, for layers 1, 5 and 10 cm, had decreasing differences in the content of K (Appendix).

For the other three bases connected to soil fertility, Ca and Mg there were no significant changes in the average values for the different phases of the *quilombola* SCS (Appendix). In regards to depth, with averages obtained from the data from all of the areas, layers 1, 5 and 10 cm had decreasing differences in the content of Ca and Mg, respectively, while the content of Al had increasing differences, respectively (Appendix).

The same happened for the potential acidity (H + Al) and for the sum of bases (SB), whose average values were calculated using all the plots. They have differences in regards to soil layer: the deeper layers have significantly lower values when compared to the more superficial ones (Appendix).

The variables correlated to soil fertility, saturation per base (V%) and saturation per aluminum (m%), had coherent results, that is, the differences in the average value of V% varied in the following decreasing order: PCC2 > PCC6 > SP5 > SP2 > SP6 > PCC7 (Appendix). These differences did not correlate with the fallow class (Appendix). PCC2 (average for V% of 56.2%) and PCC6 (V% of 46.22%) (Appendix) were soils that presented closer to eutrophic conditions. Despite these differences, there was no significant change in the soil fertility *status* from the conversion to harvest phases (Appendix). Soil layers showed decreased fertility from 1 to 10 cm (Appendix), with the averages being calculated using data from all of the plots.

The EP's soils demonstrated different O.M. and O.C. contents, and they also presented significant differences in PCC6, which had higher contents when compared to the others (118.44 $g.kg^{-1}$) (Appendix). The average values of the organic matter, CEC, organic carbon and total N (nitrogen) (Appendix) contents did not demonstrate significant variations between the SCS phases for all areas. In PCC2 and PCC6 there was an increase in the content for O.M. and O.C. after the harvest (Appendix), however the control areas had the same variation, showing that the increase was not directly related to the effect of the SCS (non-showed data). Average total N didn't show a significant variation between the phases of the SCS, with the exception of PCC6, in which the content decreased significantly in P3 ($p < 0.001$) (Appendix). The macroaggregates stability evaluation indices followed the same distribution pattern of the average values of the variables that measure the organic components of soil (O.M., O.C. and total N). The soil layers had decreasing average values for these variables from 1 to 10 cm, respectively (Appendix).

In regards to the texture of the soil, there was no change in the class between the conversion and harvest phases (Appendix). On the other hand, the 1 cm layer had less clay than the deeper layers in all plots (Appendix).

DISCUSSION

In this section, we discuss the results obtained addressing the research questions proposed in the introduction: (1) what is the role of biomass in soil fertility?; (2) does the *quilombola* SCS alter soil properties, as measured by changes in soil fertility?; (3) what are the impacts of fire on the soil compartment, and how are they influenced by the availability of biomass?

THE ROLE OF BIOMASS IN THE *QUILOMBOLA* SCS

The structure of the secondary vegetation studied herein had characteristics in common with those reviewed by Brown & Lugo (1990). Among them, the larger number of tree individuals with a DBH < 10 cm and an average height of 5 m (Table 2). The epigeal biomass of the studied experimental plots with 10-15 and 25-30 years of fallowing (Table 2) was also within the range for secondary forests in tropical mountainous ecological zones (Brown & Lugo, 1990). The stocks of epigeal biomass in the thick stalks and trunks corresponded to 81% of the total epigeal biomass, and were also very close to the values found throughout the Amazon for the same level of estimated biomass (Uhl & Jordan, 1984; McGrath, 1987; Johnson *et al*., 2001; Sampaio *et al*., 2003). However, despite the differences in the amount of biomass between the two fallow age groups, average increases in soil temperature were similar in the EP (Appendix).

This can be explained by the fact that the fraction of total biomass contained in thick stalks and trunks is usually not burned during the conversion phase in SCS (Denevan, 1971; McGrath, 1987; Thomaz *et al*., 2014). The gain in biomass from young (10-15 years) to more mature (25-30) fallows may have occurred mainly in this compartment of vegetation, while the burnt fraction (leaves, twigs and branches) could be more similar (Johnson *et al*., 2001).

The gain in biomass per year in tropical mountainous ecological zones (approximately 4.5 tons/hectares) (Brown & Lugo, 1990) corresponds to the results obtained in this study, calculated from the data in Table 3. It is also worth noting that growth rates are higher in the first 15 years of biomass growth (2 to 4 times higher), which is drastically reduced after 30 years of fallow (Uhl & Jordan, 1984; Brown & Lugo, 1990), as was also observed by other areas of the study (Ribeiro Filho, 2015). In the *quilombola* SCS, the soils with fallows between 30 to 55 years were close to the soil fertility conditions of mature forests, as described by Ribeiro Filho (2015), that is, with low fertility, which would explain the drastic reduction in the biomass's growth rate in old fallows (Brown & Lugo, 1990; Johnson *et al*., 2001).

The importance of the biomass contained in thick stalks and trunks for SCS was acknowledged by Aweto (2013), who used it as a criterion in his typology of SCS. In systems where unburned biomass is removed from the plot for other uses, as in the *Miombo* system in Zambia (Stromgaard, 1988; Ando *et al*., 2014), the cultivation/fallow ratio changes increasing the need for a longer fallow period for the recovery of the removed nutrients (Kleinman *et al*., 1995). The constant removal of biomass also causes changes in the phytophysiognomy of the forest (Stromgaard, 1988; Ando *et al*., 2014), and also affects the efficiency of fire by increasing the percentage of burned biomass (Stromgaard, 1988). In the *quilombola* SCS this biomass is not removed, thus permitting greater preservation of complex soil/vegetation nutrients, and in turn ensuring adequate regeneration of the forest to its ecological conditions.

SOIL FERTILITY DYNAMICS UNDER THE *QUILOMBOLA* SCS

One of the main benefits of the SCS's conversion phase (slash-and-burn of the vegetation) is the quick and immediate release of mineral nutrients (P, K, Ca, Mg, among others) from the ashes to the soil (Juo & Manu, 1996). Tropical soils are generally considered dystrophic due to their high acidity, low activity clay content, and low CEC that make them unsuitable for cultivation (Kleinman *et al*., 1995; Juo & Manu, 1996; Ribeiro Filho *et al*., 2013). Ribeiro Filho *et al*. (2015) confirmed the dystrophic condition for the majority of mature forest soils reviewed in different tropical regions.

