UNIVERSIDADE FEDERAL DE LAVRAS

CONVERSION OF CERRADO INTO RIPARIAN FOREST IMPACTING SOIL ATTRIBUTES

FLÁVIA APARECIDA DE ALCÂNTARA

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Thesis presented to the Lavras Federal University as part of the demands of the PhD Program in Agronomy (Soils and Plant Nutrition) in order to obtain the Doctor degree.

Supervisor

Prof. Antonio E. Furtini Neto

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LAVRAS
MINAS GERAIS - BRAZIL

To my family, for the unconditional love that unites and strengthens us.

À minha família, pelo amor incondicional que nos une e fortalece.

Rosa dos Ventos
(Chico Buarque de Holanda)

E do amor gritou-se o escândalo
no medo criou-se o trágico
no rosto pintou-se o pálido
e não rolou uma lágrima
nem uma lástima para socorrer
E na gente deu o hábito
de caminhar pelas trevas
de murmurar entre as pregas
de tirar leite das pedras
de ver o tempo correr
Mas sob o sono dos séculos
amanheceu o espetáculo
como uma chuva de pétalas
como se o céu vendo as penas
morresse de pena e chovesse o perdão
E a prudência dos sábios
nem ousou conter nos lábios
o sorriso e a paixão
pois transbordando de flores
a calma dos lagos zangou-se
a rosa dos ventos danou-se
o leito dos rios fartou-se e
inundou de água doce
a amargura do mar
numa enchente amazônica
numa explosão atlântica
e a multidão vendo em pânico
e a multidão vendo atônita
ainda que tarde, o seu despertar.

O “despertar” que essa música do Chico descreve pode ser interpretado de inúmeras maneiras... Eu o interpreto como aqueles momentos da vida em que temos coragem de ouvir nossas próprias verdades, aquelas que ficam guardadas embaixo de muita pressa, inquérito e justificativa. Seguindo essas verdades é impossível que nossas atitudes não dêem bons resultados, apesar dos prováveis tropeços. E por falar em atitudes, colocar um pouco mais de solidariedade e ética em tudo que fazemos, desde os nossos comentários mais banais até nosso trabalho, com certeza nos ajudaria a viver melhor como indivíduos e, ao mesmo tempo, como grupo. Talvez seja isso o que falte para que nós possamos viver num mundo (e num Brasil) mais justo.

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CONTENTS

GENERAL ABSTRACT

ALCÂNTARA, Flávia Aparecida de. **Conversion of cerrado into riparian forest impacting soil attributes.** Lavras: UFLA, 2002. 116 p. (Thesis – PhD in Soils and Plant Nutrition)*

Construction of Hydroelectric Power Plants (HPP) promotes the disappearance of several ecosystems, including the riparian forests, which follow the watercourses and carry out functions such as the maintenance of biodiversity and the soil protection. The Riparian Forest Project was implanted in Itutinga/Camargos reservoirs (Southern Brazil) to recover both form and function of these forests. Nevertheless, aspects related to soil sustainability in the forested areas had not been assessed so far. Soil organic matter (SOM) is a key factor for studying sustainability, since it is related to the main soil processes. We hypothesised that elucidation of changes in SOM and their relationship with alterations in physical, chemical and biological soil attributes could be useful for assessing soil sustainability. Our objectives were (i) to verify the impact of the forest plantation on soil sustainability, by comparing litter and soil (Acric Red-Yellow Latosol) samples of an area maintained under native vegetation (Brazilian savannah or "cerrado"), and other one planted with riparian species in 1992; and (ii) to contribute to the knowledge on SOM in Brazilian conditions. In order to reach these goals, we studied the impacts of the vegetation conversion on SOM dynamics (by density fractionation and $\delta^{13}C$) and chemical composition (by ^{13}C nuclear magnetic resonance and pyrolysis), and evaluated changes in soil attributes after conversion. We found that the organic material is quite different between the areas. In the cerrado, grasses (C_4-derived C) predominate, carbon input is mainly below ground (root system), SOM is easily degradable, and C stocks are higher. In the forest, C_3 vegetation is the major source of C and its input is mainly above ground, moreover SOM is more recalcitrant. Although these existing differences in SOM between cerrado and forest, and the relationships between SOM characteristics and several soil attributes for both areas, there were no consistent changes in soil conditions that could be caused by the vegetation conversion by itself. Considering the results of this research as a whole, the establishment of the riparian forest has not effectively improved soil sustainability. The soil under both areas is able to sustain the vegetation growth, with no damages to the environment. In terms of environmental sustainability, the forestation might bring about the re-composition of the lakeshores in a long-term, contributing to the recovery of the riparian forest functions.

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* Guidance Comittee: Antonio E. Furtini Neto - UFLA (Major Professor), Nilton Curi - UFLA, and Peter Buurman – WU.

RESUMO GERAL

ALCÂNTARA, Flávia Aparecida de. **Conversão de cerrado em mata ciliar e seu impacto nos atributos do solo.** Lavras: UFLA, 2002. 116 p. (Tese – Doutorado em Solos e Nutrição de plantas)[*]

A construção de usinas hidrelétricas leva ao desaparecimento de vários ecossistemas, inclusive das matas ciliares, as quais acompanham os cursos d'água e desempenham funções tais como a proteção do solo e a manutenção da biodiversidade. O Projeto Mata Ciliar foi implantado nos reservatórios de Itutinga/Camargos (MG) visando recuperar a forma e a função dessas matas. No entanto, até o presente momento a sustentabilidade do solo nas áreas submetidas ao projeto não havia sido avaliada. A matéria orgânica do solo (MOS) é um fator chave nesse tipo de avaliação, através da elucidação da relação entre alterações ocorridas em suas características e possíveis alterações nos atributos químicos, físicos e biológicos do solo. Desta forma, os objetivos deste trabalho foram: a) verificar o impacto do plantio de mata ciliar sobre a sustentabilidade do solo, através de comparações entre serapilheira e solo (Latossolo Vermelho-Amarelo Ácrico) provenientes de uma área mantida sob vegetação nativa (campo cerrado) e outra, submetida ao plantio de vegetação ciliar em 1992; e b) contribuir para o entendimento do comportamento da MOS em latossolos brasileiros. Para tal, estudou-se o impacto da conversão de vegetação sobre a dinâmica (através de fracionamento densimétrico e estudos de $\delta^{13}C$) e a composição química da MOS (através de ressonância magnética nuclear e pirólise) e avaliaram-se mudanças nos atributos do solo após a conversão. O material orgânico apresentou-se bastante distinto nas duas áreas. No cerrado, gramíneas predominam (C de origem C_4), a adição de C se dá principalmente sob o solo (sistema radicular), a MOS é mais facilmente degradável e os estoques de C são maiores. Na mata, a vegetação tipo C_3 é a principal fonte de C, a adição deste se dá sobre o solo e a MOS é composta por material mais recalcitrante. Apesar dessas diferenças e das correlações encontradas entre características da MOS e vários atributos do solo, não ocorreram mudanças consistentes nas condições do solo que pudessem ter sido causadas pela conversão de vegetação, ou seja, o estabelecimento da mata ciliar não tem acarretado em melhorias na sustentabilidade do solo. Nas duas áreas, o solo é capaz de sustentar a produção vegetal, sem prejuízos para o ambiente. Quanto à sustentabilidade ambiental, o plantio de mata ciliar deverá, a longo prazo, promover a recomposição das áreas marginais aos reservatórios, contribuindo para a recuperação de suas funções.

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[*] Comitê de Orientação: Antonio E. Furtini Neto - UFLA (Orientador), Nilton Curi - UFLA, and Peter Buurman – WU.

CHAPTER 1

1 GENERAL INTRODUCTION

Preservation of natural resources is fundamental to provide a sustainable future. Around the world, scientific community and society in general have done a common effort in order to press government and decision-makers, and ensure efficient environmental policies. Starting from the 80's the ecological movement started to grow in Brazil, and nowadays, at each generation it is noticeable how people are getting much more worried about environmental preservation. That is extremely important for a country with such a large territory, comprising extensive biomes, for instance Amazon Forest and Cerrado morphoclimatic domains, with some of the highest degrees of biodiversity in the planet.

Thanks to the Brazilian richness in water resources, with hydrographic basins widespread over the whole country, we have the cheapest electricity production of the world, moreover non-pollutant and renewable. Utilisation of this natural resource acquired force with the intensification of the economical growth starting from the 40's and promoting a great increase in energy demand.

At that time, construction of hydroelectric power plants (HPP) was done with little environmental concern. Nevertheless, damming causes the disappearance of many natural ecosystems, mainly riparian forests, which play an important role on water and soil protection, and as habitat for riparian fauna and flora. Dramatic reduction of such forests and its negative consequences for the environment, such as increase in erosive process and decrease of water quality and useful life of the reservoirs impelled the creation of programs to re-establish riparian vegetation in areas surrounding dams.

In Southern Minas Gerais State, the construction of the Itutinga/Camargos HPP, inundated an extensive area, including riparian forests.

Therefore, areas covered by other types of native vegetation, for instance typical *cerrado* (Brazilian savannahs) and pastures, were converted in lakeshores.

Only a small part of the area around those reservoirs was submitted to programs of riparian vegetation re-establishment, which initiated with the Riparian Forest Project, in 1990. Its main objective was the implementation and maintenance of mixed sustainable forests in the reservoirs vicinity, in order to recuperate both form and function of the affected areas. Since then, several studies have supplied technical subsidies on forestry aspects. However, soil sustainability had not yet been assessed.

Conversion of vegetation changes the amount and quality of the organic material that is added to the soil, due to the important role played by vegetation as "source". Such changes in litter production and chemical composition will reflect on the soil organic matter (SOM), which is directly related to several processes responsible for soil sustainability, since it affects soil chemical, physical, and biological attributes.

By understanding transformations occurred in the soil after conversion, it is possible to reach the current status of sustainability in these areas submitted to forestation, when compared to their original covering. For that, SOM (content and quality) and other soil attributes can be useful in elucidating sustainability stand-level.

Although in the last years, research on SOM in tropical conditions has increased, much more has still to be understood about its nature and dynamics, especially, on interrelations between SOM and processes such as nutrients cycling, biological activity, and aggregation.

The general objectives of this thesis were to contribute to the knowledge on SOM dynamics and chemical composition in Brazilian conditions, using widely applied technology; and to evaluate the sustainability stand-level in a lakeshore area submitted to riparian vegetation establishment. In order to reach our goals, we divided the thesis in three major chapters (2 to 4) written as independent papers, and for this reason, with some inevitable overlaps. Chapters 2 and 3 aimed at the characterisation of SOM, highlighting impacts of the vegetation conversion on its dynamics (Chapter 2) and chemical composition (Chapter 3). Chapter 4 aimed to elucidate the sustainability status of the forested area, by evaluating changes promoted in soil attributes and their relationships with changes found in SOM.

2 LITERATURE REVIEW

2.1 Environmental impacts of hydroelectric power plant construction

Between 1934 and 1988, Brazil presented one of the deepest world rates of economical development, which significantly increased the energy demand. In order to profit the most promising energy source of the country, the water resources, many hydroelectric power plants were built, damming initially rivers of the South and Southeast Brazilian regions (Davide & Botelho, 1999). However, the Brazilian hydroelectric industry was developed without ecological concern. Environmental movements only acquired political force starting from the 80's, due to the political opening and the promulgation of the current Brazilian Constitution, in 1988.

Damming causes the disappearance of thousands of km^2 of margins of rivers, lakes, and other humid ecosystems located in the deepest part of valleys, destroying several natural ecosystems by flooding. Because of their location, riparian forests are particularly threatened to anthropogenic impacts (Oliveira-Filho et al., 1994). In general, they can be defined as "vegetation following the watercourses" (Catharino, 1989). Considering the *Cerrado* morphoclimatic domain, riparian forests constitute the woody vegetation that follows the margins of medium and large rivers (Ribeiro et al., 1998), carrying out important functions. Such forests are considered essential ecosystems for soil and water resources protection, because they (i) regulate the flux of water, sediments, and nutrients between the highest parts of the hydrographic basin and the aquatic environment; (ii) control nutrient cycling, contributing to the maintenance of water quality; and (iii) provide covering and feeding for the aquatic fauna (Lima, 1989), as well as for terrestrial mammals of the Cerrado area (Redford & Fonseca, 1986). In this sense, the dramatic reduction of riparian vegetation, verified in Brazil in the last years, has increased soil erosion and reduced biodiversity (Davide & Botelho, 1999).

2.2 Itutinga/Camargos reservoirs

Consequences of human pressure were particularly outstanding in Brazilian areas under older European colonisation, such as the Rio Grande Basin, in Minas Gerais State, where riparian forests have undergone great reduction and deep disturbance (Oliveira-Filho et al., 1994). Minas Gerais presents 17 hydrographic basins (IGAM, 1998), which are inserted in very distinct ecosystems. Since 1952, when the Minas Gerais Energy Company (CEMIG) was created, 35 hydroelectric power plants were built, with a total reservoir area of 2,260 km^2, widespread over the whole State, and covering all hydrographic basins (CEMIG, 1990).

Itutinga/Camargos HPP constitute part of the CEMIG system for energy generation, and are essential for Sul de Minas and Campo das Vertentes (Campos da Mantiqueira microregion) physiographic regions of Minas Gerais. Their reservoirs accumulate respectively 792 and 11 millions of m^3 of water (Comitê Brasileiro de Grandes Barragens, 1982).

In the region under influence of these HPP, soils are mainly developed from metapelitic rocks, which constitute a class of rocks formed by very small particles (microclastic) deposited in a certain environment. These rocks originate soils with equivalent contents of silt and clay, low nutrient contents, high acidity and, sometimes, high exchangeable aluminium contents. Soils derived from pelitic rocks can be deep (reddish), when located in gentle relief, or shallow (yellowish), when located in undulated relief (Almeida & Resende, 1985).

