

# DIVISÃO 2 - PROCESSOS E PROPRIEDADES DO SOLO

## Comissão 2.1 - Biologia do solo

### MICROBIAL BIOMASS AND SOIL CHEMICAL PROPERTIES UNDER DIFFERENT LAND USE SYSTEMS IN NORTHEASTERN PARÁ<sup>(1)</sup>

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#### SUMMARY

The increase in agricultural production in the Brazilian Amazon region is mostly a result of the agricultural frontier expansion, into areas previously influenced by humans or of native vegetation. At the same time, burning is still used to clear areas in small-scale agricultural systems, leading to a loss of the soil productive capacity shortly after, forcing the opening of new areas. This study had the objective of evaluating the effect of soil preparation methods that involve plant residue shredding, left on the surface or incorporated to the soil, with or without chemical fertilization, on the soil chemical and biological properties. The experiment was conducted in 1995, in an experimental field of Yellow Latosol (Oxisol) of the Embrapa Amazônia Oriental, northeastern Pará (Brazil). The experiment was arranged in randomized blocks, in a 2x6 factorial design, with two management systems and six treatments evaluated twice. The management systems consisted of rice (*Oriza sativa*), followed by cowpea (*Vigna unguiculata*) with manioc (*Manihot esculenta*). In the first system the crops were planted in two consecutive cycles, followed by a three-year fallow period (natural regrowth); the second system consisted of one cultivation cycle and was left fallow for three years. The following treatments were applied to the secondary forest vegetation: slash and burn, fertilized with NPK (Q+NPK); slash and burn, without fertilizer NPK (Q-NPK); cutting and shredding, leaving the residues on the soil surface, fertilized with NPK (C+NPK); cutting and shredding, leaving residues on the soil surface, without fertilizer (C-NPK); cutting and shredding, with residue

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incorporation and fertilized with NPK (I+NPK); cutting and shredding, with residue incorporation and without NPK fertilizer (I-NPK). The soil was sampled in the rainier season (April 2006) and in the drier season (September 2006), in the 0–0.1 m layer. From each plot, 10 simple samples were collected in order to generate a composite sample. In the more intensive management system the contents of microbial C (Cmic) and microbial N (Nmic) were higher, while the C (Corg) level was higher in the less intensive system. The treatments with highest Cmic and Nmic levels were those with cutting, shredding and distribution of biomass on the soil surface. Under both management systems, the chemical characteristics were in ranges that classify the soil as little fertile, although P and K (in the rainy season) were higher in the less intensive management system.

**Index terms:** secondary vegetation, burning, biomass shredding, cultivation cycles.

**RESUMO:** *BIOMASSA MICROBIANA E ATRIBUTOS QUÍMICOS DO SOLO SOB DIFERENTES SISTEMAS DE MANEJO NO NORDESTE PARAENSE*

*O aumento da produção agrícola na Amazônia brasileira tem ocorrido devido, em grande parte, à expansão da fronteira agrícola, utilizando áreas já antropizadas ou avançando sobre a vegetação primária. Ao mesmo tempo, os sistemas agrícolas, na pequena produção, continuam utilizando o fogo no preparo da área, o que leva à perda da capacidade produtiva dos solos em curto espaço de tempo, forçando a abertura de novas áreas. Este trabalho avaliou o efeito de métodos de preparo do solo e tempo de pousio que envolvem queima e trituração da vegetação, com permanência na superfície ou incorporada ao solo, com ou sem adubação mineral, em duas épocas do ano sobre os atributos químicos e biológicos do solo. O experimento foi instalado em 1995 em um Latossolo Amarelo do campo experimental da Embrapa Amazônia Oriental, no nordeste do Estado do Pará. O delineamento experimental foi em blocos casualizados, arranjados em esquema fatorial 2 x 6, sendo dois sistemas de manejo e seis tratamentos, estudados em duas épocas de coleta. Os sistemas de manejo envolveram as culturas de arroz (*Oriza sativa*), seguido de feijão-caupi (*Vigna unguiculata*) e mandioca (*Manihot esculenta*). Um sistema constou de dois ciclos de cultivo seguidos, deixando em pousio por três anos; e o outro, de um ciclo de cultivo, deixando em pousio por três anos. Os tratamentos foram: corte e queima da vegetação, com adubação NPK (Q+NPK); corte e queima da vegetação, sem adubação NPK (Q-NPK); corte e trituração da vegetação, deixando-a na superfície do solo, com adubação NPK (C+NPK); corte e trituração da vegetação, deixando-a na superfície do solo, sem adubação NPK (C-NPK); corte e trituração da vegetação, com incorporação e com adubação NPK (I+NPK); e corte e trituração da vegetação, com incorporação e sem adubação NPK (I-NPK). As coletas de solo foram realizadas na estação mais chuvosa (abril de 2006) e na menos chuvosa (setembro de 2006), na profundidade de 0,0–0,1 m. Em cada parcela, foram coletadas 10 amostras simples para compor uma amostra composta. O sistema de manejo mais intensivo apresentou maiores teores de C microbiano (Cmic) e N microbiano (Nmic), ao passo que o sistema menos intensivo mostrou maior teor de C orgânico. Os tratamentos que apresentaram maior teor de Cmic e Nmic foram aqueles em que houve corte, trituração e deposição da biomassa na superfície do solo. Os atributos químicos nos dois sistemas de manejo encontram-se em faixas que enquadram os solos como de baixa fertilidade; no entanto, P e K (no período chuvoso) foram mais elevados no sistema de manejo menos intensivo.*

*Termos de indexação:* vegetação secundária, queima, trituração da biomassa, ciclo de cultivos.

## INTRODUCTION

The need to increase agricultural production in Brazil to meet the growing food demand has resulted, inevitably, in an expansion of the agricultural frontier into anthropic or native forest areas. Inappropriate farming practices, such as the use of fire and non-use of conservation techniques has triggered an accelerated degradation of soils in the Amazon.