The changes in the soil during the cultivation phase are a result of an interaction of different processes: clearing the area and the interruption of the cycle of nutrients; slash-and-burn and addition of the ashes; decrease of the O.M. and nutrients; and physical deterioration (Aweto, 2013). Different soil parameters have been used to evaluate the SCS cycle (Sanchez, 1977; Tulaphitak *et al*., 1985; Bewket & Stroosnijder, 2003). In the conversion phase, the quantity of nutrients released depends on their concentration in the biomass and fire efficiency (Juo & Manu, 1996; Ribeiro Filho *et al*., 2013). Yet, a fast increase of pH, exchangeable bases, CTC and P available in the surface of the soil is expected after burning (Juo & Manu, 1996; Ribeiro Filho *et al*., 2013, 2015).

The soils from the experimental plots in this study had different initial fertility conditions (Appendix). From an agronomic standpoint, the 10-15 year plots had relatively better soil than the 25-30 year ones (Appendix). Yet, soil fertility in the older fallow areas was superior to mature forest soils that composed the forest matrix of the studied area, with V% < 10% and m% > 80% (Ribeiro Filho, 2015).

Despite having different initial fertility conditions, the six experimental plots investigated did not show significant changes during the agricultural phase (conversion and cultivation) (Appendix). Fertility *status* in the older plots (25-30 years) did not change after the use of fire. In contrast, the plots with shorter fallow periods increased their K content after the fire, but this increase was not maintained after the harvest (Figure 3). This difference in K is explained by this nutrient's higher concentration in the leaves portion of the younger groundcover when compared to the older ones (Johnson *et al*., 2001). This is corroborated by the decreasing concentration of macronutrients in the ashes: P > K > Mg > Ca (Thomaz *et al*., 2014), as well as the fast transfer of K from ashes to the soil (Menzies & Gillman, 2003).

Therefore, our results indicate that the dynamics of the largest proportion of nutrients of the soil/vegetation complex (stocked in the trunks, thick branches and roots) of the *quilombola* SCS may not be connected to the use of fire, as discussed in the next section. The unburned biomass maintains a considerable part of the stock of nutrients from the system, which is released by the decomposition and mineralization of organic matter throughout the whole SCS cycle, from cultivation to fallow (Ewel *et al*., 1981; McGrath, 1987; Andriesse & Schelhaas, 1987a, 1987b; Johnson *et al*., 2001; Sampaio *et al*., 2003; Thomaz *et al*., 2014).

One could argue that the results were biased by the atypical drought in the region during the 2013-2014 summer season (Ianovali, 2015), that compromised crop production in the experimental plots. In the EP, agricultural production was compromised during the pollination and fructification phases of the cultivars (Ianovali, 2015), thus avoiding nutrient loss due to uncovered soil. Yet, the removal of nutrients contained in the crops was minimized and the residues were left on the soil after the harvest phase. For this reason, the impact of agricultural production on the stock of nutrients could not be evaluated.

The eutrophic condition of the soils in the intermediate stage of fallow (10-15 years) of the *quilombola* SCS is less sensitive to the corrective effects of the ashes produced by the fire (Ando *et al*., 2014), with the exception of the increase of K (Yemefack *et al*., 2006).

As stated above, the O.M., as well as the O.C. and total N of the soil, maintained the same levels of the initial condition of the soil after the agricultural phase (conversion and cultivation). However, the content of O.M. in the soils of both classes of groundcover is significantly lower than the content in the mature forest soil (Ribeiro Filho, 2015). Therefore, the preservation of the O.M. in the agricultural phase does not mean that the *quilombola* SCS is not losing this soil component (Ribeiro Filho *et al*., 2015; Ribeiro Filho, 2015).

Lal (2005) showed that the conversion of natural ecosystems to agroecosystems generally causes a depletion of 25-50% of the O.M.. The conditioning factors are related to the decrease of the production of litter and the exposure of soil to the weather, leading to the stabilization of the quantity of O.M. at a lower level (Murty *et al*., 2002; Lal, 2005; Aweto, 2013). In turn, the decrease in the production of litter is influenced by the number of cultivation cycles, the crop management, texture and structure of the soil, fire intensity, as well as the ecological zone (Murty *et al*., 2002; Lal, 2009; Aweto, 2013; Ando *et al*., 2014).

When a mature forest is converted, the loss of O.M. is more significant (Nye & Greenland, 1960; Juo & Manu, 1996; Giardina *et al*., 2000; Murty *et al*., 2002), and it could take a century for the soil to return to its initial condition (Nye & Greenland, 1960; Uhl & Jordan, 1984; Brown & Lugo, 1990; Juo & Manu, 1996; Giardina *et al*., 2000; Murty *et al*., 2002). However, slashing mature vegetation is not only more difficult due to the larger DBH of the trunks, requiring more manpower, but it requires much more efficient fire to remove the necessary nutrients from the vegetation to the soil, due to its dystrophic nature. Not only do thin branches and leaves need to be burned, but thicker branches and trunks as well.

The higher efficiency of the fire increases the risk of uncontrolled fire, in addition to increasing the temperature of the soil, causing more negative effects in its properties (Ribeiro Filho *et al*., 2013; Ando *et al*., 2014). Furthermore, the immediate availability of large quantities of nutrients augments the risk of losing them from the system, due to the increase of in decomposition rate, water and wind erosion, and leaching (Sampaio *et al*., 2003; Yemefack *et al*., 2006; Ribeiro Filho *et al*., 2013; Thomaz, 2013). The *quilombola* SCS currently restricts its cycle exclusively to secondary vegetation areas (Pedroso-Junior *et al*., 2008, 2009; Adams *et al*., 2013) and therefore the O.M. is stabilized at a much lower level than for mature forest soils (Ribeiro Filho, 2015).

Regarding the dynamics of the texture of soil, our results show that it did not vary during the studied diacronic. As previously discussed, the drastic decrease of rainfall averages during the cultivation phase could have minimized the effects of the soil exposure, especially erosion (Ribeiro Filho *et al*., 2013; Thomaz, 2013). Yet, the high temperatures recorded (Ianovali, 2015) could be responsible for an increase in the decomposition and mineralization rate of the O.M., causing its decrease in the plots soil (Giardina *et al*., 2000; Murty *et al*., 2002). However, a reduction of O.M. was not verified by this study, corroborated by the evaluation of the macroaggregates' stability dynamics (Appendix).