Giarola et al. (1997) carried out a pedologic survey in Itutinga/Camargos reservoirs area and found the following geographical expression of mapped soils: dystrophic Cambisol (Inceptisol), 40.71%: allic Cambisol, 5.69%; dystrophic Dark-Red Latosol (Oxisol), 16.06%: dystrophic Red-Yellow Latosol (Oxisol), 1.13%; acric Red-Yellow Latosol (Oxisol), 13.37%; allic Litholic soils, 11.31% and outcroppings, hydromorfic soils and inclusions, 11.73%.

Latosols (Oxisols), quite expressive in the area, present as main characteristics low base saturation, great depth, and porosity. The very well expressed granular structure gives to these soils high permeability, mainly when formed under vertical substrata. Among them, the Typic Acric Red-Yellow Latosol (Anionic Acrustox) one presents higher moisture retention, reflex of its restriction to drainage (Chagas, 1994; Chagas et al., 1997).

The Campos da Mantiqueira microregion presents forest and *campo cerrado* (open savannah), as primitive vegetation. Its forests are remainders of primary vegetation that included *cerradão*, and both semi-deciduous tropical and perennial subtropical forests (Golfari, 1975). Natural vegetation still prevails around the lakes formed in Itutinga/Camargos reservoirs (Brazil, 1983), and areas under native vegetation of *cerrado*, *campo cerrado* and even native pastures may be found. However, due to the substantial elevation of the water level, these areas, originally distant from water, became lakeshores.

2.3 Programs of vegetation re-establishment and their evaluation

Under the hydroelectric company's point of view, the resolution of environmental problems (mainly related to re-establishment of vegetation covering) is important not only in an ecological perspective, but also in maintaining the useful life of water reservoirs (Silva, 1999). Only in 1986, the first *Plano Diretor para a Conservação e Recuperação do Meio Ambiente* (I PDMA), aiming at environmental conservation and recovery near HPP areas, was published. Since then, several programs of environmental vegetation re-establishment were created in order to develop technological research on reforestation models in great part of the Brazilian hydroelectric reservoirs.

In 1988 CEMIG began to develop studies and actions with the objective to obtain appropriate technology to recompose marginal areas. At that time, Itutinga/Camargos reservoirs were chosen to start the Riparian Forest Project, through a partnership with the Departments of Forest Science and Soil Science of the Lavras Federal University (UFLA). Several studies in Forestry Science have been carried out since the project was implemented. Nevertheless, some unexplained aspects impede the complete development of this type of recovery programs in Brazil (Kageyama et al., 1992). For instance, very little work has been done with regards to soil evaluation in areas submitted to riparian forests planting.

For both agricultural and natural systems it is already well established that carbon storage, nutrient cycling, and aggregation, among other important processes, control the soil capacity for sustaining vegetation. However, the concept of soil sustainability should include the whole environment. Hence, a "sustainable" soil must be able to keep vegetation growth (and cycles) and not negatively influence the environment where it is inserted; on the contrary, it should contribute to conservation of other natural resources, such water. Especially in planted systems, aiming at environmental restoration, it is necessary to verify whether and how changes can be caused in soil attributes and thus, affect soil sustainability.

2.4 Soil organic matter and soil processes

Recently, soil organic matter has been mentioned as a key indicator of soil quality (Doran, 1997) and a key component of all terrestrial ecosystems (Bartjes & Sombroek, 1997). This consensus results from two main facts: first, its content can be sensitive to alterations promoted in soil; and second, most of the attributes linked to basic soil functions are closely related to the organic fraction.

Notwithstanding that organic matter content may be a good attribute for representing soil quality, system sustainability hardly ever can be assessed through accompaniment in time of just one variable. It is important to know the existing SOM content, and in addition, its nature. According to Novotny & Martin-Neto (1999) several of its properties depends on macromolecular characteristics.

Organic matter reacts in soil by different ways: ionic exchange (linked to cation exchange capacity - CEC); reactions with soil minerals (for instance, binding processes in clay particles), and organic molecules (adsorption of organic molecules as agrochemical residues); and complexation with metallic cations (decrease of heavy metals concentration in soil solution and Al^{+3}complexation) (Canellas et al., 1999a). These reactions give to SOM a fundamental role on many soil chemical, physical, and biological attributes. Among chemical characteristics and properties affected by SOM, stand out nutrient availability, cation exchange capacity, and complexation of toxicant elements and micronutrients. Aggregation is the major soil physical characteristic affected by SOM. Starting from the effect on aggregation, indirectly other soil physical attributes are affected, such as bulk density, porosity, aeration, and water retention/infiltration capacity. Soil organic matter directly affects soil biological attributes, acting as a source of carbon, energy, and nutrients for chemoheterotrophic microorganisms. Its effect on microbiology can be evaluated through microbial activity and biomass, which represent an integration of SOM influences on soil biological conditions (Bayer & Mielniczuck, 1999).

Vegetation is the major source of SOM, defining the amount of material added to the soil and, also, its chemical composition. Any variation on SOM abundance and quality, caused by vegetation conversion or management practices, exercises an important effect on several of the soil processes happening inside a certain ecosystem, for instance carbon storage. The intensity of these processes is directly related to the soil capacity for sustaining primary production and biological activity (Bartjes & Sombroek, 1997). Hence, a better understanding of the relationships between them and SOM, in natural and modified ecosystems, might be a good approach in evaluating the impact of human activities.

Several works have been carried out evaluating the impact of cultivation on those processes and their relation with SOM. Aggregate stability usually is positively correlated to SOM content and increases when conservation practices are used, such as no tillage, green manuring, and alley cropping (Reicherdt et al., 1993; Mapa & Gunasena, 1995; Castro-Filho et al., 1998; Silva & Mielniczuk, 1998). Several works demonstrated positive effects of SOM preventing soil losses by erosion, which were smaller when soil covering was efficient (Braida & Cassol, 1999; Hernani et al., 1999) or when organic carbon content was high (Angulo et al., 1984). Among biological parameters, microbial biomass has been used in a great number of works and considered a microbiological parameter capable to indicate short-term changes in soil quality (Silva Filho & Vidor, 1984; Fernandes et al., 1997; Wick et al., 1998; Marchiori Júnior & Melo, 1999). Positive effects of increasing SOM contents on soil fertility are also widely found in literature. Several results showed that increases in SOM stocks, by no-tillage or green manuring, increase CEC and nutrient availability, and decrease acidity and aluminium toxicity (Franco & Souto, 1984; Testa et al. 1992; Miyasawa et al., 1993; Aita et al., 1994; Alcântara et al., 2000).

2.5 Soil organic matter fractionation and chemical characterisation

Use of total SOM content to understand its role on soil processes is quite valid, but in many cases, the elucidation of some questions can be unsatisfactory. It happens due to the great complexity of SOM, which is a mix of partially decomposed organic residues (vegetal or animal), live soil biomass (organic material inside the living cells), and humified material or humus (highly decomposed material). The later may be defined as a series of substances with dark-brown to black colour; chemically complex; and presenting low solubility, structural irregularity and strong physical and chemical connections to each other and to mineral fraction (Guerra & Santos, 1999).

Due to its complex structure and interactions with the mineral matrix, the physical and chemical properties of humic substances are difficult to define precisely. A variety of techniques have been developed to fractionate samples into distinctive and less complex parts (Swift, 1996). Chemical and physical methods have been used as an attempt to obtain different and meaningful fractions. According to Cambardella & Elliot (1993), chemical fractionation has not been effective in separating organic matter fractions with significant differences in composition and dynamics. On the other hand, physical methods can be less destructive. The obtained fractions usually are more directly related to the structure and function of SOM *in situ* than chemical extractions (Christensen, 1992). Two basic principles are widely used for soil physical fractionation: density and particle-size separation. Both methods have been applied, individually or together, to separate SOM with significant differences in chemical composition, location in soil matrix, and degree of association with clay particles (Christensen, 1992).

Density fractionation allows a better understanding of SOM decomposition through separation of the light (< 1.7 g cm^{-3}) from the heavy fraction (> 1.7 g cm^{-3}). Generally, it is established that the first one still has litter characteristics and a fast decomposition rate, and the heavy fraction consists mainly of highly decomposed material, with a much slower decomposition rate (Golchin et al., 1995). However, this definition is not straightforward since labile material can be present in the heavy fraction and also, rather stable fragments, as charcoal, can remain in the light one.

Ultrasonication is the most common method used to obtain a high degree of soil structure disruption prior to physical fractionation (Christensen, 1987). Association of ultrasonic energy with physical fractionation has been used in several works in order to detect differences in the stability of organic matter associated to different soil fractions (Christensen, 1987) or differences that evidence changes caused by cultivation (Cambardella & Elliot, 1994), as well as to obtain information about system sustainability (Feigl et al., 1995).

Soil organic matter chemical composition can be very sensitive to environmental changes. Techniques like Cross Polarisation-Magic Angle Spinning (CPMAS) solid state ^{13}C nuclear magnetic resonance (NMR) spectroscopy, and pyrolysis associated to gas-chromatography and mass-spectrometry (Py-GC/MS) have provided a better understanding of SOM composition. Their use, together with soil physical fractionation, would be a powerful tool in monitoring SOM transformations in soils submitted to alterations.

Only about 10-15 years ago, the development of NMR technique has allowed its intensive use in SOM studies. Its under-utilisation has been attributed to lack of equipment, specialists in NMR involved with such studies, and opportunities for researchers' training (Preston, 1996). In Brazil, Ceretta et al. (1999) consider these limitations quite accentuated, which can explain that only recently the first SOM studies using NMR were published (e.g. Ceretta, 1995; Martin-Neto et al., 1995). Cross polarisation and magic angle spinning permits to obtain spectra with high resolution for ^{13}C in solid-state samples (Preston, 1996). The main objective of CPMAS ^{13}C NMR is to evaluate the signals of the different C nuclei in SOM (Conte et al., 1997). According to the chemical-shift range, alkyl, O-alkyl, aromatic and carbonyl carbon types are detected and quantified as relative proportions of the total area. Actually, the term semi-quantified is more appropriate. Some authors point out the short relaxation time ($T_{1\rho}$, H) and low contents of carbon in most of mineral soils can alter relative areas of peaks (Kinchesh et al., 1995a,b). Other important problem is the difference in transference of energy from the hydrogen nucleus to the different C nuclei, during the cross polarisation, causing diverse contact times for each C nucleus.

Pyrolysis-GC/MS was used for the first time by Simmonds et al. (1969), in superficial samples of California desert land (with 0.34% of C), aiming at its further utilisation in an exploratory assay in Mars (Saiz-Jimenez, 1994). According to Schulten (1993), cited by Canellas et al. (1999b), the technique might be very useful in studying SOM in geochemical, structural, and ecological points of view. In agricultural land, it is able to quickly discriminate soil organic components, showing direct relevance in soil science. Pyrolysis promotes a break of large molecules into smaller fragments, which are separated by gas chromatography and identified by mass spectrometry. It allows very rapid screening of complex materials and requires only sub-milligram sample sizes (Stamkiewicz et al., 1996). This type of thermal degradation technique has showed a great potential for evaluating contamination of agricultural areas by pollutants, as well as qualitative changes in SOM under soils submitted to different management systems (e.g. Leeuw et al. 1986; Stuczynsk et al., 1997). In Brazil, only one work using Py-GC/MS technique was found in literature (Canellas, 1999).

2.6 Research proposition

Conversion of vegetation represents an important change in the amount and chemical composition of the organic material that is added, and later, decomposed in the soil. We hypothesise that such a change may unleash alterations in chemical, physical, and biological soil attributes. In this sense, soil organic matter can be a useful tool in order to identify changes in soil processes, when such vegetation conversion takes place.

Although during the last years in Brazil we could observe a considerable increase in number and quality of works focussing on SOM, there is still a big gap in this study line for our soils. Starting from the elucidation of relationships between SOM and soil processes, a great progress could be reached in understanding tropical systems sustainability. In addition, programs of re-establishment of riparian areas in hydroelectric reservoir vicinities are quite recent in Brazil. Due to this fact, nowadays there is no knowledge on alterations caused in soil by its implantation. Research on this topic may permit the evaluation of this type of program, in terms of promoting sustainability of lakeshores formed by damming.

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CHAPTER 2

IMPACT OF THE CONVERSION OF GRASSY CERRADO INTO RIPARIAN FOREST ON SOIL ORGANIC MATTER, AS REVEALED BY DENSITY FRACTIONS AND $\delta^{13}C$ ISOTOPIC RATIOS IN AN OXISOL

ABSTRACT

ALCÂNTARA, Flávia Aparecida de. **Impact of the conversion of grassy cerrado into riparian forest on soil organic matter, as revealed by density fractions and $\delta^{13}C$ isotopic ratios in an Oxisol.** Lavras: UFLA, 2002. Chap. 2. 27 p. (Thesis - PhD in Soils and Plant Nutrition)[+]

In order to evaluate the impact of establishing riparian forests (C_3-derived C) on soils previously under grassy cerrado (C_4-derived C) on soil organic matter (SOM), and to better understand SOM dynamics in Brazilian Latosols (Oxisols), we combined physical fractionation and carbon isotopic analysis of a typical Acric Red-Yellow Latosol (Anionic Acrustox). Soil under native vegetation (Brazilian savannah or *cerrado*) was used as reference and compared with soil under riparian forest since 1992. Due to the predominance of grasses, carbon input is mainly below ground in the cerrado. In such soil, the decomposition process was more efficient, and much C and N were transferred to the heavy fraction. In the forest there was a change to above-ground litter input (largely superficial), leading to higher C and N stocks in the light fraction and lower in the heavy one. This change promoted a reduction in C and N (total) stocks with conversion. There was enrichment in $\delta^{13}C$ with soil depth for both areas, which is already well documented for C_3 systems, but not for the C_4 or mixed ones. This phenomenon in the cerrado, where the litter is mixed and the system is in steady state, appeared to be similar to that occurred in C_3 system. Eight years after the conversion, $\delta^{13}C$ decreased, indicating more contribution of C_3-C to the total soil organic C. This contribution and the losses of C_4-C as well, due mainly to the predominance of above-ground C input, tended to be higher in the topsoil. The existing replacement of C_3-C by C_4-C indicated a relatively rapid dynamics of SOM in this tropical soil. Error propagation in replacement calculations allowed a more realistic interpretation of the carbon origin data.