In the Eastern Amazonia, Denich et al. (2004) compared the slash-and-burn with the cutting and shredding system and found a negative nutrient balance in the soil. Burning is being used as a cheap way of clearing areas, aside from releasing nutrients retained in the biomass, which decreases soil acidity, stimulates microbial activity and reduces weed invasion (Sanchez & Salinas, 1982; Sampaio et al., 2008). On the other hand, the burning of vegetation

as a way of preparing the area for planting has been condemned in view of the nutrient losses, environmental degradation, gradual loss of biodiversity, greenhouse gas emissions into the atmosphere, increased soil erosion, changes in the hydrological and biogeochemical cycle and risks of accidental fires (Ruivo et al., 2007). The absence of management practices to reduce or avoid burning has reduced the period of agricultural exploitation to less than 10 years (Metzger, 2000).

The reduction of fallow periods has led to a new vegetation composition with mostly shrubs, which has failed to restore soil properties to appropriate levels, mainly in terms of organic matter (OM). Therefore, technologies for improved efficiency in nutrient cycling and increased OM may help increase the productivity in burning-free systems and contribute significantly to the sustainability of agricultural production in the tropics, by enhancing the use of nutrients from the remaining vegetation.

The system of cutting and mechanical shredding of fallow vegetation, leaving the residues on the soil surface, has been an alternative technology to replace burning and mitigate other deleterious impacts of agricultural practices (Kato et al., 1999, 2006). However, the sustainability of agroecosystems depends crucially on the quality of the decomposing organic material, which can be a significant and potentially mineralizable portion of nutrients readily available to plants. Nutrient cycling in Amazonian ecosystems is fast and the response strong to seasonal fluctuations in humidity and temperature, but also the type of cultivation and residue management.

The microbial community is an OM fraction that represents an important ecological characteristic, considered a nutrient and energy reservoir and, consequently, potential supplier of plant nutrients (Gama-Rodrigues et al., 1994). The microorganisms absorb C and N at a ratio of 30:1. The development of microorganisms depends on the availability of OM, aeration, moisture, temperature, structure, nutrients, pH and micro-parasites and antagonists (Gama-Rodrigues et al., 2008). The study of soil microbial biomass (SMB) and its activity is important for agriculture, since the higher the SMB, the greater is the temporary immobilization of C, N and other nutrients and therefore the lower the nutrient loss from the soil/plant system (Wang et al., 2003; Moreira & Malavolta, 2004). Moreover, a high microbial activity as in the tropics, may increase the availability of nutrients to rates exceeding the capacity or demand of plant uptake.

Once the intensity of biological activity is highest in the topsoil, negative interferences with the action of microorganisms and thus nutrient availability are likely if the surface layer is removed by the soil use and/or inadequate management. The C content of soil and microbial biomass are influenced by the type of land use and represent important indicators of the

modifications caused by soil cultivation (De-Polli & Guerra, 1996; Gama-Rodrigues et al., 2005).

Thus, SMB can be seen as an ecological attribute to assess land use techniques, allowing more rapid information about changes in soil organic properties caused by crops or forest devastation and to evaluate the regeneration of soils after removal of its surface layer (Friguetto & Schineider, 2000; Zimmermann & Frey, 2002; Gama-Rodrigues et al., 2008).

The purpose of this study was to assess how methods of soil management and fallow periods that involve burning and shredding of plant residues left on the surface or incorporated into the soil, with and without mineral fertilization, in two growing seasons influence the soil chemical properties and microbial biomass.

## MATERIAL AND METHODS

The study was conducted in an experimental field of Embrapa Amazônia Oriental - CPATU (lat 0 ° 58 ' and 01 ° 38 ' S; long 47 ° 26 ' and 48 ° 42 ' W; 39 m asl) in Igarapé-Açu, in the Northeast of the State of Pará. The soil was characterized as cohesive typical Yellow Latosol (Oxisol) of, medium texture, derived from the Barreiras Formation (Embrapa, 2006). The climate is hot and humid, Am<sub>1</sub> (Köppen classification). The annual rainfall is approximately 2,500 mm and relative humidity 80–90 %, with possible seasonal variations. The two seasons are well-defined, with an average maximum temperature and minimum average monthly range of 33.7 and 21.5 °C, respectively (Pacheco & Bastos, 2007).

Prior to the experiment, the vegetation had been left fallow for 10 years, with natural regrowth of predominantly tree species, 25 % of biomass in legume species, and a total volume of biomass of 59 t ha<sup>-1</sup> (Kato et al., 1999).

The experiment was arranged in a randomized block design arranged in a 2 x 6 factorial scheme with three replications, consisting of two management systems and six treatments in two growing seasons. The managements were applied in two adjacent study areas of 1 ha each, divided into 10 x 12 m plots.

Five soil samples were collected in transects from the 0–0.1 m layer of each plot, resulting in 10 samples. Then the litter was removed from the soil surface of all plots. The soil samples were taken 11 years after the start of the experiment, in the rainy (April 2006) and in the dry season (September 2006). At the time of sampling, the management system I (MS I) was lying fallow and in management system II (MS II) cassava was grown (April), followed by fallow (September). These samples were stored in plastic bags and transported ice-cooled, in a polystyrene box to the laboratory. There the samples were crumbled, roots removed and the soil sieved through 2 mm mesh and stored in a refrigerator for eight days.

The following management systems were used: MS I - a more intensive land use, consisting of two subsequent crop cycles, followed by three fallow years, and MS II - less intensive soil exploitation, consisting of one crop cycle, followed by three fallow years. In both management systems rice (*Oryza sativa*) - cv. Xingu was planted, followed by cowpea (*Vigna unguiculata*) - cv. BR3 - Tracuateua and cassava (*Manihot esculenta*) - cv. Pretinha.

The following treatments were applied: slash and burn system with NPK fertilization (Q+NPK); slash and burn system without fertilization NPK (Q-NPK); cutting and shredding vegetation, leaving residues on the soil surface, with NPK fertilization (C+NPK); and cutting and shredding vegetation, leaving it on the soil surface without fertilizer NPK (C-NPK); cutting, shredding and incorporating vegetation, with NPK fertilization (I+NPK); and cutting, shredding and incorporating vegetation, without NPK fertilization (I-NPK).

In the burning treatment, the cut vegetation was burned when dry. In the other treatments the natural fallow vegetation (Capoeira) was cut and chopped by a so-called forest shredder, and the residues distributed evenly over the soil surface or incorporated, according to the treatment.