Most of the results presented for the soil's variables evaluated in the *quilombola* SCS seem to disagree with those found in the majority of studies that evaluate the dynamics of the soil under the SCS's conversion and cultivation phases (Ribeiro Filho *et al*., 2013, 2015). The studies meta-analyzed by Ribeiro Filho *et al*. (2015) showed, for example, that the pH of the soils under SCS increases. But the majority evaluated its dynamics using synchronic methods (Yemefack *et al*., 2006), which do not capture the soil dynamics under the immediate influence of fire. In the *quilombola* SCS, soil acidity is altered in the fallow phase, presumably when the slow decomposition of the majority of the vegetation did not burn during the conversion phase.

On the other hand, the soil's CEC did not change during the agricultural phase in the *quilombola* SCS, corroborating the results obtained by the meta-analysis (Ribeiro Filho *et al*., 2013, 2015). However, the study with synchronic method used to evaluate the *quilombola* SCS (Ribeiro Filho, 2015) showed that soil CEC in mature forests is significantly higher than in secondary forests of different age classes. The increase in O.M. and the presence of the mantle of roots on mature forests soils may explain this difference (Giardina *et al*., 2000; Murty *et al*., 2002).

The diachronic method used here opens new perspectives for the understanding of the role of fire in the nutrient dynamics of the of the soil/vegetation complex under SCS. Moreover, it contributes to the demystification of the use of fire, generally described as the main source of negative impacts of the soils subjected to shifting cultivation (Ribeiro Filho *et al*., 2013), as can be seen in the next section.

THE IMPACT OF FIRE ON THE SOIL/ VEGETATION COMPLEX

The fire used in the SCS is considered essential by the *quilombola* farmers, as well as in other SCS's in tropical regions (Kauffman *et al*., 1993; Giardina *et al*., 2000; Tanaka *et al*., 2001, 2004; Carmenta *et al*., 2013; Norgrove & Hauser, 2014). However, the usually top-down policies that regulate the use of fire are characterized by wrongful understandings of local practices, capacities and rationales (Carmenta *et al*., 2013), putting at risk SCS's and criminalizing traditional people's subsistence activities (Adams *et al*., 2013; Carmenta *et al*., 2013; Futemma *et al*., 2015).

The efficiency of fire in shifting cultivation systems can vary from 30 to 58% of the total slashed biomass (Kauffman *et al*., 1995; Fearnside & Barbosa, 1998;

Graça *et al*., 1999; Sorrensen, 2000; Sampaio *et al*., 2003). The production of ashes is equivalent to approximately 2% of the slashed biomass, and the production of coal may be two or three times larger (Kauffman *et al*., 1995; Fearnside & Barbosa, 1998; Graça *et al*., 1999; Sorrensen, 2000; Sampaio *et al*., 2003). The majority of the remaining slashed vegetation (from 60 to 80% of total biomass, represented by the scorched material plus trunks and branches with a DBH above 5-10 cm and roots) is left on the soil during cultivation and fallow phases (Denevan, 1971; McGrath, 1987; Fearnside & Barbosa, 1998; Graça *et al.*, 1999; Kauffman, 2003; Sampaio *et al*., 2003; Thomaz *et al*., 2014). Despite not having been evaluated in a systematic manner, this study observed that the fire consumed the same components from the epigeal biomass of the previously mentioned studies.

The efficiency of the fire in the conversion of groundcover in the plots under the *quilombola* SCS was the average for the majority of the EP's (Table 3). Burning the vegetation generally makes only a fraction of the total nutrients fixed in the epigeal biomass immediately available, between 15 to 18% of the total slashed biomass (Ewel *et al*., 1981; Andriesse & Schelhaas, 1987a, 1987b; Johnson *et al*., 2001; Kauffman, 2003; Sampaio *et al*., 2003; Thomaz *et al*., 2014). The remaining biomass will decompose in a slow process that may take from 5 to 20 years (Jordan, 1985; Proctor, 1989), as verified in the *quilombola* SCS. The speed of this process will depend on the slashed vegetation's structure, composition, type; the soil's structure, texture, topography; the type of farming; and the ecological zone in which the SCS is established (Andriesse & Schelhaas, 1987a, 1987b; Brown & Lugo, 1990; Sanchez & Logan, 1992).

The fire, which promotes the production of fertilizing ashes in SCS (Nye & Greenland, 1960; Sampaio *et al*., 2003; Ribeiro Filho *et al*., 2013; Thomaz *et al*., 2014), did not significantly alter the soil fertility *status* of the EP's (Appendix). These soils, when converted, already had an altered and augmented fertility *status* when compared to mature forest soils, probably due to the slow decomposition and mineralization of the unburned biomass from previous cultivation cycles (Ribeiro Filho, 2015).

The possible explanation for the lower fertility of soils fallowed for 25-30 years, when compared to the younger groundcover, is that the vegetation has probably already fixed all the unburned biomass from previous cultivation, since this time period is longer than the one needed for its decomposition (Ribeiro Filho, 2015). Therefore, the regeneration of secondary vegetation that is 25-30 years or older would depend on the remaining stock of nutrients available in the soil, mainly the organic matter (Appendix) (Juo & Manu, 1996; Sampaio *et al*., 2003; Yemefack *et al*., 2006), which would progressively lead to the dystrophic condition found in mature forests. According to Sanchez & Logan (1992), the fallow would not improve fertility *per se*, but simply accumulate nutrients in the plants' biomass.

In the EP investigated here, there was no increase in the temperature of the soil surface after the fire (Table 3) that could compromise the micro and macrofauna and the seeds bank, or promote the volatilization of elements such as Nitrogen and Sulfur (Nye & Greenland, 1960; Kauffman, 2003; Sampaio *et al*., 2003; Yemefack *et al*., 2006; Mamede & Araújo, 2008; Thomaz *et al*., 2014). As mentioned above, the low impact of the fire on the soil may be explained by the partial burning of the slashed biomass (McGrath, 1987; Sampaio *et al*., 2003; Thomaz *et al*., 2014; Ando *et al*., 2014). Moreover, during the burning of vegetation the soil humidity prevents the temperatures from exceeding 100 °C before all the water evaporates (Neary *et al*., 1999; Thomaz *et al*., 2014; Ando *et al.*, 2014). Similar results were obtained by Kauffman *et al*. (1995), Certini (2005), Sampaio *et al*. (2003), and Thomaz *et al*. (2014).