[+] Guidance Comittee: Antonio E. Furtini Neto - UFLA (Major Professor), Nilton Curi - UFLA, and Peter Buurman – WU.

RESUMO

ALCÂNTARA, Flávia Aparecida de. **Impacto da conversão de cerrado em mata ciliar sobre a matéria orgânica do solo, avaliado por fracionamento densimétrico e análise isotópica de carbono ($\delta^{13}C$) em um Latossolo.** Lavras: UFLA, 2002. Cap. 2. 27 p. (Tese - Doutorado em Solos e Nutrição de Plantas)[+]

O fracionamento físico do solo e a análise isotópica de carbono ($\delta^{13}C$) foram empregados com o objetivo de avaliar o estabelecimento de mata ciliar (carbono de origem C_3) em um Latossolo Vermelho-Amarelo Ácrico previamente ocupado por cerrado "campo sujo" (carbono de origem C_4) sobre a matéria orgânica do solo (MOS), e compreender melhor a dinâmica da MOS em Latossolos. Amostras de solo sob cerrado, utilizadas como referência, foram comparadas com amostras sob mata ciliar, a qual foi implantada em 1992. Devido à predominância de gramíneas, a entrada de carbono no sistema cerrado ocorre principalmente sob o solo, através do sistema radicular. Nessa área, o processo de decomposição se mostrou mais eficiente, sendo mais C e N transferidos para a fração pesada da MOS. Com a implantação da mata, houve uma mudança na entrada de carbono, a qual passou a ocorrer predominantemente sobre a superfície do solo, através da deposição da serapilheira. Como conseqüência, a fração leve apresentou maiores estoques de C e N do que sob cerrado, enquanto a fração pesada, menores. Tal mudança na entrada de C provocou a redução dos estoques totais de C e N sob mata, já que a fração pesada representa a maior parte da MOS. Nas duas áreas, ocorreu enriquecimento em $\delta^{13}C$ com a profundidade do solo, fenômeno já bem estudado e documentado para os sistemas C_3, mas não para os C_4 ou mistos. No cerrado, onde a serapilheira é mista e o sistema está em equilíbrio, tal fenômeno parece ocorrer de maneira similar à existente em sistemas C_3 puros. Oito anos após a conversão da vegetação, os valores de $\delta^{13}C$ diminuíram, indicando maior contribuição de C-C_3 para o C orgânico total do solo. Tal contribuição, bem como as perdas de C-C_4, tenderam a ser maiores na camada mais superficial do solo. A substituição de C-C_4 por C-C_3 ocorrida no período estudado indica uma dinâmica de C relativamente rápida. A análise estatística de Propagação do Erro, realizada para os dados referentes à substituição de carbono, permitiu uma interpretação mais minuciosa dos dados sobre a origem deste no solo.

[+] Comitê de Orientação: Antonio E. Furtini Neto - UFLA (Orientador), Nilton Curi - UFLA, and Peter Buurman – WU.

1 INTRODUCTION

Construction of hydroelectric power plants contributes to the disappearance of several natural ecosystems. Due to their location, riparian forests are particularly threatened. Because of the critical situation of the riparian forests of the Centre-South Region of Brazil, a large incentive was given to the study of alternatives to preserve or recover such forests. In late 80's, many programs of riparian vegetation re-establishment appeared, aiming at technological research on reforestation models in the vicinities of hydroelectric reservoirs. The Riparian Forest Project, one of the first Brazilian programs, was implemented in the Itutinga/Camargos reservoir in 1990. The native vegetation still prevails and lakeside areas covered by *cerrado* (Brazilian savannah), which varies from grasslands to woodlands, can still be found. Only a small part of the shores was replanted with riparian species (C_3 vegetation), including some areas covered by grassy cerrado (predominantly C_4 vegetation).

Very little work has been done on evaluation of vegetation re-establishment programs in Brazil and most of it does not focus on SOM. Greater knowledge about carbon stocks and SOM fractions is necessary to elucidate carbon storage in tropical conditions, mainly when there is a conversion between C_3 and C_4 vegetation or vice-versa.

It is well known that the discrimination between the two stable isotopes of carbon, ^{13}C and ^{12}C, in favour of the lighter ^{12}C, is dominated by the primary carboxylation steps in photosynthesis, particularly the reaction catalysed by ribulose byphosphate carboxylase. As the primary carboxylation step occurs in C_3 plants but not in C_4 plants, the degree of discrimination against ^{13}C is greater in C_3 plants (Lefroy et al., 1993). Carbon isotopic composition of SOM is a function of the relative contribution of C_3 and/or C_4 plants to the soil organic C pool (Midwood & Boutton, 1998). It corresponds closely to that of the vegetation cover, since the fractionation of ^{13}C during the transformation of plant residues into SOM is smaller than the difference between C_3 and C_4 litter (Balesdent et al., 1993). A replacement of vegetation will gradually change the isotopic composition (Bonde et al., 1992). The introduction of C_3 plants ($\delta^{13}C \cong$ -27‰) to a soil previously developed under C_4 vegetation ($\delta^{13}C \cong$ -13‰), or vice-versa, causes an *in situ* labelling of the new organic matter incorporated into the soil (Lefroy et al., 1993). This can be used to evaluate the dynamics of the carbon incorporated when such conversion occurs. In Brazilian soils, the isotopic composition method has been used successfully to reconstruct past vegetation changes (Pessenda et al., 1996; Martinelli et al., 1996), and to estimate the SOM turnover (Modenesi et al., 1982; Volkoff & Cerri, 1987; Feigl et al., 1995; Roscoe et al., 2001).

Physical fractionation of soil organic matter with application of ultrasonic energy has been used in several studies of SOM stability (Christensen, 1987), of changes caused by cultivation (Cambardella & Elliot, 1994), and of systems sustainability (Feigl et al., 1995). Density fractionation allows a better understanding of SOM decomposition through separation of the light (< 1.7 g cm^{-3}) from the heavy fraction (> 1.7 g cm^{-3}). While the first one still has litter characteristics and a fast decomposition rate, the heavy fraction consists mainly of highly decomposed material, with a much slower decomposition rate (Golchin et al., 1995).

In this work we combined physical fractionation and carbon isotopic analysis aiming to (i) evaluate the impact of establishing riparian forests on soils previously under grassy cerrado on SOM dynamics and, (ii) contribute to a better understanding of SOM dynamics in Brazilian Latosols (Oxisols).

2 MATERIAL AND METHODS

2.1 Site description

The study was carried out in the Itutinga/Camargos reservoirs, located in southern Minas Gerais State (Campo das Vertentes physiographic region), Brazil (Figure 1), at 917 m of altitude. The mean annual temperature is 19.4 °C, and the mean annual precipitation is 1529 mm, with a dry period from April to September (Brasil, 1992). This region is part of Paraná River basin and drained by rivers from Grande River sub-basin. We selected a site in the vicinities of Itutinga/Camargos reservoirs, which was partially submitted to the "Riparian Forest Project". The soil (characterised in Table 1) is a homogeneous Typic Acric Red-Yellow Latosol (Anionic Acrustox) (Chagas et al., 1997).

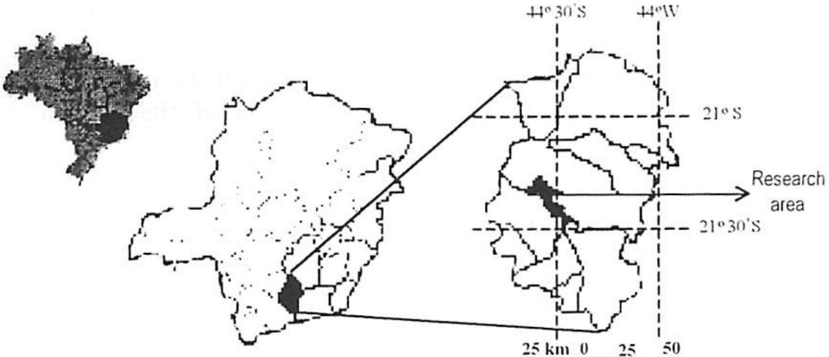

FIGURE 1. Location of the studied area in the Itutinga/Camargos reservoirs, Minas Gerais State, Brazil.

Two areas within this site were chosen. They are located 200 m apart, in opposite hillsides of the site. The first area was taken as reference because it was maintained under native vegetation (grassy cerrado), which is a grassland with scattered shrubs (canopy density < 5% of total area) (Ribeiro & Walter, 1998). In this area, among the grasses, the most widespread ones are *Panicum* sp., *Paspalum* sp., *Melinis minutiflora*, *Setaria geniculata*, and *Eragrostis prolifera*, and among the shrubs, *Solanum grandiflorum* and *Dimorphandra mollis*. The second area was converted into forest in 1992, as part of the above-mentioned project. It was planted with a mixture of riparian species, after excluding native vegetation. The most important planted tree species are *Trema micrantha*, *Senna multijulga*, *Mimosa scabrella*, *Croton floribundus*, and species of *Acacia* spp., *Anadenanthera* spp., *Inga* spp., and *Tabebuia* spp. Canopy density can range from 50% (dry season) to 90% (wet season). Both areas were plotted 5 meters from the reservoir margin, in order to discount the depleted area, which is subject to periodic flooding and presents species adapted to such condition.

TABLE 1. Profile characteristics* and texture, bulk density, organic carbon, pH, and effective CEC for the first 20 cm of the studied Anionic Acrustox.

Profile characteristics	**Drainage class**	Well drained
	Horizons classification	moderate "A"
	Horizons depth / thickness	"A + AB" = 0.58 m "B" > 2 m
	Colour	"B" = yellowish colours changing to reddish at 1.1 m.
Texture (g kg^{-1})	**Clay**	410
	Silt	360
	Sand	230
Bulk density (g dm^{-3})		1.38
Total organic carbon content (g kg^{-1})		23
pH		4.9
Effective CEC (cmol$_c$ dm^{-3})		1.8

* Classification according to EMBRAPA (1999).

2.2 Soil and litter sampling

Sampling was done in May/2000. For that, we used the randomised blocks experimental design in factorial scheme with four replications. Each area was sub-divided into four blocks (replicates), which were defined based on land quotas. The same land quotas were used in both areas in order to plot the blocks. Thus, each block was placed in the same position in the hillside for both areas. One composite sample was taken per block, each one a mixture of ten sub-samples collected in a "zigzag" pattern. Four different soil depths were sampled (0-2.5, 2.5-5, 5-10 and 10-20 cm), resulting in 16 composite soil samples in each area. Litter was collected with a 50 x 50 cm frame, placed on the same sites used for soil sub-samples, resulting in 4 composite samples in each area. The soil samples were air-dried and passed through a 2 mm sieve to remove coarse debris. The aboveground litter samples were oven-dried (60°C), weighted, and ground to a fine powder.

2.3 Soil organic matter fractionation

Soil organic matter was separated by density fractionation using a NaI solution (1.7 g cm^{-3}) (Gregorich & Ellert, 1993). In short, 20 g of sample were placed in a 200 mL centrifuge tube with 150 mL of NaI solution, shaken by hand and ultra sonicated at 270 J mL^{-1}, with a Vibracell VCX 600 probe-type model, calorimetrically calibrated as described by Roscoe et al. (2000a). After centrifugation (3500 rpm, 15 min), the sample was left standing at room temperature for about 5 minutes, and then the supernatant was filtered through a membrane filter (Whatman GF/A) into a millipore vacuum unit. The sediment was re-suspended in NaI and centrifuged once more as described above. The fractions recovered on the filter were washed with 0.01 mol L^{-1} $CaCl_2$ solution (100 mL) and distilled water (200 mL). The two light sub fractions were joined, oven dried at 50°C, weighed, ground by hand, and stored for subsequent analysis. This fraction was called "light fraction" (LF-OM). The sediment left after the second separation ("heavy fraction" - HF-OM) was washed one time with 0.01 mol L^{-1} $CaCl_2$ and about ten times with distilled water (until the clay fraction remained in suspension after 24 hours), freeze-dried, ground in a sample mill, and stored for subsequent analysis.

2.4 Analytical methods

All soil and litter samples were analysed for organic carbon (OC) and total nitrogen by flash combustion, using an Interscience Elemental Analyser EA1180. Soil bulk density was determined using the paraffin method (Blake & Hartge, 1986).

Abundance of ^{13}C in litter and soil samples was determined after conversion of total C to CO_2, purified by CuO and Ag, in a VG/SIRA 9 Mass Spectrometer at the Centre for Isotope Research at the University of Groningen, the Netherlands. By convention, isotope ratios are expressed as $\delta^{13}C$ (‰):

$$\delta^{13}C = [(R_{sample}/R_{standard}) - 1] \times 1000 \qquad (1)$$

Where R is the molar ratio of the heavy to light isotope of the sample or standard. The standard is Vienna - Pee Dee Belemnite (V-PDB) (Ehleringer et al., 2000).

2.5 Carbon origin estimations

The percentage of carbon originated from C_4 vegetation was estimated for the litter in cerrado, according to equation (2) (Balesdent & Mariotti, 1996):

$$C_{C4} = 100 \times [(\delta_{CL} - \delta_{C3}) / (\delta_{C4} - \delta_{C3})] \qquad (2)$$

Where C_{C4} is the soil organic carbon derived from C_4 vegetation, δ_{CL} is the $\delta^{13}C$ of the cerrado litter, δ_{C3} is the $\delta^{13}C$ of soil organic carbon derived from C_3 vegetation, and δ_{C4} is the $\delta^{13}C$ of soil organic carbon derived from C_4 vegetation.