In the fertilized treatments, fertilizer was only applied in the early rice cycle, at rates of 50, 60 and 30 kg ha<sup>-1</sup> NPK, respectively, as urea, triple superphosphate and KCl. At planting, 40 % of N and the entire amounts of P and K were applied, and the remaining 60 % N 45 days after germination. Cowpea was fertilized with PK at rates of 50 and 60 kg ha<sup>-1</sup> in the form of triple superphosphate and KCl. Cassava was not fertilized.

Rice was planted in 0.3 x 0.3 m spacing, followed by cowpea, spaced 0.3 x 0.5 m. Cassava was planted 20 days after cowpea, at a spacing of 1.0 x 1.0 m. The first cycle began in January 1995 and ended in July 1996 for MS II; at this time, the more intensively used area (MS I) was lying fallow. In MS I, from the beginning of the experiment, every two crop cycles were followed by a three-year fallow period, while in MS II every crop cycle was followed by a three-year fallow period. The soil chemical analysis was performed according to Embrapa (1997), to determine: total N by semi-micro Kjeldahl distillation (Bremner & Mulvaney, 1982), pH in water (1:2.5), organic C, by the volumetric oxidation method with K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> and titration with ammonium ferrous sulfate; exchangeable Ca, Mg and Al by extraction with 1 mol L<sup>-1</sup> KCl; exchangeable K and Na by Mehlich-1 and flame photometry; available P extraction by Mehlich-1 and determination by colorimetry; H + Al extraction with 0.5 mol L<sup>-1</sup> calcium acetate and pH 7.0 and determination with NaOH solution.

The potential acidity (H + Al), exchangeable bases and exchangeable Al were used to calculate the total

cation exchange capacity (CEC) and effective cation exchange capacity (CECe).

The fumigation-extraction method was used to estimate microbial C (Cmic) (Vance et al., 1987; Tate et al., 1988) and microbial N (Nmic) (Brookes et al., 1985). Samples of 25 g (fresh weight), with moisture adjusted to 50 % water holding capacity (when necessary) were placed in a desiccator and subjected to fumigation with alcohol-free chloroform for 24 h. Immediately after fumigation, the samples were shaken for 30 min in 0.5 mol L<sup>-1</sup> K<sub>2</sub>SO<sub>4</sub> extracts and then filtered. The non-fumigated were weighed at the same time as the fumigated samples and stored in a refrigerator until removal of the fumigated samples from the desiccator for simultaneous extraction.

The determination of Cmic in the fumigated and non-fumigated extracts, was made by dichromatometry (De-Polli & Guerra, 1999). For the calculation, the C content of fumigated samples was subtracted from the values of non-fumigated samples and the difference divided by the correction factor (Kc) of 0.26 (Feigl et al., 1995).

The Nmic was estimated by Kjeldahl digestion. The correction factor (Kn) for the calculation was 0.54 (Brookes et al., 1985; Joergensen & Mueller, 1996). From the original values the ratios between microbial C and soil organic C (Cmic/Corg) and microbial N and soil total N (Nmic/Ntotal) were calculated, expressed in percentage.

The results were subjected to analysis of variance, and when a significant interaction of factors or its separate effects was found, the Duncan test was applied (probability 1 and 5 %).

## RESULTS AND DISCUSSION

The less intensive management system with one crop cycle and three years fallow growth (MS II) was more effective in maintaining Cmic in all treatments in the rainy season (Figure 1). On the other hand, in the less rainy period, the Cmic content in MS II was lower in all treatments except in C+NPK and C-NPK. In a study of different management systems, Silva et al. (2010) reported that the Cmic levels were inversely proportional to the intensity of soil management. In a comparison of different vegetation covers, Gama-Rodrigues et al. (2008) found no difference in Cmic levels between areas with Capoeira and pasture.

When treatments were compared within the management systems, the Cmic level in MS I in treatment NPK and C+NPK was low, even differing from or even lower than that with burning without NPK in the dry season (Figure 1). In a study on the impact of organic residue burning on biological properties, Nunes et al. (2009) found lower levels of Cmic in the burned area. Other studies have shown

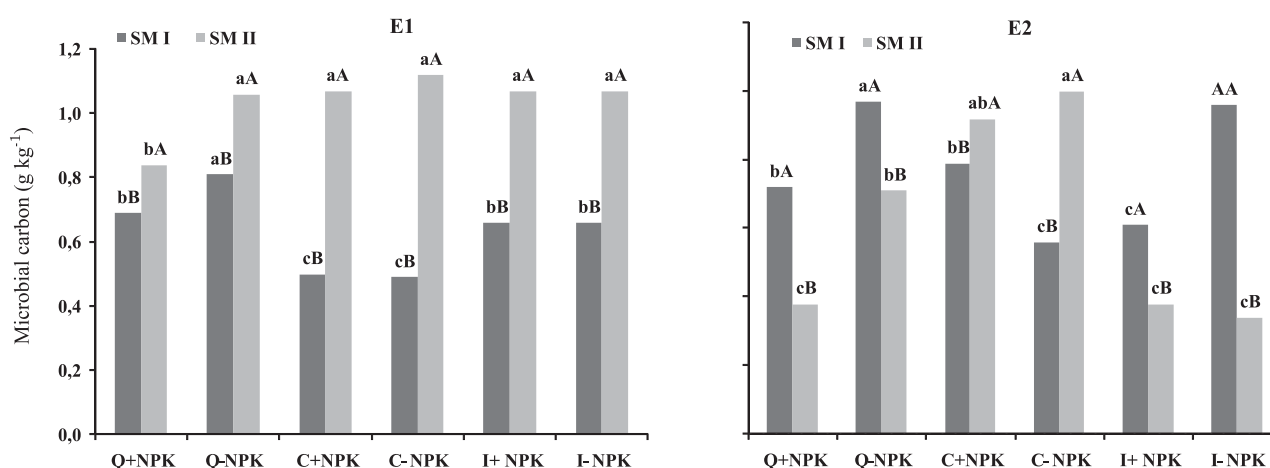


Figure 1. Microbial carbon in a Yellow Latosol, in the 0-0.1 m layer, under management systems in two seasons, rainy (S1) and dry (S2), S1, CV (%) = 6.9; S2, CV (%) = 20.4.

that the content remains constant in time (Fenn et al., 1993; Garcia & Rice 1994) or increases in the short term (Fernandes et al., 2007). On the other hand, Ojima et al. (1994) suggested that short-term responses to the annual burning of grasslands include increases in the Cmic levels, but reductions of microbial activity are expected as a result of burning in the long term (over 10 years), as was actually the case in this study.