The use of fire by the *quilombolas*, in addition to being a cheap way of making room for cultivation areas, may introduce nutrients to the soil through the ashes, control pests and diseases and increase the mineralization of N (Aweto, 2013). Likewise, the use of fire enables the *quilombola* SCS's farmers to optimize the scarce manpower in this system (Pedroso-Junior *et al*., 2008, 2009; Adams *et al*., 2013; Ianovali, 2015). In other systems (Norgrove & Hauser, 2014), burning the vegetation decreased the risk of farmers being attacked by venomous animals, as well as of predation by animals that were run off by the fire.

Although the exclusion of fire might be necessary to speed up the recovery of SCS and increased the stock of carbon in the ecosystem (Norgrove & Hauser, 2014), the results from the diachronic method showed that the fire used by in the *quilombola* SCS does not risk the viability and sustainability of the system, provided there is enough area available to maintain production. In the communities of São Pedro and Pedro Cubas de Cima investigated here the farming area available for shifting cultivation (secondary vegetation) corresponds to 15%-18% of the territory, respectively (Munari, 2009; Adams *et al*., 2013). In addition to having the function of recovering the soil/vegetation complex affected by the *quilombola* SCS, these areas have important values for human use, such as collecting medicinal plants and wood for making tools and construction, as well as attracting fauna (Pedroso-Junior *et al*., 2008; Taqueda, 2009; Adams *et al*., 2013; Prado *et al.*, 2014; Ianovali, 2015).

CONCLUSIONS

The results of the diachronic method used in this study showed that the *quilombola* SCS does not alter soil's fertility properties during the conversion and cultivation phases, including the use of fire. The plots that have 10-15 years of fallow have more fertile soils than those with 25-30 years. Our initial hypothesis was that the older plots with more biomass would burn more efficiently and would show significant changes in the soil's fertility. However, with the exception of K, the other evaluated soil variables responded in the same manner for both fallow classes of the experimental plots.

This study highlighted the fact that the *quilombola* SCS is quite specific when compared to the general SCS concept. In this system, the maintenance of nutrients of the soil/vegetation complex in the system happens due to a dynamic rarely described in the revised literature. Namely, that the movement of nutrients from the vegetation compartment to agricultural availability uses fire as a key agent, but only when a new area is incorporated into the system at first. After the mature forest areas are cleared, the SCS cycle is established in secondary vegetation plots, where fire is less efficient, leaving unburned biomass that slowly provides nutrients to the system, especially during the fallow period. The soils from fallow areas between ten and 30 years have eutrophic fertility conditions in relation to the mature forests, and are therefore viable from an agronomic standpoint. Therefore, the data on the impact of the *quilombola* SCS on the remaining Atlantic forest soils of the Ribeira Valley (São Paulo, Brazil) concur as proscribed by law, which considers that the ideal fallow cycle for farming is between 10-12 years.

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Appendix. Descriptive analyzes of soil sub-samples collected in the pre-conversion (P1), post-fire (P2), and post-harvest (P3) at three depths in the areas of experimental fields. Legends: * = average significantly different – General Linear Model (MLG) – set with Tukey (P2 different from P1); ** = average significantly different – General Linear Model (MLG) – set with Tukey (P3 different from P1); P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Al = aluminum; SB = sum of bases; CEC = cation exchange capacity; V = saturation of the CEC per base; m = saturation of the CEC per aluminum; O.M. = organic matter; O.C. = organic carbon; Total N = Total Nitrogen; WMD = Weighted Medium Diameter; GAD = Geometric Average Diameter.

(Continue)

Área PCC2	Soil depht (cm)	N	pH (H_2O)			pH (KCl)			P ($mg.kg^{-1}$)			K (mmloc kg^{-1})		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	5.48	5.84	5.36	4.84	4.68	4.94	2.60	4.20	2.00	4.02	5.38	6.60
	5.00	9	5.10	5.07	5.08	4.35	4.12	4.55	1.50	2.00	2.00	2.02	4.30	4.17
	10.00	9	5.03	4.78	4.87	4.10	3.85	4.15	1.5	1.17	1.67	1.35	1.45	3.50
Standard deviation	1.00	9	0.25	0.61	0.55	0.33	0.55	0.54	0.55	2.17	0.71	1.34	2.04	3.21
	5.00	9	0.25	0.67	0.24	0.30	0.49	0.34	0.55	1.10	0.63	0.29	2.86	2.32
	10.00	9	0.12	0.40	0.22	0.17	0.30	0.18	0.55	0.41	0.82	0.31	0.79	2.26

Área PCC2	Soil depht (cm)	N	Ca (mmloc kg^{-1})			Mg (mmloc kg^{-1})			Al (mmloc kg^{-1})			H + Al (mmloc kg^{-1})		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	71.40	76.40	76.60	34.60	28.40	39.00	2.60	5.40	2.60	80.80	77.20	72.60
	5.00	9	35.83	34.17	59.50	19.17	15.67	22.50	6.17	9.00	3.50	69.83	73.17	62.33
	10.00	9	10.00	11.50	14.33	9.83	8.33	10.00	11.83	14.00	5.67	63.00	69.33	59.50
Standard deviation	1.00	9	23.30	32.99	38.58	14.12	14.01	18.59	2.07	2.51	3.05	6.61	11.86	7.83
	5.00	9	17.54	21.66	40.36	7.57	6.38	12.37	5.12	9.01	4.81	8.08	20.48	6.31
	10.00	9	6.32	12.11	5.35	1.60	4.84	3.10	4.71	10.22	2.73	2.97	7.99	6.50

Área PCC2	Soil depht (cm)	N	SB (mmloc kg^{-1})			CEC (mmloc kg^{-1})			V (%)			m (%)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	110.02	110.04	122.20	190.72	187.30	194.80	56.20	56.40	61.00	3.00	2.80	5.60
	5.00	9	57.02	54.18	86.17	126.95	127.28	148.50	43.33	41.17	53.50	12.67	7.50	18.33
	10.00	9	20.98	21.63	27.83	83.88	91.18	87.33	24.67	21.67	31.50	37.17	18.17	42.50
Standard deviation	1.00	9	35.55	48.19	42.04	31.85	39.30	38.01	10.80	13.63	11.94	4.12	5.72	4.83
	5.00	9	24.50	29.80	51.35	18.64	31.28	49.62	13.16	16.63	17.96	13.03	15.20	22.38
	10.00	9	7.66	17.75	7.57	5.56	23.24	7.34	7.15	11.48	7.56	14.12	11.00	28.44