The reference values for C_3-derived C were those observed for the forest litter (-29.04 ± 0.24 ‰). For C_4-derived C, we used the value of -13.00 ‰, which is the average for C_4 plants (Boutton, 1996). This value is in agreement with the value -13.52 ± 0.07 ‰, reported by Roscoe et al. (2001) for similar C_4 vegetation.

As the cerrado area was in steady state, the proportion of C derived from C_4 plants at all soil depths should be equal to that in the litter, as calculated by equation (2). For the calculations of the percentages of C_4-derived C under forest, we assumed that C_3- and C_4-derived organic matter would show the same proportional $\delta^{13}C$ fractionation with depth. Thus, we estimated the expected signature of C_3-derived C at each depth of the forest area by considering the fractionation observed for the total C in the cerrado. In this area, the increases in $\delta^{13}C$ from litter to the first (0-2.5 cm), second (2.5-5 cm), third (5-10 cm), and fourth (10-20 cm) depths (Table 2) were in average 2.83, 3.46, 3.99, and 4.51 ‰ respectively. Using these values and the $\delta^{13}C$ of the forest litter we obtained the values of -26.21, -25.58, -25.05, and -24.53 ‰ in average for the same soil depths, respectively. They were in agreement with those observed by Roscoe et al. (2000b) for a woodland savannah (C_3 vegetation), in similar soil and environmental conditions. These authors observed values in the soil of -27.42, -26.48, -24.85, -24.57, and -24.23 ‰, for depth intervals of 0-3, 3-5, 5-10, 10-15, and 15-20 cm, respectively. Then, we used the values obtained as described above in equation (3) to calculate the percentages of C_4-derived carbon in each depth interval of the forest soil:

$$C_{C4} = 100 \times [(\delta_T - \delta_{C3soil}) / (\delta_{C4litter} - \delta_{C3litter})] \qquad (3)$$

Where C_{C4} is the same as in equation (2), δ_T is the $\delta^{13}C$ of the total soil organic carbon in forest, δ_{C3soil} is the $\delta^{13}C$ of the soil estimated as described before, $\delta_{C4litter}$ is the $\delta^{13}C$ of the C_4-derived litter, and $\delta_{C3litter}$ is the $\delta^{13}C$ of the C_3-derived litter.

Data of OC per mass (g kg^{-1}) and bulk density (g cm^{-3}) (Table 2) were used to calculate OC contents per volume (g dm^{-3}). The later were used, together with the percentage of C from C_4 vegetation, to quantify the organic carbon, per volume of soil, originating from C_4 plants at each depth and area.

In order to calculate the losses of C_4-C in the forest soil, we used the cerrado profile as a reference. The loss of C_4-C is the difference between the C_4-derived C in cerrado and forest. The balance was calculated as the difference between total organic carbon in forest and cerrado for each depth.

2.6 Statistical methods

From the input variables δ_T, $\delta_{C3litter}$, $\delta_{C4litter}$, δ_{C3soil}, OC $_{(mass)}$ and bulk density, we calculated four output variables for each depth: proportion of C_4-derived C in forest (C_4-$C_{Proportion}$), contents of C_4-derived C in forest (C_4-$C_{Content}$), losses of C_4-derived C in forest (C_4-C_{Loss}), and balance of OC ($C_{Balance}$) in forest. In order to assess the uncertainty of these output variables, we used the methodology proposed by Veldkamp & Weitz (1994) which is based on Monte Carlo simulations. In this procedure, the probability distributions of the input variables were randomly sampled and combined in the calculations. The calculations were repeated 500 times and the probability distributions of the output variables were estimated. We assumed normal distribution and no mutual correlation for the input variables.

3 RESULTS

3.1 Organic C and N in litter, soil and density fractions

The litter of the forest showed to be richer in nitrogen and had a lower C:N ratio than the litter of the reference area. However, there was no difference in carbon concentration in the litter of both areas. Forest produced twice as much litter dry matter as the cerrado. This caused higher C and N stocks in the litter under the planted forest than under cerrado (Table 2).

Carbon and nitrogen concentrations (g kg^{-1}) in both soil profiles declined towards 20 cm (Table 3). Their contents per volume (g dm^{-3}) are shown in Figure 2. The soil under cerrado presented significantly higher C and N contents at 2.5-5 and 5-10 cm and for N also at 10-20 cm. In addition, converting cerrado into forest reduced C and N stocks for bulk soil.

TABLE 2. C (mass fraction), N (mass fraction), C:N ratio, dry matter production (DM) and stocks of C and N for cerrado and forest litter.

Area	C	N	C:N	DM	Stocks	
					C	N
	(g kg^{-1})				(kg ha^{-1})	
Cerrado	410.2±9.0[a]	6.5±0.3	63.1±2.4	352.6±16.7	145.0±9.5	2.3±0.1
Forest	426.2±7.6	11.9±0.2	35.6±0.5	699.2±20.0	298.0±10.3	8.4±0.2

[a] mean ± standard error (n = 4)

TABLE 3. Litter $\delta^{13}C$ and soil bulk density (BD), C (mass fraction), N (mass fraction), C:N ratio, stocks of C and N and $\delta^{13}C$, as a function of depth under cerrado and forest.

	BD (g cm^{-3})	C	N (g kg^{-1})	C:N	$\delta^{13}C$ (‰)
			Cerrado		
Litter					-18.31 ± 0.34
Depth (cm)					
0 – 2.5	1.34 ± 0.03[a]	26.5 ± 0.8	1.85 ± 0.06	14.3 ± 0.4	-15.48 ± 0.34
2.5 – 5	1.34 ± 0.03	23.8 ± 0.9	1.75 ± 0.09	13.7 ± 0.5	-14.85 ± 0.32
5 – 10	1.41 ± 0.02	22.4 ± 1.4	1.65 ± 0.06	13.5 ± 0.4	-14.32 ± 0.23
10 – 20	1.40 ± 0.02	19.5 ± 0.50	1.48 ± 0.06	13.3 ± 0.5	-13.80 ± 0.20
Stocks [b] **(g m^{-2})**		5980 ± 160	440 ± 14		
			Forest		
Litter					-29.04 ± 0.24
Depth (cm)					
0 – 2.5	1.40 ± 0.03	26.0 ± 1.1	1.83 ± 0.10	14.3 ± 0.2	-20.97 ± 0.25
2.5 – 5	1.42 ± 0.02	20.2 ± 1.0	1.43 ± 0.08	14.2 ± 0.1	-18.40 ± 0.46
5 – 10	1.36 ± 0.03	18.6 ± 0.6	1.33 ± 0.08	14.1 ± 0.4	-16.82 ± 0.26
10 – 20	1.35 ± 0.03	17.9 ± 1.0	1.28 ± 0.05	14.0 ± 0.3	-16.07 ± 0.13
Stocks [b] **(g m^{-2})**		5520 ± 180	380 ± 8		

[a] mean ± standard error (n = 4), [b] stocks for the first 20 cm.

[redacted]

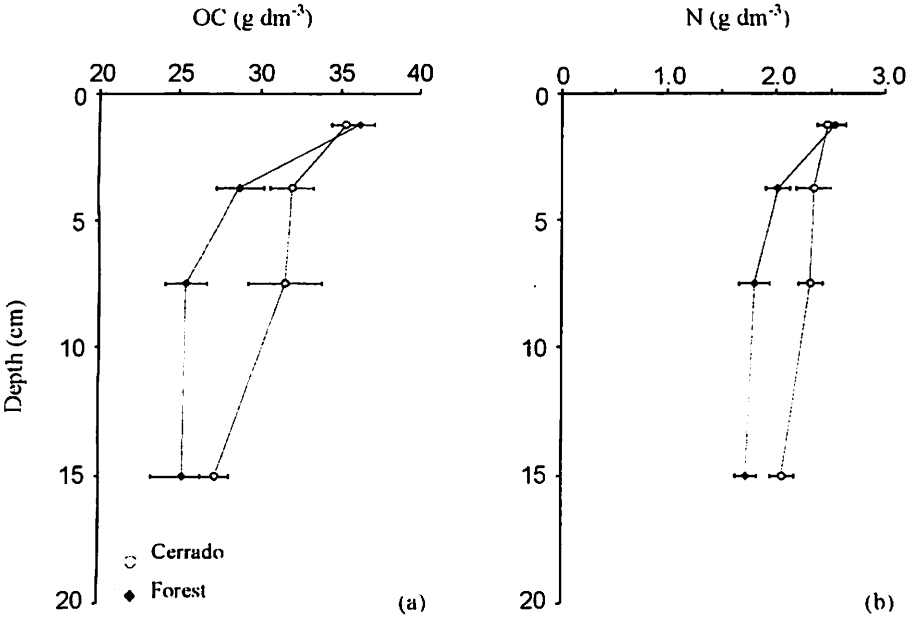

FIGURE 2. Contents of organic carbon (OC) (a) and total nitrogen (N) (b) per volume of soil, for cerrado and forest soil profiles (mean ± standard error).

Upon fractionation, the recovery of organic C ranged from 90 to 110%, with an average of 99%. Losses of organic C during the fractionation procedure occurred due to losses of light fraction, which could pass through the filter membrane (<1.6 μm); and losses of material during the various steps of sample manipulation.

Table 4 shows C and N concentrations, C:N ratio and the percentage of total C in the density fractions. For both data sets, the light fraction had higher concentrations of C and N than the heavy one. With the conversion of cerrado into forest, the C and N concentrations increased in the light fraction, while they remained constant in the heavy one. In addition, the higher N concentration in the light fraction under forest was followed by lower C:N values.

TABLE 4. C (mass fraction), N (mass fraction) and C:N ratio for density fractions, and percentage of total C in the light fraction, as a function of depth under cerrado and forest, and contribution of each fraction to the total soil stocks.

	Fractions						
Depth	**Light**			**Heavy**			
(cm)	C	N	C:N	C	N	C:N	**C light**
	$(g\ kg^{-1})$ [b]			**$(g\ kg^{-1})$** [b]			**(% of total)**
				Cerrado			
0 – 2.5	301.1±12[a]	10.1±0.8	30.1±1.7	24.5±1.2	1.6±0.14	15.4±0.9	6.1±0.4
2.5 – 5	265.6±46	8.2±1.3	32.6±3.1	23.8±4.1	1.6±0.22	14.8±0.8	3.7±0.3
5 – 10	281.7±11	10.2±1.9	29.9±4.5	20.4±2.7	1.4±0.10	14.5±0.9	3.9±0.5
10 – 20	273.5±16	10.7±1.9	27.3±3.3	18.7±1.3	1.3±0.06	14.8±1.0	3.2±0.3
Stocks [c] **$(g\ m^{-2})$**	223.5 ± 20	9.0 ± 0.6		5660 ± 156	388 ± 7		
				Forest			
0 – 2.5	354.6±10	16.5±0.5	21.5±0.4	22.3±1.5	1.4±0.18	15.6±1.4	11.5±1.2
2.5 – 5	311.9±15	14.2±0.7	22.1±0.9	19.2±2.8	1.2±0.24	15.5±1.8	6.2±0.7
5 – 10	298.8±7	15.2±0.6	19.8±0.6	19.0±3.1	1.2±0.17	15.2±2.0	5.2±0.9
10 – 20	322.9±22	14.8±1.2	21.9±0.8	18.0±2.9	1.3±0.17	14.1±2.4	4.0±0.5
Stocks [c] **$(g\ m^{-2})$**	310.5 ± 19	14.6±1.0		5170 ± 130	355 ± 16		

[a] mean ± standard error (n = 4); [b] grams of C (N) per kilo of fraction; and [c] stocks for the first 20 cm, in g of C (N) originating from each fraction per m^2 of soil.

Trends with depth in C and N contents from light and heavy fractions per volume of whole soil are reported in Figure 3. The contribution of the C from light fraction to the total soil organic carbon tended to be higher under forest. For the heavy fraction, the opposite was found: the contribution of the C in this fraction to the total soil organic C was higher under cerrado. Between areas, the most remarkable differences for the light fraction occurred in the topsoil (0 – 5 cm). As for the heavy fraction, although there were no significant differences in total C and N concentrations between cerrado and forest soils, we observed higher C contents between 2.5 and 5 cm, and higher N contents at 2.5-5 and 5-10 cm under cerrado (Figure 3). The stocks for the soil fractions were calculated as grams of C (N) from the light (heavy) fraction per square meter of whole soil to a depth of 20 cm (Table 4). Forest plantation promoted an increase of the stocks of C and N originated from light fraction in the soil, and a decrease of the ones originated from heavy fraction.

3.2 $\delta^{13}C$ of litter and soil

The $\delta^{13}C$ results for litter and soil were reported in Table 3. The values were significantly different for cerrado and forest, reflecting the difference in the vegetation type. Values of $\delta^{13}C$ increased from litter to the topsoil and downward till 20 cm for both soil profiles. The differences in the signature between forest and cerrado were, in average, 10.73‰ for the litter and 5.49, 3.55, 2.50, and 2.27‰ for the first, second, third, and fourth depth, respectively.

3.3 Organic carbon origin

In the cerrado litter the proportion of organic C originated from C_4 plants was 67 ± 4 %. As the cerrado area is in steady state, this proportion was used for all depths in the calculations of C_4-C_{Loss}.