In all treatments, it was observed that the Cmic values were not affected by NPK fertilization in the rainy season, except for the treatment with burning, where a decrease was observed in soil with chemical fertilization (Figure 1). This result does not confirm findings of Chu et al. (2007) in a long-term experiment, in which the use of mineral with organic fertilizer increased the soil Cmic.

The Cmic contents found in this study are consistent with results for other Amazonian soils (Feigl et al., 1995; Davidson et al., 2004; Vasconcelos et al., 2005). In the dry period, the Cmic content was highest in MS I, except in the treatments C+NPK and C-NPK, which were higher in MS II, however, in the treatment mean, the systems were equal (Figure 1). In soil under Caatinga (natural growth) in the semi-arid region in the northeast of Brazil, Nunes et al. (2009) observed no change in the Cmic level of a deforested area where residues were evenly distributed and corn and bean planted in an area after a five-year fallow period.

Small variations in microbial N (Nmic) were observed between systems of soil management and the treatments (Figure 2). In the rainy season, the Nmic content varied between management systems only in the treatments with biomass deposition on the soil surface and was higher in MS II. In the dry season, the change occurred only in the C-NPK treatment, which was highest in MS II as well. This was probably due to environmental factors and/or the release of immobilized N in the process known as

remobilization, resulting from the depletion of C sources and the death of microbacteria (Rosa et al., 2009). The greatest amount of Nmic in the treatments C+NPK and C-NPK, in the less intensive MS II, can be related to the deposition of biomass on the soil surface, which led to a greater nutrient incorporation in the soil with longer persistence in this system because of the longer fallow period.

In a comparison of soil management systems with and without maintenance of vegetation on the surface, Rosa et al. (2009) observed higher Nmic levels in the system with vegetation cover than in the system without. Vargas et al. (2005) observed long-term increases in Nmic in no-tillage pasture soil and attributed this finding to a higher plant biomass production and the subsequent increase of Corg. According to Zaman et al. (2002), additions of organic residues, concomitantly with N fertilizers, increased Nmic compared to the treatment without the addition of organic waste, after the first year of fertilization.

The Nmic contents observed in this study, especially in the treatments with deposition of biomass on the surface were higher than reported by several other authors (Vasconcelos et al., 2005; Bittencourt et al., 2006) in studies conducted under the same conditions, in Amazonian soils in the state of Pará. This indicates greater N immobilization by soil microbial biomass (SMB), probably resulting from a longer duration of crop residues on the surface, which increases the availability of substrate in the top centimeters of the soil and leads to a higher nutrient concentration in the SMB.

The observed values for the Cmic/Nmic ratio differed statistically among management systems, in the treatments Q+NPK and I-NPK in the rainy season and in the treatments Q-NPK, I+NPK and I-NPK in the dry period (Table 1). On the other hand, by the treatment mean, the management systems varied only in the dry season, where the Cmic/Nmic ratio in the more intensive MS I was higher.

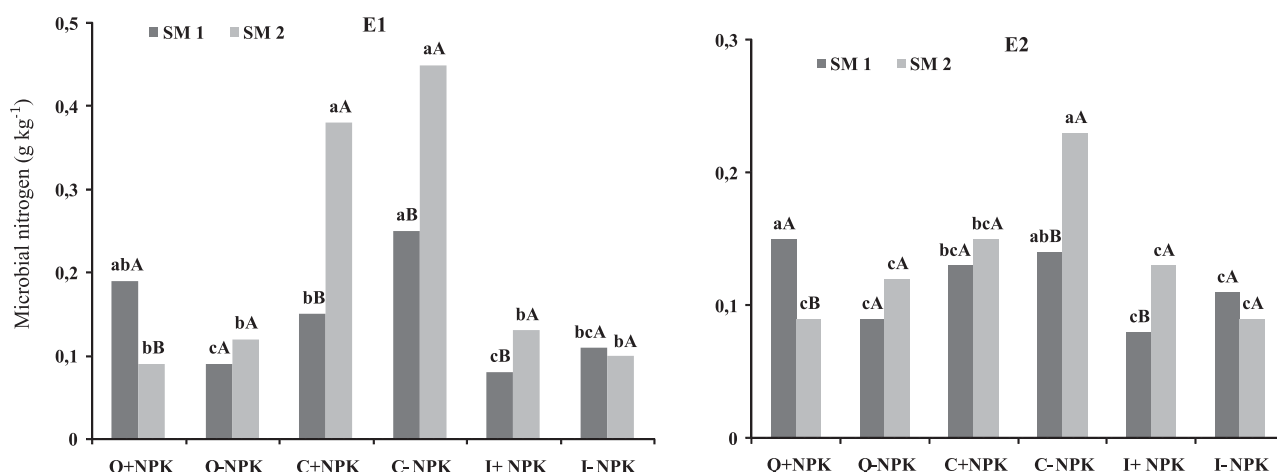


Figure 2. Microbial nitrogen in a Yellow Latosol, in the 0–0.1 m layer, under management systems in two seasons, rainy (S1) and dry (S2), S1, CV (%) = 6.9; S2, CV (%) = 29.8.

Table 1. Relations of microbial carbon and nitrogen (Cmic/Nmic) and of microbial and organic carbon (Cmic/Corg), microbial and total nitrogen (Nmic/Ntotal), under two land use systems, under different treatments of secondary vegetation, in the 0–0.1 m layer, in two seasons, rainy (S1) and- dry (S2)