Área PCC2	Soil depht (cm)	N	O.M. (g/kg)			O.C. (g/kg)			Total N (g/kg)				Total sand (g/kg)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	N	P1	P2	P3
Average	1.00	9	93.20	79.40	202.20*	54.20	45.80	117.40	4.14	3.44	2.26	3	224.67	292.33	315.33
	5.00	9	48.50	48.67	52.33	28.00	28.17	30.50	3.42	3.71	2.08	3	202.33	265.00	281.67
	10.00	9	30.83	31.33	43.83	17.83	18.17	25.50	2.43	2.52	2.12	3	181.67	247.67	248.33
Standard deviation	1.00	9	29.29	25.44	82.31	17.05	14.96	47.56	0.78	1.06	0.51	3	16.17	15.31	4.16
	5.00	9	4.76	6.38	6.12	2.76	3.82	3.51	0.36	0.95	0.41	3	12.66	13.08	1.53
	10.00	9	3.92	6.31	22.46	2.23	3.54	13.14	1.17	0.71	0.72	3	26.08	12.74	8.50

Appendix. (Continue)

Área PCC2	Soil depht (cm)	N	Silt (g/kg)			Clay (g/kg)			Aggregate stability (WMD)			Aggregate stability (GAD)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	3	289.67	308.67	297.00	401.33	399.00	387.33	2.10	2.38	2.46	1.60	1.50	2.02
	5.00	3	313.33	286.33	299.00	484.67	448.67	419.00						
	10.00	3	311.00	267.67	267.67	591.67	484.67							
Standard deviation	1.00	3	99.68	14.57	3.61	100.76	6.56	1.15	0.29	0.19	0.75	0.01	0.09	0.72
	5.00	3	36.07	20.23	15.62	24.68	33.20	13.86						
	10.00	3	124.15	31.50	8.39	50.36	39.17							

Área PCC6	Soil depht (cm)	N	pH (H2O)			pH (KCl)			P ($mg.kg^{-1}$)			K (mmloc kg^{-1})		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	5.12	5.60	4.59	4.14	4.64	4.07	16.89	40.44*	20.78	7.33	14.62*	6.33
	5.00	9	4.70	4.78	4.32	3.80	3.77	3.83	7.11	12.11	9.33	3.39	6.11	4.22
	10.00	9	4.63	4.54	4.43	3.74	3.58	3.79	3.78	4.44	8.89	1.89	2.58	2.44
Standard deviation	1.00	9	0.29	0.50	0.19	0.21	0.52	0.22	7.42	21.23	10.83	2.93	4.77	2.60
	5.00	9	0.22	0.20	0.16	0.07	0.11	0.10	3.10	4.46	3.39	1.51	1.75	2.59
	10.00	9	0.17	0.13	0.21	0.07	0.11	0.06	1.56	1.13	11.87	0.50	1.04	1.01

Área PCC6	Soil depht (cm)	N	Ca (mmloc kg^{-1})			Mg (mmloc kg^{-1})			Al (mmloc kg^{-1})			H + Al (mmloc kg^{-1})		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	61.33	79.44	55.11	37.56	47.44	34.78	7.33	4.78	14.33	125.22	91.56	117.67
	5.00	9	24.89	35.89	29.78	19.00	24.78	19.44	24.11	15.22	29.56	121.89	112.67	119.89
	10.00	9	10.44	14.89	14.11	8.89	11.44	9.78	37.67	31.78	38.22	107.44	102.22	105.56
Standard deviation	1.00	9	14.92	26.25	19.06	6.52	9.32	10.85	8.69	3.96	7.78	16.76	19.26	27.83
	5.00	9	3.30	12.95	8.73	5.81	6.61	3.64	8.72	6.30	8.40	14.97	16.81	24.78
	10.00	9	3.36	3.48	7.08	4.54	3.32	4.24	3.35	3.07	6.91	7.54	10.21	18.43

Área PCC6	Soil depht (cm)	N	SB (mmloc kg^{-1})			CEC (mmloc kg^{-1})			V (%)			m (%)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	106.31	141.54	96.22	231.73	233.20	213.89	46.22	59.89	44.56	6.22	3.78	14.33
	5.00	9	47.51	66.68	53.44	169.40	179.26	173.33	27.89	36.89	31.33	32.89	19.67	35.89
	10.00	9	21.19	28.63	26.33	128.79	130.99	131.89	16.56	21.89	19.78	64.44	53.00	60.00
Standard deviation	1.00	9	14.19	33.83	27.39	21.94	31.03	45.26	4.74	10.15	7.33	6.53	4.84	10.12
	5.00	9	8.46	17.52	10.69	20.24	22.80	23.99	3.41	7.75	7.75	11.16	11.41	10.61
	10.00	9	7.68	6.19	10.85	9.79	13.81	22.50	4.90	3.59	6.42	8.17	7.12	11.95

Appendix. (Continue)

Área PCC6	Soil depht (cm)	N	O.M. (g/kg)			O.C. (g/kg)			Total N (g/kg)			N	Total sand (g/kg)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3		P1	P2	P3
Average	1.00	9	118.44	108.22	206.44**	68.56	62.78	119.56**	3.92	3.76	1.95**	3	48.00	98.00	87.67
	5.00	9	80.44	67.56	125.22	46.44	39.11	72.56	3.47	4.10	2.38	3	40.33	56.33	67.00
	10.00	9	45.00	47.89	45.56	26.11	27.89	26.44	3.22	3.31	1.89	3	39.33	41.33	41.33
Standard deviation	1.00	9	25.58	18.85	72.68	14.79	10.87	42.21	1.30	1.03	0.74	3	11.53	15.87	11.59
	5.00	9	24.64	11.59	62.02	14.41	6.68	35.97	1.73	0.47	0.57	3	12.66	6.11	11.00
	10.00	9	5.96	3.33	8.62	3.48	1.90	5.10	1.49	0.34	0.73	3	12.06	4.73	7.77

Área PCC6	Soil depht (cm)	N	Silt (g/kg)			Clay (g/kg)		
			P1	P2	P3	P1	P2	P3
Average	1.00	3	538.67	520.00	574.00	413.67	382.00	338.33
	5.00	3	563.33	507.67	586.00	396.00	435.67	347.33
	10.00	3	562.00	489.67	589.00	398.67	469.33	369.00
Standard deviation	1.00	3	51.43	10.44	17.32	62.07	5.57	5.86
	5.00	3	16.26	28.54	13.53	28.35	28.75	13.05
	10.00	3	34.07	19.30	12.17	44.75	23.63	13.75