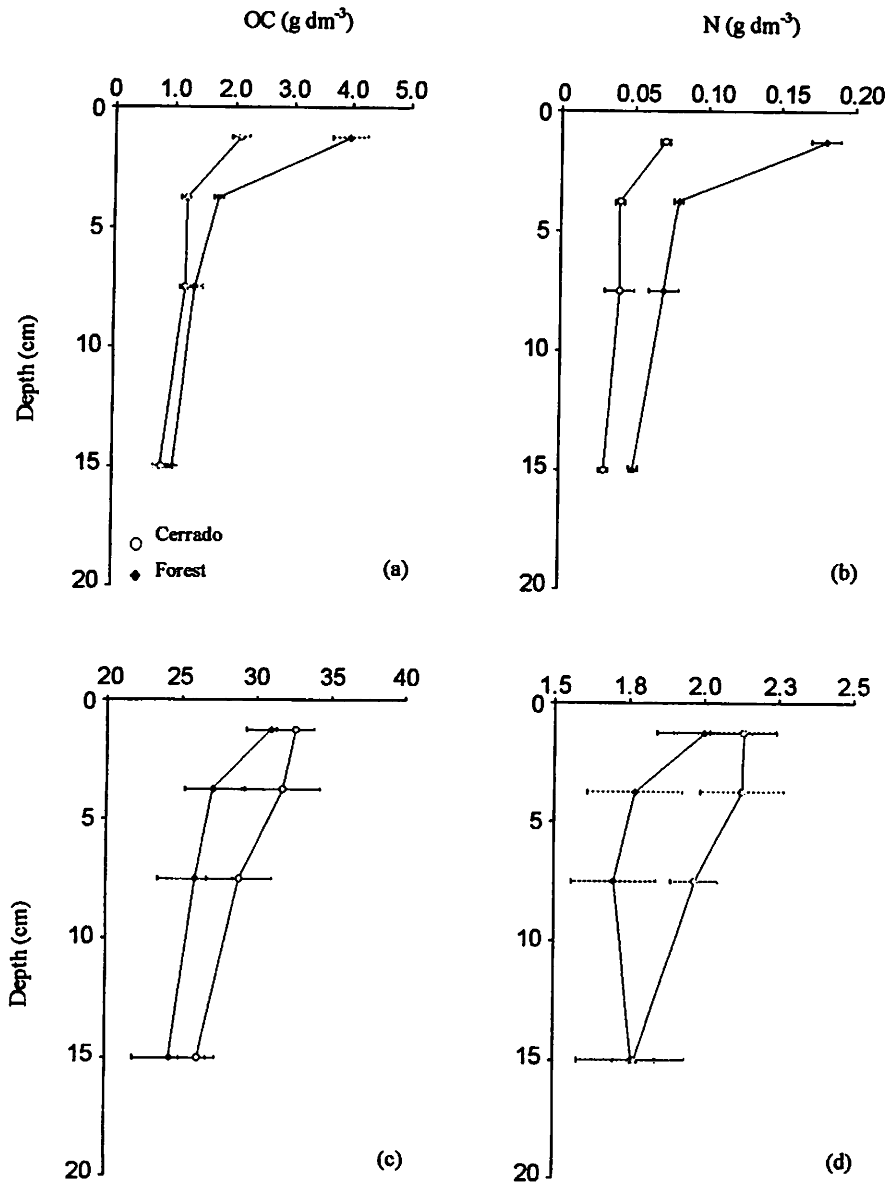

FIGURE 3. Contents of OC and N originating from light (a and b, respectively), and heavy fraction (c and d, respectively) per volume of whole soil (mean ± standard error).

Table 5 reports the statistics of the probability distributions of the output variables (C_4-$C_{Proportion}$, C_4-$C_{Content}$, C_4-C_{Loss}, and $C_{Balance}$) after 500 Monte Carlo simulations. The variability increased from the percentage of C_4-$C_{Proportion}$ to the $C_{Balance}$. For all soil depths, C_4-$C_{Proportion}$ was lower under forest than under cerrado, and suggested a relative increase in C_3-derived material. In addition, C_4-$C_{Proportion}$ tended to increase with depth, and indicated a higher increment in C_3-derived material in the topsoil.

Figure 5 presents the contents and losses of C_4-derived C, and the balance of organic carbon in the planted forest. C_4-C_{Loss} was significantly higher in the top (0-2.5 cm) than at 10-20 cm depth. The balance did not show significant changes, due to the high uncertainties, but tended to be positive at 0-2.5 cm (high litter addition), and negative for the deeper layers (less contribution from grass roots).

TABLE 5. Summary of statistics for the output variables, concerning to the forest area, of 500 Monte Carlo simulations.

	C_4-$C_{Proportion}$ (%)	Organic Carbon (g dm^{-3})		
		C_4-$C_{Content}$	C_4-C_{Loss}	$C_{Balance}$
		Depth (cm)		
		0-2.5		
Mean	35.28	12.85	11.21	1.03
SD	7.53	3.11	3.10	4.22
CV (%)	21	24	28	410
		2.5-5		
Mean	46.95	13.47	8.34	-3.16
SD	8.18	2.78	3.04	4.04
CV (%)	17	21	36	128
		5-10		
Mean	52.77	13.46	7.70	-5.80
SD	6.21	1.86	3.04	4.31
CV (%)	12	14	39	74
		10-20		
Mean	57.07	13.80	4.50	-2.87
SD	5.40	2.06	2.07	3.34
CV (%)	9	15	46	116

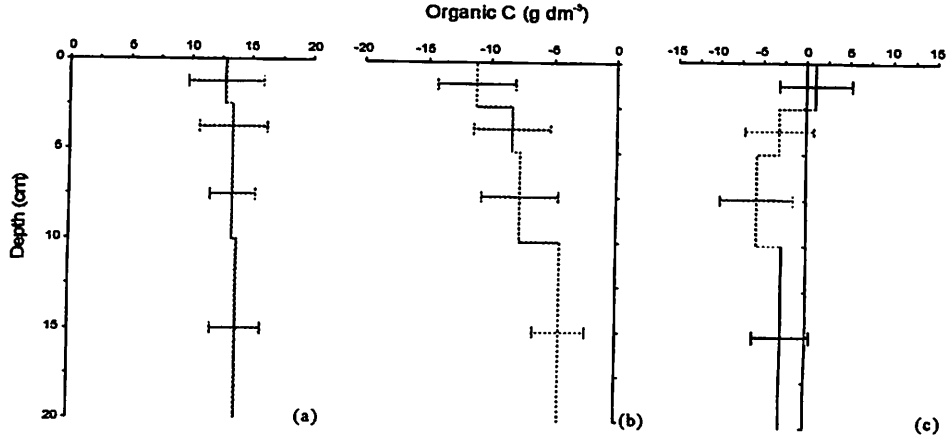

FIGURE 5. Contents of C_4-derived C (a), losses of C_4-derived C (b), and balance (c) of Organic Carbon (g dm^{-3}), for each soil depth of the forest area. Horizontal bars represent the standard deviation of 500 Monte Carlo simulations.

4 DISCUSSION

4.1 Organic C and N in litter, soil and density fractions

The litter characteristics are totally dependent on the plant species. In the planted riparian forest, there are many *Leguminosae* species (e.g. *Acacia spp.*), which are able to bind N_2 from the atmosphere through association with *Rhyzobium* sp. bacteria. Litter from these tree species has a lower C:N ratio than that of grasses, which are known for their high C:N ratio. This explains the higher N concentration and consequently the lower C:N ratio in the forest litter.

Forest litter can work as a sponge, improving the superficial drainage, facilitating water infiltration and reducing runoff (Davide & Botelho, 1999). The much higher litter production by the forest cover may benefit both water retention and soil quality in the topsoil, and is the main responsible for the higher C and N stocks in the forest litter.

Decrease of C and N concentrations towards 20 cm, for both bulk soil and fractions, can be seen as a normal effect of diminishing SOM content with depth. Regarding the density fractions, independently of the area, higher C and N concentrations and C:N ratio in the light fraction were expected, since this fraction is chemically more similar to the litter than the heavy one, which is closely linked to the mineral matrix (Golchin et al., 1995).

The trends for C and N contents clearly show that the difference in the input mode is important in understanding the C and N balance of light and heavy fractions after conversion. Two main factors are related to the input mode: the location and the type of organic material. It seems that more undecomposed and partially decomposed material can be found in the soil under forest due to the mostly superficial input in this area, where the fall of material (leaves, branches, fruits, etc.) is constant on the ground. In addition to the fact that this material is added **on** the soil, mainly large fragments compose it, which can "accumulate" in the less decomposed fraction. In the soil under cerrado, the scenario is completely different: the input appears to be largely below ground. As grasses predominate, the organic carbon input originating from roots (death/decomposition) could be higher than the superficial one. The high amount of thin roots, in close contact with the soil, together with the intense biological activity in the rhizosphere, cause rapid decomposition. The carbon is largely added **within** the soil by organic materials as exudates and root debris, which facilitates the decomposition process. Thus, much C and N are transferred from the light to the heavy fraction.

Assad et al. (1997) studied the root density in soils under open shrubby savannah and riparian forest. They found, for the first 100 cm of soil, a density of 829 roots m^{-2} in the soil under riparian forest, and 1508 roots m^{-2} in the soil under cerrado, which contributed for a higher C stock in the later (144.2 Mg ha^{-1} and 167.3 Mg ha^{-1}, respectively). The network of roots constitutes an important source of organic material and, according to these authors, its distribution and density should be taken into account when evaluating the potential of these soils.

With the change in the C input mode, from a below-ground system (cerrado) to an above-ground one (forest), there was a reduction in the C and N stocks in the heavy fraction, which constitutes the major part of the SOM. Such a reduction influenced C and N stocks for bulk soil, which were lower under forest despite the increase in the light fraction.

4.2 $\delta^{13}C$ of litter and soil

The forest litter is virtually pure C_3 material. Values around -27‰ have been found in litter of Brazilian forests (Modenesi et al., 1982; Volkoff & Cerri, 1987) and woody savannah (Roscoe et al., 2000b). Conversely, the signature for cerrado litter is clearly a mixture of C_3 and C_4 material, and reflects the vegetation composition, dominated by grass with few C_3 shrubs.

Results in Table 3 showed that both soils under cerrado and forest had the same increasing pattern in $\delta^{13}C$ (from litter to soil and from topsoil downward). Although this phenomenon is well documented in the literature for C_3 systems (Balesdent & Mariotti, 1996; Nadelhoffer & Fry, 1988; Ehleringer et al., 2000), very few data is available for soils under C_4 vegetation, and no consistent pattern with depth has been described. In addition, little work has been done on conversion from C_4 into C_3 vegetation.

According to Ehleringer et al. (2000), in C_3-dominated ecosystems, increase in $\delta^{13}C$ values from the vegetation to soil may occur even without shifts in the photosynthetic pathway of the dominant vegetation. They summarised data from the literature showing that roots are enriched in $\delta^{13}C$ (about 1‰) in relation to the above-ground biomass. Furthermore, the authors reviewed the most important hypotheses for explaining $\delta^{13}C$ enrichment over time and with depth in C_3 ecosystems. They affirm that the C mixing hypothesis (addition of microbial biomass material, which is usually enriched in ^{13}C in relation to the surrounding substrate, to the fresh residues) and, in a lesser extent, the Suess effect (decrease in the isotopic ratio of atmospheric CO_2 over the last 150 years, as a result of fossil fuel burning and additional biosphere mineralization) might be more appropriate than the other hypotheses. The later are the hypotheses of microbial fractionation during litter decomposition and preferential microbial decomposition of litter and SOM, which have not been supported by experimental data.

In the cerrado, where the litter is a mixture of C_3- and C_4-C, the $\delta^{13}C$ enrichment from litter to soil and with soil depth may be partially explained by the mentioned hypotheses. Nevertheless, it can hardly be done for the part of the material that is derived from C_4 vegetation. Assumptions of equal isotopic discrimination for both C_3 and C_4 material, as well as of absence of discrimination for C_4-C, have been widely discussed, but none of them has been properly supported by the literature so far (Ehleringer et al., 2000; Roscoe & Buurman, 2002). Considering our results, in a system in steady state, with a non-pure C_4 litter, the pattern of increasing $\delta^{13}C$ appears to be similar to that occurred in pure C_3 systems.

An additional processes (apart from the ones already discussed for C_3 ecosystems) might be acting in the forest: the increasing $\delta^{13}C$ pattern can also be related to the remains of C_4-derived C, especially with depth. The most remarkable changes in $\delta^{13}C$ from cerrado to forest happened in the first layers, where the new material is added. For both litter and soil, the conversion of cerrado into forest substantially decreased the values of $\delta^{13}C$, especially in the upper layers. Martin et al. (1990) worked on a sandy Ferrasol from Ivory Coast under savannah vegetation (predominantly C_4) and protected against fire for 18 years. A progressive invasion by C_3 species during this time lead to considerable changes in $\delta^{13}C$. However, such changes occurred more rapidly in the upper 10 cm depth (~10‰) than in the subsurface (~3‰), showing the strong influence of the new carbon addition in the topsoil.

4.3 Organic carbon origin

The variability of the output variables, after Monte Carlo simulations is dependent on the number of input variables used in the calculations. The balance of organic carbon had the highest uncertainty because six input variables (δ_T, $\delta_{C3litter}$, $\delta_{C4litter}$, δ_{C3soil}, OC $_{(mass)}$, and bulk density) were used in its calculation. According to Veldkamp & Weitz (1994), the $\delta^{13}C$ method, which has been intensively applied in studies of SOM, always requires a large set of input data. These authors verified the uncertainty analysis of the $\delta^{13}C$ method used for an Eutric Hapludand soil in Costa Rica. From the frequency distribution of the input data they sampled 200 randomly chosen data combinations that were used to calculate the soil organic carbon pool in forest and pasture (planted after forest clearing), and the loss of carbon 25 years after the forest clearing. They found a high uncertainty, especially for C loss, which was attributed to the spatial variability (as main responsible), measurement error, and small-scale variability. The later can not be controlled and the spatial variability is very difficult to control, since for that it is necessary to sample in the exactly same points at different times. Therefore, when the $\delta^{13}C$ method is applied in SOM studies, the variability should be assessed in order to make the interpretation of the results more reliable.

Conversion to forest has not been effective in increasing, or even maintaining, the contents and stocks of OC in the soil, mainly because of the change from a below-ground carbon input to an above-ground one. During the studied period there was replacement of C_4- by C_3-derived C coming from the forest litter. This replacement tends to increase with time since there is no longer input of C_4-C. Nevertheless, only for the upper layer there was a slight tendency of increasing the organic carbon. In the remaining soil depths the tendency of negative OC balance means that the C_3-C added by the above-ground input system was not yet enough to replace all C_4-derived C decomposed in this time.