Management system	Season	Treatment						Means <sup>(1)</sup>
		Q+NPK	Q NPK	C+NPKC	NPK	I+NPK	I-NPK	
Cmic/Nmic								
MS I	S1	3.65bBC	9.32aA	3.32aC	1.96aCD	8.32aA	5.87bB	5.41a
MS II		9.55aA	8.87aB	2.82aC	2.48aC	8.27aB	10.77aA	7.13a
CV (%) = 6.1								
MS I	S2	4.98aC	11.07aA	7.18aB	3.83aC	8.47aB	8.76aB	7.38a
MS II		4.27aB	7.17bA	6.06aA	4.46aB	2.75bC	3.55bBC	4.71b
CV (%) = 24.3								
Cmic/Corg (%)								
MS I	S1	10.48aBC	13.89aA	7.41bC	8.61aBC	12.53aA	9.81aBC	10.45a
MS II		7.95bC	10.21bB	14.92aA	9.75aB	11.49aB	8.33aBC	10.44a
CV (%) = 10.7								
MS I	S2	9.51a	15.10aA	9.70aB	6.36bC	7.85aC	10.04aB	9.78a
MS II		3.91bC	6.94bB	9.05aA	9.10aA	4.51bBC	3.86bC	6.22b
CV (%) = 18.6								
Nmic/Ntotal (%)								
MS I	S1	40.48aA	20.83aB	23.66bB	48.08aA	16.17bB	20.23aB	28.24a
MS II		15.63bB	16.75bB	47.90aA	48.69aA	19.85aB	15.72bB	27.42a
CV (%) = 8.1								
MS I	S2	19.47aA	17.62aAB	15.86bB	18.52bA	13.70bC	16.98aB	16.98a
MS II		12.88bCD	14.85bC	17.24aB	22.22aA	18.42aB	12.81bD	16.40a
CV (%) = 28.4								

<sup>(1)</sup> Small-case letters in the column compare the management systems in each season; capital letters in the row compare the treatments in each management system and season, and small-case letters \* compare the treatment means, by the Duncan test at 5%. MS I: Management system I, two crop cycles and three-year fallow period, and MS II: Management system II, one crop cycle and three-year fallow period.

The Cmic/Nmic ratio ranged from 1.96 (C-NPK) to 11.07 (Q-NPK), considering the management systems, treatment and evaluation periods. The high value observed in the burning treatment can be related to greater microbial activity due to greater substrate availability in the soil, stimulated by the release of

nutrients, necromass of the burned vegetation and increased activity of the root system due to the intensified growth of the species (Fernandes et al., 2007). A high Cmic/Nmic ratio (11) was observed by Fernandes et al. (2007), in a hydromorphic ferrocyclic Espodosol, in the central region of the Pantanal in a

burned area. These authors suggest that burning may have caused a qualitative change in the SMB, since it increased the  $C_{mic}/N_{mic}$  ratio.

The  $C_{mic}/C_{org}$  ratio only varied between management systems in the treatments with burning and C+NPK in the rainy season, however there was no variation between the treatment means (Table 1). On the other hand, in the rainy season all treatments except C+NPK differed significantly between the two management systems. The highest values of  $C_{mic}/C_{org}$  in MS I may be related to increased microbial activity, because of a better quality (Gama-Rodrigues et al., 2008) and increased amount of crop residues, due to the two subsequent crop cycles, unlike in MS II with only one. De Polli & Guerra (1999) claim that in systems with incorporation of plant material, the antimicrobial activity is exponentiated and, consequently, the production of  $C_{mic}$ . According to Wardle (1994), the ratio between microbial C and organic C indicates the quality of OM.

The contribution of  $C_{mic}$  to  $C_{org}$  ranged from 7.41 to 14.92 % in the rainy season and from 3.86 to 15.10 % in the drier period (Table 1). The soil  $C_{mic}/C_{org}$  ratio found in this study in both periods was higher than cited elsewhere (Cerri et al., 1985; Souza et al., 2006; Fonseca et al., 2007; Silva et al., 2007, 2010). However, Vasconcelos et al. (2005) found values ranging from 2.2 to 18 % at different ages of secondary vegetation in Eastern Amazonia. Basante et al. (2001) found values ranging from 3 to 11, in native forest, and 3.2 to 10, in soils under eucalyptus plantation in the Amazon.

Most likely, the results presented in this study reflect important processes related to SOM addition and alterations, and also the conversion efficiency of  $C_{org}$  into  $C_{mic}$ , which is an indicator of the equilibrium in the system (Xavier et al., 2006; Fonseca et al., 2007).

Balota et al. (1998) mentioned that a higher or lower  $C_{mic}/C_{org}$  ratio indicates, respectively, a tendency of accumulation or loss of soil C. Thus, modified values reflect the input or output pattern of SOM, the conversion efficiency of microbial C, the losses of soil C and stabilization of organic C by the soil mineral fraction.

For the contribution of  $N_{mic}$  to  $N_{total}$  differences between treatments and seasons were significant, as well as the interaction between management systems and treatments (Table 1). The highest values were observed for treatments Q+NPK and C-NPK in the rainy season, in disagreement with values of the literature, which can be attributed to the high  $N_{mic}$  values found in this study (Figure 2). When evaluating  $N_{mic}$  of an Ultisol under different land uses (woodland savanna, grain crops and natural pasture) in Redenção/PA, Bittencourt et al. (2006) found values of 17.8 for the ratio  $N_{mic}/N_{total}$ , in the rainy season, under natural pasture. Fernandes et al. (2007) found values ranging from 4 to 15 for the

ratio  $N_{mic}/N_{total}$  in the central region of the Pantanal. Thus, SMB becomes a reservoir of the soil. It is worth mentioning the higher efficiency of N immobilization in the shredding treatments, with as well as without fertilization (Table 1). These relations ( $C_{mic}/C_{org}$  and  $N_{mic}/N_{total}$ ) indicate the fractions of  $C_{org}$  and  $N_{total}$  that are incorporated in SMB, expressing the quality of SOM (Gama-Rodrigues, 1999).

The levels of  $C_{org}$  and  $N_{total}$  did not differ significantly between treatments, in MS I in the rainy season (Table 2). The contents of  $C_{org}$  observed ranged from 5.35 to 12.98 g kg<sup>-1</sup>, which is considered low (Tomé Jr., 1999). The  $N_{total}$  concentrations ranged from 0.44 to 1.06 g kg<sup>-1</sup>, considering the management systems, treatments and seasons. In tropical regions, the OM decomposition rates are high, leading to low values of C and N accumulated in soil. Values similar to those obtained in this study for  $N_{total}$  (1.04 g kg<sup>-1</sup>) were found by Bittencourt et al. (2006), in an Ultisol in different ecosystems in Redenção/PA.

The values of the soil C/N ratio were below 12, indicating predominance of mineralization, i.e., the decomposition rates and nutrient availability to the soil tend to be high (Moreira & Siqueira, 2002). The higher the soil N content, the lower the C/N ratio and the greater the nitrogen availability to the soil microbiota.