Área PCC7	Soil depht (cm)	N	pH (H_2O)			pH (KCl)			P ($mg.kg^{-1}$)			K ($mmloc\ kg^{-1}$)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	3.91	4.06	3.98	3.46	3.43	3.57	5.67	12.78*	11.11	3.36	4.36	3.33
	5.00	9	3.92	3.77	3.58	3.50	3.37	3.46	2.89	14.00	4.56	1.89	3.47	2.00
	10.00	9	4.06	3.80	3.68	3.58	3.43	3.51	2.00	4.89	2.89	1.34	2.19	2.00
Standard deviation	1.00	9	0.38	0.47	0.48	0.16	0.23	0.26	1.12	9.31	6.33	0.86	2.22	1.32
	5.00	9	0.30	0.28	0.20	0.13	0.20	0.14	0.93	21.89	2.24	0.29	0.98	0.50
	10.00	9	0.25	0.22	0.24	0.11	0.21	0.09	0.71	4.43	1.54	0.19	1.16	0.71

Área PCC7	Soil depht (cm)	N	Ca ($mmloc\ kg^{-1}$)			Mg ($mmloc\ kg^{-1}$)			Al ($mmloc\ kg^{-1}$)			H+Al ($mmloc\ kg^{-1}$)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	4.56	8.67	9.33	10.78	10.11	8.89	55.56	38.67	41.89	168.11	140.78	130.22
	5.00	9	1.11	3.33	3.00	3.56	5.67	2.56	51.00	44.78	47.56	121.33	133.67	103.44
	10.00	9		0.67	2.33	2.00	3.11	1.44	45.33	41.56	42.44	94.44	106.56	99.89
Standard deviation	1.00	9	2.35	6.12	7.98	4.74	5.88	6.60	11.22	14.97	16.39	40.48	27.03	34.06
	5.00	9	0.33	2.40	1.87	1.51	2.18	1.33	6.76	10.00	9.53	22.27	16.16	18.60
	10.00	9		1.41	1.58	0.50	2.20	0.73	4.03	7.91	6.42	15.22	10.44	23.81

Appendix. (Continue)

Área PCC7	Soil depht (cm)	N	SB (mmloc kg^{-1})			CEC (mmloc kg^{-1})			V (%)			m (%)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	18.61	23.22	21.56	186.68	163.96	151.78	10.44	14.78	15.11	74.67	62.44	66.11
	5.00	9	6.49	12.47	7.67	127.68	146.14	111.11	5.11	8.78	7.33	88.67	78.11	86.11
	10.00	9	4.12	6.96	5.89	98.54	113.33	105.78	4.44	6.22	5.33	91.56	85.67	88.00
Standard deviation	1.00	9	6.81	13.66	15.66	42.45	17.49	23.72	3.43	9.73	11.78	9.26	21.01	21.98
	5.00	9	1.60	4.84	3.28	23.11	14.21	17.69	1.36	3.87	3.35	2.60	8.87	5.37
	10.00	9	0.73	4.21	2.47	15.28	11.49	24.96	1.01	3.15	1.73	1.51	7.78	3.61

Área PCC7	Soil depht (cm)	N	O.M. (g/kg)			O.C. (g/kg)			Total N (g/kg)				Total sand (g/kg)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	N	P1	P2	P3
Average	1.00	9	116.33	81.33	122.11	67.44	47.00	70.89	3.39	4.47	2.20	3	144.33	153.00	169.67
	5.00	9	65.56	72.11	49.11	38.00	41.78	28.44	3.34	3.23	2.16	3	170.33	155.33	166.00
	10.00	9	44.67	51.33	36.67	25.89	29.89	21.22	3.03	3.05	1.87	3	150.67	164.67	197.67
Standard deviation	1.00	9	14.77	23.84	72.65	8.68	13.84	41.92	1.43	0.84	0.72	3	29.54	14.18	33.84
	5.00	9	27.68	21.23	8.82	16.09	12.19	4.90	1.44	0.57	0.77	3	45.36	25.42	45.90
	10.00	9	13.56	11.68	10.05	8.08	6.83	5.91	1.54	0.54	0.59	3	38.55	35.47	20.03

Área PCC7	Soil depht (cm)	N	Silt (g/kg)			Clay (g/kg)			Aggregate stability (WMD)			Aggregate stability (GAD)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	3	414.00	385.33	398.00	441.67	461.67	432.67	2.61	2.43	2.59	1.60	1.49	1.52
	5.00	3	373.33	379.00	394.33	456.00	465.67	439.67						
	10.00	3	402.67	321.33	363.00	446.67	513.67	439.33						
Standard deviation	1.00	3	61.51	22.90	33.87	39.43	11.93	67.66	0.15	0.25	0.13	0.02	0.10	0.05
	5.00	3	54.93	58.85	47.96	31.10	44.23	74.20						
	10.00	3	20.60	41.40	61.99	30.62	6.51	73.05						

Área SP2	Soil depht (cm)	N	pH (H_2O)			pH (KCl)			P (mg.kg^{-1})			K (mmloc kg^{-1})		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	4.88	4.61	5.24	3.91	4.08	4.79	3.78	7.67	4.11	3.18	8.40*	3.78
	5.00	9	4.61	4.44	4.76	3.70	3.74	4.34**	2.33	4.44	2.22	1.66	6.62*	2.11
	10.00	9	4.63	4.34	4.67	3.70	3.64	4.37**	1.89	2.33	1.89	1.08	3.19	1.78
Standard deviation	1.00	9	0.39	0.50	0.42	0.31	0.55	1.30	1.20	4.03	2.32	1.15	4.76	2.28
	5.00	9	0.21	0.42	0.17	0.10	0.22	1.20	0.87	1.94	0.83	0.56	4.61	1.05
	10.00	9	0.17	0.30	0.19	0.10	0.10	1.18	0.60	0.87	1.05	0.22	1.90	0.83

Appendix. (Continue)

Área SP2	Soil depht (cm)	N	Ca (mmloc kg^{-1})			Mg (mmloc kg^{-1})			Al (mmloc kg^{-1})			H + Al (mmloc kg^{-1})		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	39.00	37.44	39.78	19.22	16.00	16.78	14.44	11.11	13.11	113.89	101.00	117.78
	5.00	9	13.89	18.00	10.56	8.67	9.78	7.11	27.89	15.11	28.22	94.33	105.11	119.78
	10.00	9	6.11	7.33	7.33	4.89	4.44	5.33	30.11	20.22	30.89	82.78	95.44	111.56
Standard deviation	1.00	9	18.57	29.19	25.12	6.85	7.86	7.77	9.40	9.40	12.15	17.96	17.40	17.69
	5.00	9	9.53	8.67	5.61	3.64	3.11	3.06	7.70	7.62	10.49	19.49	11.71	20.04
	10.00	9	5.30	3.50	8.35	1.62	2.30	4.24	8.15	9.30	10.47	13.09	11.07	35.88