The considerable C_4-C loss of 27% over a period of eight years suggests a relatively fast carbon dynamics. It is currently well known that the turnover rates of SOM in temperate and tropical ecosystems are very different. The climate (mainly temperature and precipitation) is one of the main factors that affects SOM processes (Shang & Tiessen, 1997). In a cultivated Oxisol, the later authors found 14% of total C loss in 6 years of manual cultivation, and a lower stability of SOM than in the native site, indicating that the organic matter in this soil is quite labile. Roscoe et al. (2001) verified, for a clayey Oxisol, a high replacement of organic carbon after conversion of woody savannah (predominantly C_3) into pasture. For bulk soil the replacement range was 36% in the Ap horizon after 23 years, suggesting a fast turnover rate. In an Ultisol of the Amazon Basin after 80 years of the conversion of tropical forest into pasture, 30% of the all "new" C was accumulated in the first 10 cm of soil between the second and fourth years after the conversion (Feigl et al., 1995).

5 CONCLUSIONS

Although eight years after the conversion of grassy cerrado into riparian forest could be considered a relatively short period, it was possible to detect alterations in SOM stocks and dynamics in the studied Oxisol.

During this time, the change of a below-ground carbon input (grassy cerrado) to an above-ground one (riparian forest) had a negative impact on C and N stocks in soil. This change also promoted a higher replacement of C_4-C by

C_3-C in the forest topsoil. However, considering the whole forest soil profile, losses of C_4-C have been higher than gains of C_3-C.

High uncertainty in the replacement data based on the method is caused by the large set of input data, which promotes a propagation of the natural variability of each involved input variable. Assessment of uncertainty allowed a more realistic approach in the interpretation of carbon dynamics.

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CHAPTER 3

CONVERSION OF CERRADO INTO RIPARIAN FOREST AND ITS EFFECT ON CHEMICAL COMPOSITION OF SOIL ORGANIC MATTER, AS CHARACTERISED BY CPMAS ^{13}C NMR AND PYROLYSIS-GC/MS

ABSTRACT

ALCÂNTARA, Flávia Aparecida de. **Conversion of cerrado into riparian forest and its effect on chemical composition of soil organic matter, as characterised by CPMAS ^{13}C NMR and pyrolysis-GC/MS.** Lavras: UFLA, 2002. Chap. 3. 36 p. (Thesis – PhD in Soils and Plant Nutrition)$^{+}$

We combined Cross Polarisation-Magic Angle Spinning (CPMAS) solid state ^{13}C NMR spectroscopy and pyrolysis associated to gas-chromatography/mass-spectrometry (Py-GC/MS) to evaluate the impact on soil organic matter (SOM) chemical composition of establishing riparian forest on soils under *cerrado* (Brazilian savannah), and to better understand SOM quality in Brazilian Latosols (Oxisols). We sampled litter and soil in two adjacent areas: one maintained under cerrado, and another planted with riparian species in 1992. Soil samples were submitted to alkaline extraction before CPMAS ^{13}C NMR and Py-GC/MS. In both systems, the chemistry linked to the transformation of litter into SOM reflected very active addition/decomposition. Eight years after the vegetation conversion, SOM quality changed due to the addition of the forest litter, chemically different from the cerrado one. The later is richer in easily degradable compounds and has been replaced by a more recalcitrant litter in the forest. Semi-quantification and factor analysis of pyrolysis data highlighted important aspects: i) clear separation of forest topsoil, where the addition of new material has occurred; ii) similarity between cerrado profile and forest subsoil, due to the remaining influence of material from cerrado on forest subsoil; and iii) remarkable presence of polysaccharides in the deepest soil depth under cerrado, due to large influence of grass roots. Factor analysis allowed explaining around 40% of the total variance of pyrolysis data. Further research on quantitative approach of SOM pyrolysis data might be developed to detail the application of the method and reach higher explanation of variation.

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RESUMO

ALCÂNTARA, Flávia Aparecida de. **Conversão de cerrado em mata ciliar e seu efeito sobre a composição química da matéria orgânica, caracterizada por CPMAS ^{13}C RMN e pirólise-CG/EM.** Lavras: UFLA, 2002. Cap. 3. 36 p. (Tese – Doutorado em Solos e Nutrição de Plantas)*

As técnicas de Polarização Cruzada e Ângulo Mágico (CPMAS) em ^{13}C Ressonância Magnética Nuclear (RMN) e pirólise associada a cromatografia gasosa e espectrometria de massa (pirólise-CG/EM) foram utilizadas em conjunto, visando avaliar o efeito da conversão de vegetação nativa (cerrado) em mata ciliar sobre a composição química da matéria orgânica do solo (MOS) e compreender melhor a qualidade da MOS em Latossolos. Amostras de serapilheira e solo foram coletadas em duas áreas adjacentes: a primeira mantida sob cerrado, e a segunda submetida ao plantio de mata ciliar em 1992. A extração alcalina da MOS foi realizada como passo prévio às análises de CPMAS ^{13}C RMN e pirólise-CG/EM. Nas duas áreas, os processos químicos relacionados com a transformação de serapilheira em MOS refletiram tanto adição quanto decomposição de material orgânico bastante ativas. Oito anos após a conversão da vegetação ocorreram mudanças na qualidade da MOS devido à adição da serapilheira da mata, quimicamente diferente do material incorporado no cerrado. O último, mais rico em componentes facilmente degradáveis, vem sendo substituído por uma serapilheira de características mais recalcitrantes na mata. Importantes aspectos sobre a composição química da MOS foram destacados pela Análise de Fatores realizada para os dados semi-quantitativos da pirólise: 1) diferenciação das camadas superficiais da mata, onde a adição do novo material vem ocorrendo; 2) similaridade entre a MOS do perfil sob cerrado e das camadas mais profundas da mata, devido à existência, na última, de material remanescente de cerrado em profundidade; e 3) grande presença de polissacarídeos na MOS da camada mais profunda sob cerrado, onde há grande influência do sistema radicular das gramíneas sobre a formação da matéria orgânica. Através da utilização da Análise de Fatores, conseguiu-se alcançar em torno de 40% de explicação para a variabilidade dos dados de pirólise. Para que maiores porcentagens de explicação sejam possíveis, bem como para propiciar um maior detalhamento do método, sugere-se maior desenvolvimento de pesquisa visando a abordagem semi-quantitativa da pirólise-CG/EM em estudos de MOS.

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1 INTRODUCTION

The intensification of the Brazilian economical growth, starting from the 1940's, caused a great increase in energy demand. Many hydroelectric power plants were constructed at that time, with little concern about environmental quality (Davide & Botelho, 1999). Damming causes the disappearance of several ecosystems, including riparian forests, which are particularly threatened due to their location in the deepest part of the valleys. In the last years, due to the critical situation of the riparian forests of Central-South Brazil, a large incentive was given to the study of alternatives to preserve or recover such forests. Since then, programs of environmental vegetation re-composition appeared, aiming to develop technological research on reforestation models in most hydroelectric reservoir vicinities.

Despite great knowledge developed by these recovery programs, some unexplained aspects still impede complete development of the projects (Kageyama et al., 1992). Very little work has been focused on soil changes after the establishment of riparian forests on soils surrounding dams. In order to address the soil quality, directly linked to the environmental sustainability, much more importance has to be given to the soil organic matter (SOM), which is considered a key indicator of soil quality (Doran, 1997). Soil organic matter mediates many of the chemical, physical, and biological processes, controlling the soil capacity of performing successfully (Quideau et al., 2000).

In the Itutinga/Camargos reservoirs (Southern Brazil), the Riparian Forest Project, one of the first Brazilian projects, was implemented in 1990. The native vegetation still prevails, and lakeside areas covered by *cerrado* (Brazilian savannah), which varies from grasslands to woodlands, can still be found. Only a small part of the shores was replanted with riparian species (C_3 vegetation), including some areas originally covered by grassy cerrado (predominantly C_4

vegetation). In Chapter 2, we showed that with the conversion of grassy cerrado into riparian forest, the most important change was a shift of below-ground to above-ground carbon input, which caused a reduction in C and N stocks. However, although changes in SOM quantity are quite indicative, changes in its quality should also be assessed, since the chemical composition of SOM is closely related to decomposition processes. As SOM chemical composition is also dependent on the litter type, it can be gradually affected by changes in vegetation cover. Furthermore, there is little information on SOM quality in tropical conditions.

Various procedures can be used to extract SOM previous to the study of its chemical composition. Alkaline extraction by NaOH and/or $Na_4P_2O_7$ has been used in many works to separate the organic material (e.g. Nierop & Buurman, 1998; Clapp & Hayes, 1999; Velthorst et al., 1999). Usually, the procedure allows good carbon recovery rates. Treatment of the extracts with HF-HCl is needed in some cases, since high ash contents can interfere with studies of SOM chemistry. The presence of paramagnetic ions, Fe in particular, causes broadening decreasing the effectiveness of nuclear magnetic resonance (NMR) (Dai & Johnson, 1999). In Oxisols with high contents of iron, such treatment is necessary.

Cross Polarisation-Magic Angle Spinning (CPMAS) solid state ^{13}C NMR spectroscopy and pyrolysis associated to gas-chromatography and mass-spectrometry (Py-GC/MS) can be applied to the whole soil or to the extracted organic matter in order to access its chemical composition. Both have been widely used in SOM studies, and since they provide complementary information to the SOM chemical composition, their combination is particularly advantageous. While the ^{13}C NMR provides an "average structural" composition of the whole organic material, Py-GC/MS allows recognition of individual moieties (Fabri et al., 1998).

Solid state ^{13}C NMR is more versatile than the solution NMR and its sensitivity is quite good due to the high sample concentration (Mao et al., 2000). The specific objective of CPMAS ^{13}C NMR is the quantitative evaluation of the signals of different carbon nuclei. It is generally considered semi-quantitative due to the short relaxation time applied (less than 1 ms) and the relatively low carbon content of most of the mineral soils (10-50 g kg^{-1}) (Kinchesh et al., 1995a,b). In addition, there are differences between the induction time for the different C nuclei during the cross polarisation. According to Zech & Kögel-Knabner (1994) its importance lies in the assessment of the complex structure of the humified, stable SOM compounds. It makes possible to identify different carbon types and their changes during decomposition and humification (Zech et al., 1997).

Pyrolysis-GC/MS involves chromatographic separation of pyrolytic products into single components and their identification by mass spectrometry. The main advantage of this technique is that extensive information can be derived on several compounds that are formed by pyrolysis of different components in organic material (Zhang et al., 1999). However, the pyrolysates obtained from macromolecular structures are very complex and there are some difficulties in the interpretation of data from SOM pyrolytic studies (Saiz-Jimenez, 1994).

In this work we combined CPMAS ^{13}C NMR and pyrolysis-GC/MS for litter and extracted organic matter, aiming to evaluate the effect of establishing riparian forest on soils previously under grassy cerrado on SOM chemical composition and, in addition, to contribute to the knowledge of SOM quality in Brazilian Latosols (Oxisols).

2 MATERIAL AND METHODS

2.1 Site description

The study was carried out in the Itutinga/Camargos reservoirs, located in southern Minas Gerais State (Campo das Vertentes physiographic region), between 21°15' and 21°50' S and 44°15' and 44°45' W, and at 917 m of altitude. The mean annual temperature is 19.4 °C, and the mean annual precipitation is 1529 mm, with a dry period from April to September (Brasil, 1992). This region is part of Paraná River basin and drained by rivers from Grande River sub-basin. We selected a site in the vicinities of Itutinga/Camargos reservoirs, which was partially submitted to the Riparian Forest Project. The soil (characterised in Table 1, Chapter 2) is a homogeneous Typic Acric Red-Yellow Latosol (Anionic Acrustox) (Chagas et al., 1997).

Two areas within this site were chosen. They are located 200 m apart, in opposite hillsides of the site. The first area was taken as reference because it was maintained under native vegetation (grassy cerrado), which is a grassland with scattered shrubs. The second area was converted into forest in 1992, as part of the above-mentioned project. It was planted with a mixture of riparian species, after excluding native vegetation. The most important plant species in native and planted areas are named in the Material and Methods section of the Chapter 2. Both areas were plotted 5 meters from the reservoir margin, in order to discount the depleted area, which is subject to periodic flooding and presents species adapted to such condition.

2.2 Experimental design and material sampling

Sampling was done in May/2000. For that, we used the randomised blocks experimental design in factorial scheme with four replications. Each area was sub-divided into four blocks (replicates), which were defined based on land quotas. The same land quotas were used in both areas in order to plot the blocks. Thus, each block was placed in the same position in the hillside for both areas. One composite sample was taken per block, each one a mixture of ten sub-samples collected in a "zigzag" pattern. Four different soil depths were sampled (0-2.5, 2.5-5, 5-10, and 10-20 cm), resulting in 16 composite soil samples in each area. Litter was collected with a 50 x 50 cm frame, placed on the same sites used for soil sub-samples, resulting in 4 composite samples in each area. The soil samples were air-dried and passed through a 2 mm sieve to remove coarse debris. The aboveground litter samples were oven-dried (60°C), weighted, and ground to a fine powder.