In the less intensive management system (MS II), in the period with most rain, the C/N ratio (11.06) was highest in the treatment C+NPK, differing significantly from the others (Table 2). In the dry season, the values were highest in the treatments Q+NPK and C+NPK in MS I. The addition of biomass to surface soil by ground vegetation slowed down decomposition, resulting in a greater accumulation of soil C, thus increasing the C/N. On the other hand, in the burned area, in MS I and dry season, the longer fallow period with natural regrowth increases the soil C content due to the higher C/N than under crop cultivation in the area.

The mean soil pH values were not affected by treatments and management systems (Table 3). These results can be explained by the absence of liming in the study areas.

The P concentrations were affected by soil management systems and treatments (Table 4). In the mean of all treatments a higher P content was observed in MS II (less intensive use), regardless of the sampling time. In the treatments with biomass burning and NPK fertilization, the P levels were highest. This was a result of P deposition by biomass ashes and P fertilization. There were also increased P levels in all fertilized treatments. According to Coutinho (1982), burning accelerates OM mineralization, causing a loss of energy, C, N and S to the atmosphere, and promotes P accumulation in the surface layer. In a long-term experiment, Chu et al. (2007) observed that the P-containing mineral

**Table 2. Organic carbon (Corg), N total and ratio of Corg/Ntotal in two land use systems, under different treatments of secondary vegetation in the 0–0.1 m layer, in the rainy (S1) and dry season (S2)**

Management system	Season	Treatment						Means <sup>(1)</sup>
		Q+NPK	Q-NPK	C+NPK	C- NPK	I+ NPK	I- NPK	
					Corg (g kg <sup>-1</sup> )			
MS I	S1	6.69bA	5.86bA	6.75aA	5.69bA	5.35bA	6.70bA	6.17b
MS II		10.58aBC	10.42aBC	7.22aD	11.71aAB	9.37Ca	12.98aA	10.38a
CV (%) = 13.0								
MS I	S2	7.29bBC	6.47bC	8.26aAB	8.82bA	7.82aB	9.71aA	8.06a
MS II		9.72aAB	10.43Aa	10.13aA	11.00Aa	8.24aB	8.74aB	9.71a
CV (%) = 12.3					Ntotal (g kg <sup>-1</sup> )			
MS I	S1	0.48bA	0.44bA	0.64bA	0.53bA	0.50bA	0.55bA	0.52a
MS II		0.58aB	0.72aAB	0.80aA	0.93aA	0.66aB	0.64aB	0.72a
CV (%) = 6.4								
MS I	S2	0.75aAB	0.55bB	0.85aA	0.75bAB	0.61aB	0.66aB	0.69a
MS II		0.69aB	0.84aAB	0.91aA	1.06aA	0.79aB	0.75aB	0.84a
CV (%) = 22.3					Corg/Ntotal			
MS I	S1	7.22aB	7.64aB	9.48bA	9.30aA	9.85aA	8.24aAB	8.62a
MS II		5.49aC	6.98aC	11.06aA	8.07aB	7.08aBC	4.97aCD	7.28a
CV (%) = 14.9								
MS I	S2	10.56aA	8.43aB	10.63aA	8.53aB	7.83aBC	6.99aC	8.83a
MS II		7.17bB	7.73aB	8.99aA	9.72aA	9.50aA	8.58aAB	8.61a
CV (%) = 23.4								

<sup>(1)</sup> Small-case letters in the column compare the management systems, in each season. capital letters in the row compare the treatments in each management system and season. and small-case letters \* compare the treatment means by the Duncan test, at 5 %. MS I: Management system I; two crop cycles and three-year fallow period and MS II: Management system II; one crop cycle and three-year fallow period.

fertilizers (NPK and NP) increased microbial activity, suggesting an increase in biomass and root exudates. The highest P levels observed in the area with burning of biomass were higher than those reported by Silva et al. (2006), in a study conducted in a medium texture Oxisol, in Pará, using burning (9.3 mg dm<sup>-3</sup>). However, unlike in this study these authors did not apply mineral fertilization.

The soil K contents in the soil management systems and treatments were only affected in the rainy season (Table 3). The results for all treatments ranged from 0.30 to 1.30 mmol<sub>c</sub> dm<sup>-3</sup>, values considered low (Rajj et al., 1996). The highest K levels were observed in MS II in the rainy season, probably due to the longer fallow period, resulting in a shorter cultivation period and lower nutrient export. Similar results were observed by Silva et al. (2007), in a study on different land use systems in Marituba-Pará, where K concentrations were highest in the rainy season and the less intensive systems.

The Na content was not affected by management systems and soil treatments, differing significantly only in the seasons (Table 3). The Na concentration in soil ranged from 0.03 to 0.16 cmol<sub>c</sub> dm<sup>-3</sup>, and the values were highest in the MS I, in the rainy season in treatments without mineral fertilizer. The behavior of Na in the soil is similar to that of K, ie, it occurs as

exchangeable cation. This ion is easily removed from the soil by leaching and, in general, there is less total N than K in soils of humid climates (Rajj, 1991).

There were significant differences between management systems and treatments for Ca levels (Table 3). The Ca and Mg concentrations were highest in MS II, in the treatment Q+NPK in the dry season. For Mg, statistical differences in the treatment C+NPK between the management systems were only observed in the rainy season. This result may be related to the release of these nutrients to the soil through the incorporation of Ca and Mg-rich ashes, after burning, increasing nutrient accumulation. According to Ribeiro et al. (1999), the soil Ca and Mg contents found in this study are classified as low to medium.