Área SP2	Soil depht (cm)	N	SB (mmloc kg^{-1})			CEC (mmloc kg^{-1})			V (%)			m (%)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	61.43	61.82	60.33	175.30	162.81	178.11	34.33	35.67	32.00	22.00	21.00	24.78
	5.00	9	24.42	34.43	19.89	118.71	139.61	139.67	19.78	24.11	14.33	55.44	32.67	58.11
	10.00	9	12.24	15.03	14.44	95.03	110.63	126.00	13.22	13.44	11.00	70.67	54.89	69.44
Standard deviation	1.00	9	25.47	38.94	32.55	24.17	30.64	30.93	10.98	16.39	15.37	17.13	18.03	28.19
	5.00	9	12.81	14.24	9.09	25.06	16.71	17.69	9.05	8.28	6.67	19.16	19.79	19.09
	10.00	9	6.44	5.79	12.99	8.64	11.01	43.50	7.92	5.03	6.20	16.84	22.70	19.51

Área SP2	Soil depht (cm)	N	O.M. (g/kg)			O.C. (g/kg)			Total N (g/kg)				Total sand (g/kg)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	N	P1	P2	P3
Average	1.00	9	104.78	71.33	69.56	60.67	41.44	40.33	2.34	3.38	2.09	3	418.33	424.67	368.67
	5.00	9	52.44	55.78	51.00	30.67	32.33	29.67	3.00	3.55	2.13	3	402.00	428.67	360.00
	10.00	9	42.00	43.33	46.11	24.33	25.22	26.67	2.75	3.07	2.31	3	354.00	383.00	351.67
Standard deviation	1.00	9	26.21	16.50	23.74	14.96	9.55	13.59	0.91	1.05	0.28	3	55.77	36.30	64.86
	5.00	9	8.32	6.85	4.56	4.85	4.18	2.60	1.41	0.56	0.23	3	37.59	55.59	18.36
	10.00	9	4.90	3.28	25.43	2.74	1.79	14.83	0.75	0.67	0.40	3	80.73	25.71	33.01

Área SP2	Soil depht (cm)	N	Silt (g/kg)			Clay (g/kg)			Aggregate stability (WMD)			Aggregate stability (GAD)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	3	262.00	231.33	180.67	319.67	344.00	451.00	2.67	2.61	1.58	1.58	2.79	1.59
	5.00	3	246.00	225.33	183.67	352.33	346.00	456.00						
	10.00	3	235.33	228.67	173.67	410.67	388.33	474.67						
Standard deviation	1.00	3	46.23	18.15	9.87	14.43	31.43	54.95	0.04	0.05	0.02	0.02	0.02	0.00
	5.00	3	12.29	50.52	14.05	25.54	34.70	31.32						
	10.00	3	24.50	12.50	14.05	63.45	37.87	38.28						

Appendix. (Continue)

Área SP5	Soil dephth (cm)	N	pH (H_2O)			pH (KCl)			P ($mg.kg^{-1}$)			K ($mmoloc\ kg^{-1}$)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	5.52	5.32	5.74	4.26	4.34	4.60	5.22	11.33	4.89	5.10	15.09*	9.33
	5.00	9	5.12	5.13	5.12	3.89	4.10	4.18	3.78	8.22	3.89	3.02	11.59	5.89
	10.00	9	5.02	4.79	4.93	3.71	3.66	3.83	2.89	3.44	2.11	1.57	4.33	3.11
Standard deviation	1.00	9	0.36	0.40	0.44	0.24	0.46	0.68	4.58	8.96	2.47	2.00	6.22	7.35
	5.00	9	0.33	0.30	0.53	0.16	0.34	0.58	2.59	8.00	1.27	0.66	3.15	5.11
	10.00	9	0.27	0.21	0.30	0.09	0.09	0.16	2.37	2.88	0.93	0.21	1.19	2.67

Área SP5	Soil dephth (cm)	N	Ca ($mmoloc\ kg^{-1}$)			Mg ($mmoloc\ kg^{-1}$)			Al ($mmoloc\ kg^{-1}$)			H + Al ($mmoloc\ kg^{-1}$)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	36.22	32.44	42.33	23.11	23.78	24.56	8.33	8.78	10.44	86.11	80.67	95.00
	5.00	9	18.00	23.11	25.56	15.00	18.67	16.89	18.67	9.22	12.89	86.56	87.11	89.89
	10.00	9	6.33	6.78	8.22	7.56	8.67	7.33	26.22	25.00	23.89	74.00	85.44	85.89
Standard deviation	1.00	9	13.18	9.72	27.81	6.86	5.93	7.81	8.14	6.80	10.84	16.19	13.77	62.17
	5.00	9	11.37	9.58	18.31	6.32	4.87	7.04	10.30	5.12	13.03	10.20	9.41	27.55
	10.00	9	4.69	2.95	6.22	4.33	2.50	2.78	6.22	3.61	13.17	7.75	9.89	21.05

Área SP5	Soil dephth (cm)	N	SB (mmoloc kg-1)			CEC (mmoloc kg-1)			V (%)			m (%)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	64.67	71.34	76.22	150.77	152.11	171.22	42.78	46.78	46.67	13.33	10.78	14.89
	5.00	9	35.99	53.58	48.33	122.44	140.60	138.22	28.89	37.78	34.33	36.33	15.56	22.11
	10.00	9	15.54	20.06	18.67	89.58	105.50	104.56	16.67	18.67	17.89	64.11	55.78	54.56
Standard deviation	1.00	9	19.02	18.03	35.07	10.00	19.60	49.72	12.00	9.13	22.11	14.27	7.31	16.94
	5.00	9	17.04	14.80	28.28	11.05	16.30	28.47	11.43	6.92	15.87	20.21	9.38	23.59
	10.00	9	7.93	4.57	11.14	14.42	13.00	22.27	6.08	2.96	9.62	13.32	8.36	21.66