2.3 SOM chemical fractionation

We used an alkaline solution in order to extract soil organic material. In short, 75 g of soil sample were placed with 750 mL of extraction solution (NaOH 0.1 mol L^{-1} + $Na_4P_2O_7$ 0.1 mol L^{-1}) under nitrogen, and shaken in an end-over-end shaker (20 cycles/minute) for 24 hours. Then, we centrifuged the sample at 4000 rpm for 1 h, and filtered the aspired supernatant into a millipore vacuum filtration unit, through a 1 μm glass filter (Schleider & Schuell Gf 55). The filtered supernatant was preserved. To the residue we added some water and shook for 30 minutes on a horizontal shaker. Then, it was centrifuged at 4000 rpm for 1 h and filtered as previously described. This step constitutes the "washing" of the residue. The washed residue was preserved. We combined the two filtered supernatants and added concentrated HCl (37%) to a final pH (~ 1 - 2) and concentrated HF (48%) to a final concentration of 0.3 mol L^{-1}, and shook in an end-over-end shaker overnight. In so doing, we obtained the acidified extract, which was dialysed against demineralised water. Both extract and residue were freeze-dried. In the freeze-dried extracts, we measured ash contents by burning a sub-sample at 900°C for 5 h, and measuring the weight loss. When we found high percentages of ash, we repeated the HCl-HF treatment. For that, the extracts were dissolved in a 0.5% solution of HCl-HF, shaken on an end-over-end shaker for 24 hours, dialysed and freeze-dried. We stopped the HF-HCl treatment at ash contents around 7%, since we could lose organic material at each repetition. We measured the concentrations of carbon and total nitrogen in the soil, extracts and residues, using an Interscience Elemental Analyser EA 1108. In addition, we measured C and N concentrations in the whole soil (before extraction) and calculated the "recovery rate" as the percentage of C(N) of the whole soil that was obtained by the sum of C(N) content in residue and extracted OM.

2.4 ^{13}C NMR spectroscopy

In order to characterise litter samples and extracted soil organic matter, Cross Polarisation-Magic Angle Spinning (CPMAS) solid state ^{13}C NMR spectroscopy was performed on a Bruker AMX 300, operating at a frequency of 75.48 MHz, with acquisition time of 0.033 s, 90° pulse time of 3.5 μs, contact times of 1 to 6 ms, and spinning rate of 5 kHz. The spectra were sub-divided into alkyl-C (0-46 ppm), O-alkyl-C (46-110 ppm), aromatic-C (110-160 ppm), and carbonyl-C (160-250 ppm). Although CPMAS studies are not appropriate for absolute quantification, since a range of factors can change the intensities of peaks or areas in different regions of the spectrum (Kinchesh et al., 1995a, b), semi-quantification was done by integrating the peaks. Variable Contact Time (VCT) experiments were performed to obtain the real relative signal. Linear Backward Prediction on the Free Induction Decay (FID) and a fixed first order phase were used in the transformation of the FID to the spectrum. A line-broading of 50 Hz was used in this transformation. Because there were two peaks in the O-alkyl region (see Figures 1 and 2), both peaks were integrated and separately treated.

2.5 Pyrolysis GC/MS

Curie-Point pyrolysis was carried out on a Horizon Instruments Curie-Point pyrolyser. Litter and extracted organic matter samples were heated for 5 s at 600°C. The pyrolysis unit was connected to a Carlo Erba gas-chromatograph, and the products were separated by a fused silica column (Chrompack, 25 m, 0.25 mm i.d.) coated with CP-Sil 5 (film thickness of 0.40 μm). Helium was used as carrier gas. The initial oven temperature (40°C) was increased at a rate of 7°C min^{-1} to 320°C and maintained at this temperature for 20 minutes. The end of the GC column was coupled to a Fisons MD 800 mass spectrometer (mass range m/z 45-650, ionisation energy 70 eV, cycle time 1 s).

Because the number of mass spectrometry peaks is rather high, we selected 90 pyrolysis products. Each product, for each sample, was quantified by time integration of two component-specific masses. According to their probable source (s), the 90 products were grouped into aliphatic biopolymers (Abp), lignin (Lg), lipids (Lp), polysaccharide (Ps), polyphenols (Pp) or proteins (Pr) and we calculated the relative contribution of each group (in percentage) to the litter and extracted organic matter composition.

2.6 Statistical Analysis

Analysis of variance (ANOVA) was done for the dependent variables, obtained from C and N measurements and ^{13}C NMR spectroscopy, as a function of the independent ones (vegetation cover and soil depth) and the interaction vegetation cover x soil depth. As there was no significant effect of the interaction for any of the variables, we applied the Tukey test (0.05 significance level) for those ones which were affected by cover or soil depth, in order to compare the means of the treatments.

For pyrolysis data, we applied the same treatment for the contribution of each group of compounds. In addition, we applied factor analysis to the relative area of each one of the 90 peaks. The factor analysis was carried out as described by Meijer & Buurman (1997), using the Statistica version 5.0 software (1997).

3 RESULTS

3.1 Carbon and nitrogen distribution

The distribution of organic carbon and total nitrogen of the soil over its extracted organic matter (OM) and residue is presented in Tables 1 and 2. The recovery rate, in average for the 32 soil samples, was around 90% for both C and N, which is satisfactory. Losses of material can occur at all steps of the procedure, mainly during the transfer of material between two steps. The percentage of extracted C can be calculated by the data in Tables 1 and 2. Considering the averages by cover (Table 1) approximately 70% of the C was not extracted.

Independently of soil depth, the vegetation cover affected C and N concentrations of the total soil. Under cerrado they were higher than under forest (Table 1). The data also showed influence of depth on C and N concentrations of the total soil (Table 2). As a normal effect of decreasing SOM content with depth, they decreased towards 20 cm, independently of the vegetation cover.

For C and N concentrations in extracted organic matter and residue, and for C:N ratio as well, there were no differences between the vegetation covers and even between soil depths, which meant that the alkaline extraction extracted similar material in all soil samples.

TABLE 1. Carbon and nitrogen distribution and C:N ratio in total soil, extracted OM and residue, as a function of vegetation cover, independently of soil depth[1].

Cover	Soil			Extracted OM			Residue			Ext C[2]
	C	N	C:N	C	N	C:N	C	N	C:N	
	(g kg^{-1})			(g kg^{-1})			(g kg^{-1})			(%)
Cerrado	23.0 a	1.7 a	13.8	424	33.4	12.7	16.2	1.1	15.0	29
Forest	20.6 b	1.5 b	13.9	408	33.0	12.3	15.3	1.1	14.6	26

[1] Means (from 16 samples) in the same column followed by the same letter are not significantly different at $p<0.05$ according to Tukey's test.

[2] Percentage of extracted C = (C soil – C residue x 100)/C soil.

TABLE 2. Carbon and nitrogen distribution and C:N ratio in total soil, extracted OM and residue, a function of depth, independently of vegetation cover[1].

Depth (cm)	Soil			Extracted OM			Residue		
	C	N	C:N	C	N	C:N	C	N	C:N
	(g kg^{-1})			(g kg^{-1})			(g kg^{-1})		
0-2.5	26.2 a	1.8 a	14.2	416	32.5	12.8	17.0	1.2	14.3
2.5-5	22.0 ab	1.6 b	14.0	411	31.8	12.8	16.1	1.1	15.4
5-10	20.4 bc	1.5 bc	13.6	420	34.2	12.3	15.6	1.0	14.6
10-20	18.7 c	1.4 c	13.8	414	34.4	12.1	14.3	1.0	14.8

[1] Means (from 8 samples) in the same column followed by the same letter are not significantly different at $p<0.05$ according to Tukey's test.

3.2 ^{13}C NMR spectroscopy of litter and extracted soil organic matter

^{13}C NMR was used to address the general composition of C-litter and C-extractable by NaOH + $Na_4P_2O_7$. Figure 1 shows the CPMAS ^{13}C NMR spectra for litter samples. As the spectra of the samples from different replicates of the same area closely resembled each other, we presented only two spectra of the cerrado litter and two of the forest litter. Figure 2 shows the CPMAS ^{13}C NMR spectra for extracted OM. Two samples from each area were reported there in order to highlight some differences between the extracted OM under cerrado and forest.

The 0-46 ppm region comprises the alkyl-C, including CH_2 and CH_3 in aliphatic alkanes, fatty acids and waxes (Mahieu et al., 1999). For both litter and extracted OM (Figures 1 and 2) we found peaks near 20 ppm, assigned to terminal methyl groups. The major signals were found at 30 ppm, and originate from methylenic C in long-chain aliphatic compounds of varying origin, for instance lipids and aliphatic polymers like the hydrolyzable polyester cutin and suberin, and non-hydrolyzable cutan and suberan (Nip et al., 1986; Tegelaar et al., 1995). Broad resonances were found between 30 and 55 ppm, which reveal the presence of proteins or peptides (Kögel-Knabner, 1997).

The spectra of litter and extracted OM were dominated by signals in the O-alkyl region (46-110 ppm). This region can be divided in three sub-regions (Kögel-Knabner, 1997): 46-60 ppm, including methoxyl groups and C_6 of carbohydrates and sugars C_a of most amino-acids; 60-90 ppm, including carbohydrate-derived structures (C_2 to C_5) in hexoses, C_a of some amino-acids, higher alcohol's; and 90-110 ppm, including anomeric carbon of carbohydrates, C_2, C_6 of syringyl units of lignin. The major signals were found at 56, 62, 72 ppm and near 103 ppm. The signal at 56 ppm is attributed to methoxyl C in lignin (Kögel-Knabner, 1997). The signal at 62 ppm appeared as a shoulder in the extracted OM spectra (Figure 2), and as a peak in the litter spectra (Figure 1). It is derived from C_5 (pentose) or C_6 (hexose) of carbohydrate structures (Nierop et al., 1999). The peaks at 72 ppm and near 103 ppm are tentatively assigned to polysaccharides, as well as a shoulder found at 82 ppm (Kögel-Knabner, 1997) (Figures 1 and 2). The first one (72 ppm) is attributed to ring carbons of carbohydrates, and the second one (103 ppm) to the anomeric C_1 (Nierop et al., 1999).

The aromatic-C region (110-160 ppm) includes the phenols between 150 and 160 ppm (Mahieu et al., 1999). In this region we found main peaks near 130 and 150 ppm, but these peaks were well pronounced only for the forest litter (Figure 1). Signals at 130 and 150 ppm correspond to C-substituted aromatic carbon and phenolic C, respectively, in lignin (Kögel-Knabner, 1997). The range between 160 and 220 ppm comprises the carbonyl functional groups in aliphatic acids and benzene-carboxylic acids, C in amide and ester structures (Mahieu et al., 1999). These compounds appeared around the peak centred at 172 ppm.

We confirmed the tendencies seen in Figures 1 and 2 with the semi-quantification, obtained by integrals, which gave us the relative percentage for each carbon type. We found effect of the vegetation cover for both litter and extracted OM, independently of soil sampling depth. Table 3 shows that the O-alkyl region (polysaccharides) represented the major part of the carbon in litter and OM, followed by alkyl-C, aromatic-C and carbonyl-C for litter. For extracted organic material we found more carbonyl than aromatic carbon. The forest litter showed higher aromatic-C and alkyl-C percentages. The later contributed to the higher alkyl-C/O-alkyl-C ratio, and both contributed to the higher hydrophobicity in the forest litter. In the cerrado litter, we found higher O-alkyl-C percentages. Following the same trends, the extracted organic matter under forest had a higher aromatic-C percentage and hydrophobicity, and that extracted under cerrado presented higher O-alkyl-C

In addition, we found changes in SOM chemistry with depth, independently of the vegetation cover (Table 4). The percentages of aromatic-C and alkyl-C decreased towards 20 cm. Consequently, hydrophobicity and alkyl-C/O-alkyl-C also decreased with depth. On the other hand, the O-alkyl percentage was lower in the topsoil (0-2.5 cm) than in the rest of the soil profile.

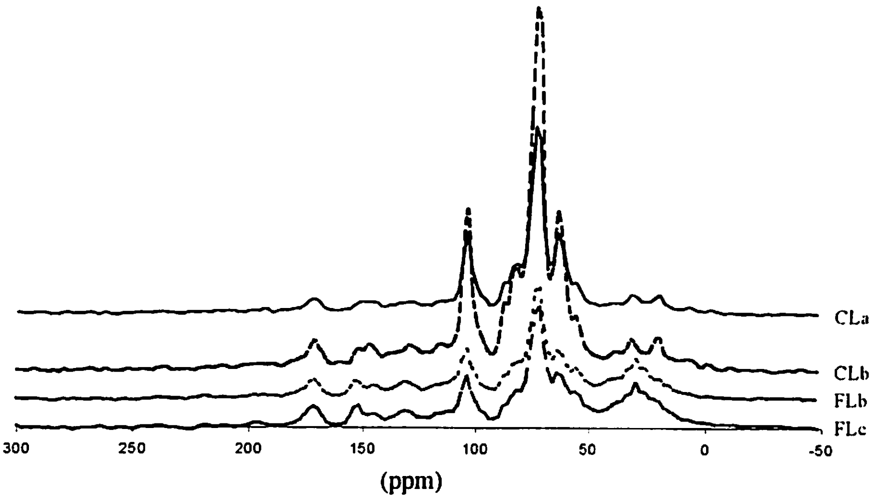

FIGURE 1. CPMAS ^{13}C NMR spectra of litter samples.
Legend: C = cerrado. F = forest. L = litter samples. a to d = replicates. Ex.: CLa (cerrado litter replicate a).

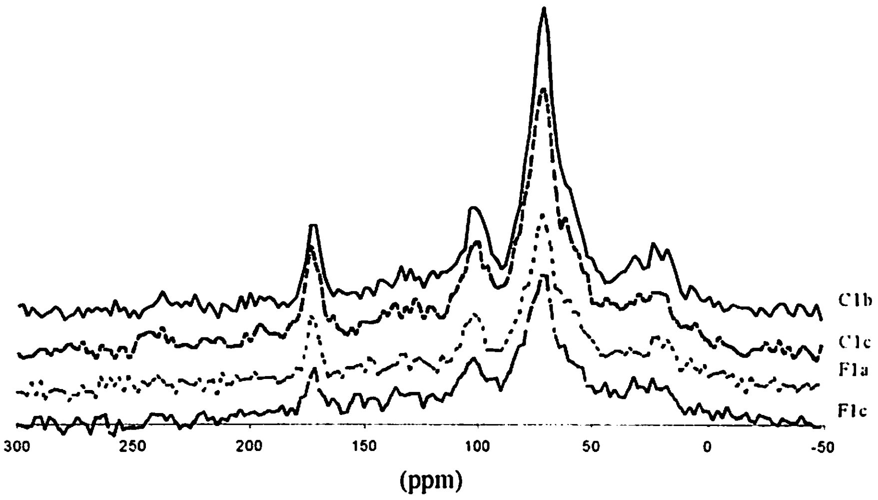

FIGURE 2. CPMAS ^{13}C spectra of SOM samples (same soil depth. different blocks). Legend: C = cerrado. F = forest. 1 to 4 = soil depths. a to d = replicates. Ex.: C1a (cerrado OM from the soil depth 0-2.5 cm and replicate a).