The contents of Al and H + Al were little influenced by the treatments, seasons and interaction between management systems and treatments (Table 3). The Al content (0.90 cmol<sub>c</sub> dm<sup>-3</sup>) was highest in MS II in the rainy season and I + NPK treatment. In general, the observed values were below 0.5 cmol<sub>c</sub> dm<sup>-3</sup>, suggesting a range of low Al content in soil (Ribeiro et al., 1999). Highest potential acidity (H + Al) was detected in the rainy season (3.08 - 5.50 cmol<sub>c</sub> kg<sup>-1</sup>). The highest values (5.50 and 5.23 cmol<sub>c</sub> kg<sup>-1</sup>) were obtained in MS II-C in treatments NPK and NPK+I, respectively, the latter coinciding with the highest



**Table 3. Values of pH, phosphorus , potassium, sodium, calcium, magnesium, aluminum and potential acidity (H + Al) of a Yellow Latosol. in the 0–0.1 m layer, under different management systems**

Management system	Season	Treatment						Means <sup>(1)</sup>
		Q+NPK	Q-NPK	C+NPK	C- NPK	I+ NPK	I- NPK	
		pH						
MS I	EI	5.07aA	4.93aA	4.67aA	4.57aA	4.57aA	4.57aA	4.73a
MS II		4.70aA	5.23aA	4.63aA	4.73aA	4.43aA	4.60aA	4.72a
CV (%) = 4.7								
MS I	S2	5.37aA	5.30aA	5.03aA	5.00aA	4.97aA	5.06aA	5.12a
MS II		5.77aA	5.70aA	5.30aA	5.20aA	5.13aA	5.27aA	5.39a
CV (%) = 4.4								
		P (mg dm <sup>-3</sup> )						
MS I	S1	5.33bA	2.33aBC	4.33bAB	3.00aB	5.67aA	2.67aBC	3.88b
MS II		11.33aA	2.67aC	7.67aB	2.33aC	6.67aB	2.00aC	5.44a
CV (%) = 21.6								
MS I	S2	2.00bA	1.33bA	2.00aA	1.33bA	3.33aA	1.67aA	1.94b
MS II		15.67aA	2.67aB	3.33aB	2.66aB	3.66aB	2.00aB	5.00a
CV (%) = 27.6								
		K (cmol <sub>c</sub> dm <sup>-3</sup> )						
MS I	S1	0.06bB	0.05aB	0.04bB	0.04bB	0.04bB	0.10aA	0.05b
MS II		0.10aA	0.07aA	0.09aA	0.12aA	0.12aA	0.13aA	0.11a
CV (%) =38.4								
MS I	S2	0.04aA	0.03aA	0.04aA	0.03aA	0.04aA	0.03aA	0.04a
MS II		0.05aA	0.03aA	0.05aA	0.05aA	0.04aA	0.04aA	0.04a
CV (%) = 21.5								
		Na (cmol <sub>c</sub> dm <sup>-3</sup> )						
MS I	S1	0.07aB	0.09aB	0.04aB	0.09bB	0.04aB	0.16aA	0.08a
MS II		0.06aB	0.05aB	0.05aB	0.15aA	0.06aB	0.06bB	0.07a
CV (%) = 35.3								
MS I	S2	0.03aA	0.03aA	0.03aA	0.03aA	0.03aA	0.03aA	0.03a
MS II		0.03aA	0.03aA	0.03aA	0.03aA	0.03aA	0.03aA	0.03a
CV (%) = 15.2								
		Ca (cmol <sub>c</sub> dm <sup>-3</sup> )						
MS1	S1	1.50aA	1.47aA	0.80bA	1.33bA	0.97aA	1.90aA	1.33a
MS2		1.57aA	1.43aA	1.47aA	2.26aA	0.76aA	1.13aA	1.44a
CV (%) = 25.3								
MS1	S2	1.77bA	1.33bB	1.10bB	1.26aB	1.13aB	1.00aB	1.27a
MS2		2.73aA	2.37aA	2.07aAB	1.77aBC	0.96aC	1.00aC	1.82a
CV (%) = 25.6								
		Mg (cmol <sub>c</sub> dm <sup>-3</sup> )						
MS1	S1	0.50aA	0.50aA	0.40aA	0.43bA	0.47aA	0.57aA	0.48a
MS2		0.60aA	0.57aA	0.60aA	0.70aA	0.47aA	0.43aA	0.56a
CV (%) = 19.0								
MS1	S2	0.53aA	0.63aA	0.47aA	0.37aA	0.47aA	0.43aA	0.48a
MS2		0.80aA	0.60aA	0.63aA	0.53aA	0.50aA	0.50aA	0.59a
CV (%) = 23.2								
		Al (cmol <sub>c</sub> dm <sup>-3</sup> )						
MS I	S1	0.27aB	0.30aB	0.63aA	0.57aA	0.47aAB	0.43aAB	0.44a
MS II		0.47aB	0.30aB	0.57aB	0.37aB	0.90aB	0.50aB	0.52a
CV (%) = 21.5								
MS I	S2	0.23aA	0.33aA	0.43aA	0.53aA	0.43aA	0.47aA	0.40a
MS II		0.13aC	0.27aBC	0.27aBC	0.37aAB	0.60aA	0.53aA	0.36a
CV (%) = 26.2								
CV (%) = 27.5		H + Al (cmol <sub>c</sub> dm <sup>-3</sup> )						
MS I	S1	3.47aA	3.08aA	4.02aA	4.35aA	3.69aA	4.95aA	3.93a
MS II		4.29aA	4.07aA	4.68aA	5.50aA	5.23aA	3.74aA	4.58a
CV (%) = 21.7								
MS I	S2	3.19aA	2.59aAB	1.98aB	2.26aB	2.42aAB	2.04aB	2.41a
MS II		2.97aA	2.59aA	3.52aA	3.36aA	3.85aA	3.85aA	3.36a

<sup>(1)</sup> Small-case letters in the column compare the management systems in each season. Capital letters in the row compare the treatments in each management system and season, and small-case letters \* compare the treatment means by the Duncan test, at 5 %. MS I: Management system I: two crop cycles and three-year fallow period and MS II: Management system II: one crop cycle and three-year fallow period; S1: rainy season; S2: dry season.

value for Al (Table 3). Several factors may have influenced the behavior of the potential soil acidity, e.g., OM content, concentration of other ions and soil moisture. The latter seems to have had the strongest influence on the results. Probably the higher soil moisture in samples of the rainy season supported the action of microorganisms that decompose SOM, increasing the speed of the release process (mineralization) of its constituents, including hydrogen linked by a covalent bond to organic radicals, with consequent increase in potential soil acidity (Mello et al., 1985).