Área SP5	Soil dephth (cm)	N	O.M. (g/kg)			O.C. (g/kg)			Total N (g/kg)				Total sand (g/kg)		
			P2	P3	P1	P1	P3	P3	P1	P2	P3	N	P1	P2	P3
Average	1.00	9	96.44	73.22	66.78	55.78	42.33	38.78	2.13	3.33	2.38	3	102.33	123.33	142.67
	5.00	9	58.78	60.78	55.22	34.00	35.33	32.11	2.12	3.22	1.93	3	116.00	128.67	128.00
	10.00	9	38.67	42.67	38.33	22.67	24.78	22.33	2.61	2.92	2.13	3	151.33	171.67	172.33
Standard deviation	1.00	9	8.28	13.75	14.51	4.79	7.98	8.45	0.69	0.50	0.78	3	10.26	17.67	21.22
	5.00	9	4.24	5.14	5.14	2.60	3.08	3.02	0.85	0.92	0.62	3	10.82	13.80	8.54
	10.00	9	3.67	6.63	8.85	2.29	3.70	5.02	0.98	0.66	0.66	3	31.01	16.26	23.12

Appendix. (Continue)

Área SP5	Soil depht (cm)	N	Silt (g/kg)			Clay (g/kg)			Aggregate stability (WMD)			Aggregate stability (GAD)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	3	527.33	467.00	470.33	370.67	409.67	387.00	2.57	2.36	2.71	1.57	1.57	1.56
	5.00	3	497.33	496.33	487.33	386.33	375.00	385.00						
	10.00	3	453.33	456.00	420.67	395.33	372.67	407.00						
Standard deviation	1.00	3	21.22	71.01	5.69	30.62	65.49	15.62	0.07	0.07	0.13	0.04	0.01	0.04
	5.00	3	25.32	28.99	17.67	15.31	26.21	9.85						
	10.00	3	20.65	1.00	19.43	14.15	15.95	35.68						

Área SP6	Soil depht (cm)	N	pH (H_2O)			pH (KCl)			P (mg.kg^{-1})			K (mmloc kg^{-1})		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	4.68	4.61	4.31	3.88	3.80	3.88	3.11	5.78	4.33	2.51	4.11	3.56
	5.00	9	4.51	4.33	4.27	3.78	3.59	3.74	2.56	3.33	3.22	1.62	3.21	2.11
	10.00	9	4.50	4.40	4.31	3.70	3.53	3.71	1.44	1.78	1.89	1.03	2.06	1.78
Standard deviation	1.00	9	0.39	0.44	0.19	0.24	0.37	0.25	0.60	3.19	1.41	0.65	1.61	3.24
	5.00	9	0.22	0.30	0.19	0.15	0.15	0.07	0.73	0.50	1.09	0.36	1.19	1.54
	10.00	9	0.14	0.23	0.38	0.11	0.10	0.08	0.53	0.67	0.60	0.31	0.78	1.39

Área SP6	Soil depht (cm)	N	Ca (mmloc kg^{-1})			Mg (mmloc kg^{-1})			Al (mmloc kg^{-1})			H+Al (mmloc kg^{-1})		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	18.78	29.56	33.33	15.89	19.11	17.89	23.22	24.11	29.00	122.67	139.22	124.11
	5.00	9	6.33	13.78	9.89	8.78	12.67	7.89	31.89	30.00	28.44	108.89	127.44	113.00
	10.00	9	2.44	4.22	4.22	4.56	5.22	3.56	33.22	36.11	33.78	85.22	101.11	90.56
Standard deviation	1.00	9	11.40	15.83	40.56	4.57	6.47	8.70	10.29	12.19	16.39	21.23	33.63	40.48
	5.00	9	3.57	9.96	6.66	1.79	6.32	3.22	7.29	13.36	14.08	14.75	19.36	20.74
	10.00	9	1.74	1.86	2.99	1.67	2.05	1.33	7.01	4.59	5.83	12.96	8.39	19.54

Área SP6	Soil depht (cm)	N	SB (mmloc kg^{-1})			CEC (mmloc kg^{-1})			V (%)			m (%)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	9	37.32	52.86	54.78	159.89	192.04	178.89	23.33	27.78	28.00	39.67	33.00	38.33
	5.00	9	16.61	29.46	19.89	125.57	156.76	132.89	13.56	18.33	14.89	65.11	49.44	55.78
	10.00	9	8.08	11.29	9.56	93.26	112.47	100.11	9.11	10.11	9.44	79.89	76.11	78.11
Standard deviation	1.00	9	14.83	22.47	48.69	20.87	33.48	74.03	8.97	12.57	12.20	18.73	17.91	21.06
	5.00	9	3.57	16.16	9.06	12.47	27.13	23.82	4.56	7.87	5.99	10.87	19.14	25.57
	10.00	9	2.73	3.80	3.97	11.41	9.15	21.87	4.28	3.22	2.60	9.44	7.51	7.39

Appendix. (Conclusion)

Área SP6	Soil depht (cm)	N	O.M. (g/kg)			O.C. (g/kg)			Total N (g/kg)				Total sand (g/kg)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	N	P1	P2	P3
Average	1.00	9	103.00	105.56	105.00	59.67	61.22	61.00	3.60	3.50	2.26	3	146.67	130.67	151.33
	5.00	9	61.33	66.33	60.44	35.56	38.33	35.11	3.03	3.63	2.56	3	146.33	123.00	128.67
	10.00	9	40.44	44.67	39.78	23.44	25.89	23.11	2.87	2.85	2.51	3	123.00	116.00	118.00
Standard deviation	1.00	9	18.43	23.77	32.12	10.82	13.77	18.45	1.08	0.78	0.51	3	8.74	17.21	27.15
	5.00	9	9.92	16.57	13.91	5.46	9.70	7.83	1.35	0.80	0.72	3	22.59	7.81	8.02
	10.00	9	6.29	5.85	7.74	3.71	3.10	4.51	1.55	0.67	0.64	3	24.43	12.53	15.59

Área SP6	Soil depht (cm)	N	Silt (g/kg)			Clay (g/kg)			Aggregate stability (WMD)			Aggregate stability (GAD)		
			P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Average	1.00	3	442.33	495.67	436.67	411.00	374.00	411.67	2.75	2.55	2.66	1.60	1.60	1.58
	5.00	3	451.33	482.00	454.67	402.67	394.67	416.67						
	10.00	3	431.67	427.00	419.67	445.00	456.67	462.33						
Standard deviation	1.00	3	32.01	20.82	14.57	38.63	19.08	30.17	0.11	0.07	0.06	0.01	0.01	0.01
	5.00	3	46.69	30.35	6.43	51.52	34.79	4.51						
	10.00	3	23.03	32.36	27.32	38.30	43.04	27.97						