The potential acidity was lowest in MS I, in the dry season, in the treatments with biomass burning ( $1.98\text{--}3.85\text{ cmol}_c\text{ kg}^{-1}$ ) (Table 3). The lower potential acidity of the management systems in the dry season

was possibly due to a lower reserve of  $\text{H}^+$  (result of lower leaching and less extraction of basic cations), to the lower decomposition of SOM and to a lower heterotrophic activity of roots and microorganisms, which extended the unfavorable conditions for microorganisms (Siqueira et al., 1994).

The values of sum of bases (SB), cation exchange capacity (CEC) and effective cation exchange capacity (CECe) ranged from low to very low (Table 4), according to Ribeiro et al. (1999), and reflect the high acidity coupled with low natural fertility. The SB and CEC values were highest in MS II, in the dry season for treatments with burning and residues left on the surface and in the rainy season in C-NPK.

The values of base saturation (V %) and aluminum saturation (m %) differed significantly only for

**Table 4. Sum of bases (SB), effective cation exchange capacity (CECe), total cation exchange capacity (CEC), base saturation (V) and aluminum saturation (m) of a Yellow Latosol in the 0–0.1 m layer, under different management systems, in Igarapé-Açu (PA)**

Management system	Season	Treatment						Means <sup>(1)</sup>
		Q+NPK	Q-NPK	C+NPK	C- NPK	I+ NPK	I- NPK	
SB ( $\text{cmol}_c\text{ dm}^{-3}$ )								
MS I	S1	2.13aA	2.10aA	1.28aA	1.90aA	1.52aA	2.73aA	1.94a
MS II		2.33aAB	2.13aAB	2.20aAB	3.24aA	1.42aB	1.76aB	2.18a
CV (%)	31.7							
MS I	S2	2.36aA	2.03aA	1.64aA	1.70aA	1.67aA	1.49aA	1.81
MS II		3.61aA	3.02aA	2.78aAB	2.39aAB	1.55aB	1.58aB	2.49a
CV (%)	27.3							
CEC ( $\text{cmol}_c\text{ dm}^{-3}$ )								
MS I	S1	5.60aB	5.18aB	5.29aB	6.24aAB	5.21aB	7.68aA	5.87a
MS II		6.62aA	6.20aA	6.88aA	5.40aA	6.65aA	5.50aA	6.21a
CV (%)	15.8							
MS I	S2	5.56aA	4.61aA	3.62aA	3.95aA	4.09aA	3.52aA	4.22a
MS II		6.58aA	5.61aA	6.30aA	5.74aA	5.40aA	5.43aA	5.84a
CV (%)	20.8							
CECe ( $\text{cmol}_c\text{ dm}^{-3}$ )								
MS I	S1	2.39aA	2.40aA	1.91aA	2.47aA	1.99aA	3.17aA	2.39a
MS II		2.80aA	2.42aA	2.77aA	3.60aA	2.32aA	2.26aA	2.70a
CV (%)	20.2							
MS I	S2	2.60aA	2.36aA	2.07aA	2.23aA	2.10aA	1.95aA	2.22a
MS II		3.75aA	3.29aA	3.05aA	2.75aA	2.15aA	2.11aA	2.85a
CV (%)	20.6							
V (%)								
MS I	S1	39.97aA	40.96aA	24.77aC	31.95aB	29.27aBC	34.52aAB	33.57a
MS II		35.24aA	35.37aA	32.00aA	37.04aA	21.30aB	31.77aA	32.12a
CV (%)	19.5							
MS I	S2	43.13aA	44.31aA	44.58aA	41.60aA	41.50aA	42.43aA	42.93a
MS II		52.88aA	53.91aA	44.33aAB	41.55aAB	29.92aB	30.08aB	42.11a
CV (%)	18.3							
m (%)								
MS I	S1	11.64aC	12.92aC	32.41aA	23.51aB	23.95aB	15.65aC	20.01a
MS II		17.48aBC	12.50aC	21.99aB	11.07aC	39.96aA	22.68aB	20.95a
CV (%)	23.2							
MS I	S2	9.77aB	14.64aB	22.27aA	25.79aA	20.54aA	23.75aA	19.46a
MS II		4.84aC	8.39aBC	9.25aB	13.59aB	28.44aA	25.30aA	14.97a
CV (%)	26.4							

<sup>(1)</sup> Small-case letters in the column compare the management systems, in each season, capital letters in the row compare the treatments in each management system and season, and small-case letters \* compare the treatment means by the Duncan test, at 5 %. MS I: Management system I: two crop cycles and three-year fallow period and MS II: Management system II: one crop cycle and three-year fallow period; S1: rainy season; S2: dry season.

treatments and seasons (Table 4). The oscillations of the values of base saturation in the treatments with burning, from highest in the dry season, to lowest in the rainy, reflect the action of basic cations from the ashes of burnt vegetation, which, by the supply of Ca and Mg, increased soil pH and insolubilization of Al in the form of hydroxides, increases base saturation (V) and decreases aluminum saturation (m). For aluminum saturation (m), the highest value ( $\approx 40\%$ ) was observed in the treatment I+NPK, which is considered high (32–50) and detrimental to most crops (Tomé Jr., 1997).

From the percentage of V and m, eutrophic, dystrophic and aluminic soil properties were defined, which are excellent indicators of the general fertility (Embrapa, 2006). In general, in the soils of the study area  $V < 50\%$ , characterizing dystrophic, i.e., less fertile soils, with low Al saturation, which are soils with  $m \geq 50\%$  and extractable Al  $\geq 4.0 \text{ cmol}_c \text{ dm}^{-3}$  (Embrapa, 2006).

Several studies (Kato et al., 1999; Metzger, 2000; Denich et al., 2004; Sampaio et al., 2008) have shown that the use of vegetation cutting and burning raises the soil fertility level, mainly due to increases in pH, base saturation and reduction of available P and exchangeable Al. However, it has also been shown that the improvement of soil fertility is relatively short-lived, requiring fallow periods, and/or fertilization.

## CONCLUSIONS

1. The more intensive management system had higher levels of microbial C ( $C_{mic}$ ) and microbial N ( $N_{mic}$ ), while organic C was higher in the less intensive system. The treatments with highest levels of  $C_{mic}$  and  $N_{mic}$  were those where the residues were cut, shred and distributed over the soil surface.

2. The ranges of the soil chemical properties under both management systems indicate low soil fertility, although P and K (in the rainy season) were higher in the less intensive management system.

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