TABLE 3. Integrated areas of carbon types determined by ^{13}C NMR, aromaticity (arom), hydrophobicity (hyd), and alkyl/O-alkyl ratio, as a function of cover, for litter and extracted OM (independently of depth) [1].

Cover	Percentage of total signal intensity				Arom[2]	Hyd[3]	Alkyl / O-alkyl
	Carbonyl	Aromatic	O-alkyl	Alkyl			
				Litter			
Cerrado	7.0	10.0 b	72.6 a	10.5 b	0.11 a	0.26 b	0.14 b
Forest	9.0	13.6 a	56.8 b	20.0 a	0.15 a	0.51 a	0.35 a
				Extracted OM			
Cerrado	12.0	9.5 b	63.7 a	15.0	0.11	0.32 b	0.24
Forest	12.0	10.5 a	61.9 b	16.0	0.12	0.36 a	0.26

[1] Means in the same column followed by the same letter are not significantly different at $p<0.05$ according to Tukey's test. Means are from 4 (litter) and 16 (OM extracted).

[2] Aromaticity was expressed as the ratio of aromatic-C divided by the sum of alkyl-C, O-alkyl-C and aromatic-C.

[3] Hydrophobicity was expressed as the ratio of the sum of aromatic-C and alkyl-C divided by the sum of Carbonyl-C and O-alkyl-C.

TABLE 4. Integrated areas of carbon types determined by ^{13}C NMR, aromaticity (arom), hydrophobicity (hyd), and alkyl/O-alkyl ratio for extracted OM, as a function of depth (independently of cover) [1].

Depth (cm)	Percentage of total signal intensity				Arom[2]	Hyd[3]	Alkyl/ O-alkyl
	Carbonyl	Aromatic	O-alkyl	Alkyl			
0-2.5	12.0	11.3 a	59.5 b	17.0 a	0.13 a	0.40 a	0.29 a
2.5-5	12.0	10.1 ab	63.2 a	15.5 ab	0.11 a	0.34 b	0.25 ab
5-10	12.0	9.8 b	63.3 a	14.6 ab	0.11 a	0.32 b	0.23 b
10-20	12.0	8.7 b	65.5 a	14.3 b	0.10 a	0.30 b	0.22 b

[1] Means (from 8 samples) in the same column followed by the same letter are not significantly different at $p<0.05$ according to Tukey's test.

[2,3] See Table 3.

3.3 Pyrolysis GC/MS

Pyrolysis-GC/MS was used to investigate the qualitative composition of litter and extracted organic matter. Table 5 shows the 90 main pyrolytic fragments (peaks) observed in the total set of litter and SOM samples, which represent the main products found for the set. All products were given a code indicating their probable source. Polysaccharides, lignin and lipids and/or aliphatic biopolymers represented the majority of the spectra in number of peaks. A series of polysaccharide-derived products was noticed in pyrolysates. Acids (peak 2), furans and reduced furans (peaks 1, 7, 9, 14 and 15), pyrans (20 and 30), and anhydrosugars (23, 25 and 40) are typical products of polysaccharides (Powels et al., 1987; Powels & Boon, 1990). Peak 20 is characteristic for pentoses, and peaks 23 and 25 for hexoses (Powels et al., 1989). Peaks 34 and 43 were due to contaminants or compounds of unknown identity.

Among the aromatic moieties detected there were benzene (3), toluene (6), styrene (12), and C_2-benzene (10, 11 and 13). Pyridine (4) is derived from alanine and polypeptides, and pyrrole (5) is derived from proline and hydroxyproline (Schulten & Schnitzer, 1998). Important signals were found for phenol (17) and methylphenol (19 and 22). Several guaiacols (21, 24, 28, 31, 33, 37 and 38) and syringols (32, 36, 39, 44, 46 and 47) were found as methoxyphenols, products of lignin breakdown, as well as vanillin (35) and vanillic acid (41). Of these, 4-vinylguaiacol (31) indicates slightly modified lignin (Saiz-Jimenez & de Leeuw, 1986). (Alkyl)phenols may be derived from lignin (Saiz-Jimenez & de Leeuw, 1986), and also from tannins (Tegelaar et al., 1995).

Aliphatic pyrolysis compounds, mostly fatty acids, alkenes and alkanes, were present in the pyrolysates. The fatty acids (48, 52, 57 and 64) originate from extractable lipids, which can be waxes and triglycerides, or from monomers of the polyester cutin and suberin, released by hydrolysis (Tegelaar et al., 1995).

TABLE 5. List of main pyrolysis products.

No.	Compound	Source[1]	Masses[2]
1	2-Methylfuran	Ps	53+82
2	Acetic acid	Ps	60
3	Benzene	Pp	51+78
4	Pyridine	Pr	52+79
5	Pyrrole	Pr	53+67
6	Toluene	Pp	65+91
7	(2*H*)-Furan-3-one	Ps	54+84
8	methyl-pyridine	Pr	66+93
9	2-furaldehyde	Ps	67+95
10	C_2 Alkyl benzene	Pp	91+106
11	C_2 Alkyl benzene	Pp	91+106
12	Vinylbenzene (Styrene)	Pp	78+104
13	C_2 Alkyl benzene	Pp	91+106
14	2,3-Dihydro-5-methylfuran-2-one	Ps	69+98
15	5-Methyl-2-furaldehyde	Ps	53+110
16	3-Hydroxy-2-penteno-1,5-lacton	Ps	58+114
17	Phenol	Pp/Lg/Pr	66+94
18	C_4 Alkyl benzene	Pp	119+134
19	2-Methylphenol	Pp/Lg/Pr	79+108
20	5,6-Dihydro-(2*H*)-pyran-2-one	Ps	85+128
21	2-methoxyphenol (Guaiacol)	Lg	109+124
22	3 and 4-methylphenol	Pp/Lg/Pr	79+108
23	Levoglucosone	Ps	69+98
24	4-methylguaiacol	Lg	123+138
25	1,4:3,6-dianhydro-α- D-glucopyranose	Ps	69+98
26	1,2-Dihydroxybenzene (Catechol)	Pp	64+110
27	4-Vinylphenol	Pp/Lg	91+120
28	4-Ethylguaiacol	Lg	137+152
29	Indole	Pr	90+117
30	1,4-Dideoxy-D-glycero-hex-1- enpyranos-3-ulose	Ps	87+144
31	4-Vinylguaiacol	Lg	135+150
32	Syringol	Lg	139+154
33	4-(1-Propenyl) guaiacol (Eugenol)	Lg	77+164
34	Unknown compound	Ps	
35	Vanillin	Lg	81+152
36	4-Methylsyringol	Lg	153+168
37	*trans*-4-(2-Propenyl) guaiacol	Lg	77+164
38	4-Acetylguaiacol	Lg	151+166
39	4-Vinylsyringol	Lg	137+180
40	Anhydroglucosan (Levoglucosan)	Ps	57+60
41	Vanillic Acid	Lg	153+168
42	Homovanillic acid	Lg	137+182
43	Unknown compound	Ps	
44	4-(1-Propenyl) syringol	Lg	91+194
45	Diketodipyrrole	Pr	93+186
46	4-Acetylsyringol	Lg	181+196
47	4-(Propan-2-one) syringol	Lg	167+210
48	Fatty acid (C_{14})	Lp	129+185
49	Alkene	Lp/Abp	55+83
50	Alkane	Lp/Abp	57+71
51	Alkene	Lp/Abp	55+83
52	Fatty acid (C_{16})	Lp	129+185
53	Alkene	Lp/Abp	55+83

(It continues)

[redacted]

TABLE 5 (Continued)

No.	Compound	Source[1]	Masses[2]
54	Alkane	Lp/Abp	57+71
55	Alkene	Lp/Abp	55+83
56	Alkane	Lp/Abp	57+71
57	Fatty acid (C_{18})	Lp	129+185
58	Alkene	Lp/Abp	55+83
59	Alkane	Lp/Abp	57+71
60	Alcohol	Lp	
61	Alkene	Lp/Abp	55+83
62	Alkane	Lp/Abp	57+71
63	Ketone	Lp	59+96
64	Fatty acid (C_{20})	Lp	129+185
65	Alkene	Lp/Abp	55+83
66	Alkane	Lp/Abp	57+71
67	Branched alkene	Lp/Abp	
68	Alkene	Lp/Abp	55+83
69	Alkane	Lp/Abp	57+71
70	Alkene	Lp/Abp	55+83
71	Alkane	Lp/Abp	57+71
72	Alkene	Lp/Abp	55+83
73	Alkane	Lp/Abp	57+71
74	Ketone	Lp	59+96
75	Alkene	Lp/Abp	55+83
76	Alkane	Lp/Abp	57+71
77	Ketone	Lp	59+96
78	Branched alcohol	Lp	
79	Alkene	Lp/Abp	55+83
80	Alkane	Lp/Abp	57+71
81	Ketone	Lp	59+96
82	Cholesterol like compound	Lp	105+147
83	Cholesterol like compound	Lp	105+147
84	Ketone	Lp	59+96
85	Alkene	Lp/Abp	55+83
86	Alkane	Lp/Abp	57+71
87	Ketone	Lp	59+96
88	Cholesterol like compound	Lp	105+147
89	Ketone	Lp	59+96
90	Ketone	Lp	59+96

Legend: Abp - aliphatic biopolymers. Lg - lignin. Lp - lipids. Ps - polysaccharides. Pp - polyphenols. Pr - proteins.

[1] To avoid long codes in factor analysis plots. we simplified source codes as follows: Pp/Lg/Pr = PP_1. Pp/Lg = PP_2. and Lp/Abp = LP_1.

[2] Two-component specific masses used for time integration.

We found a long sequence of alkene/alkane pairs, starting from peak 49. According to Nierop et al. (2001), this is common in pyrolysates of vegetal tissues and even for soil samples (Nierop et al.. 2001 and references there in).

Alkene/alkane pairs indicate a non-hydrolyzable aliphatic biopolymer (suberan) (Tegelaar et al., 1995), but they can also be produced from salts of fatty acids upon pyrolysis (Hartgers et al., 1995). In between, apart from fatty acids, we found also ketones (63, 74, 77, 81, 84, 87, 89 and 90) and a few cholesterol-like compounds (82, 83 and 88). The interpretation of the peaks 60, 67 and 78 needs further studies.

Some products can be derived from different sources (e.g. phenol may originate from polyphenols, lignin or proteins), which complicates the assessment of the contribution of each source. Notwithstanding, we tried to find out whether the vegetation conversion affected the relative contribution of the eight probable sources showed in Table 5 (Ps, Pp, Pr, Lg, Lp, and groups Pp/Lg/Pr, Pp/Lg and Lp/Abp). We did not find differences between cerrado and forest for both litter and SOM (data not shown). In addition, the coefficient of variation for most of the variables (sources) was high, indicating that the variation among samples was also high.

We also attempted to find out if the relative area of each one of the 90 peaks changed with the vegetation. Such change could mean that the conversion promoted shifts in the variation of specific SOM components. Factor analysis was used to determine the number of factors that are needed to explain the variation between the samples. We found that three factors, with an Eigen value >1, explained 46.2% of the total variance of the whole pyrogram data set (including litter samples). Figure 3 shows the scatter plot of factors 1 and 2, which together explained 40.4% of the total variance. Most of the litter samples occupied the bottom-right region, being positively correlated to the factor 1. On the other hand, SOM samples were mostly clustered in the central region, showing no strong correlation to any factor. In figure 4 we present the factor loadings of factors 1 and 2 for this set of samples. Lignin peaks formed an upper right cluster and most of them were strongly correlated to the factor 1, showing that this type of compound was responsible for separating litter and SOM samples in the scatter plot of figure 3.

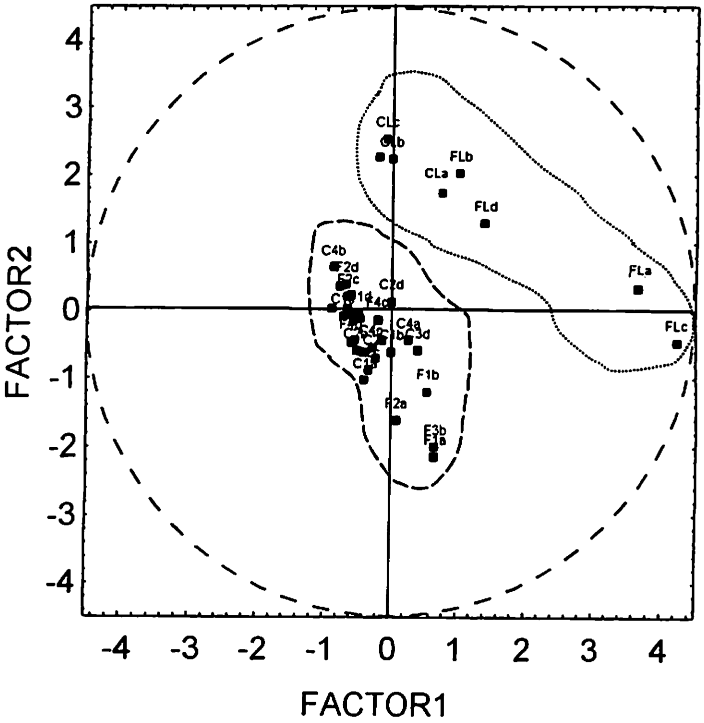

FIGURE 3. Factor scores in F1, F2 space for the whole set of litter and SOM samples (cases - C40), 90 pyrolysis peaks (variables - V90), and 3 factors (F3).
Legend: See Figures 1 and 2.

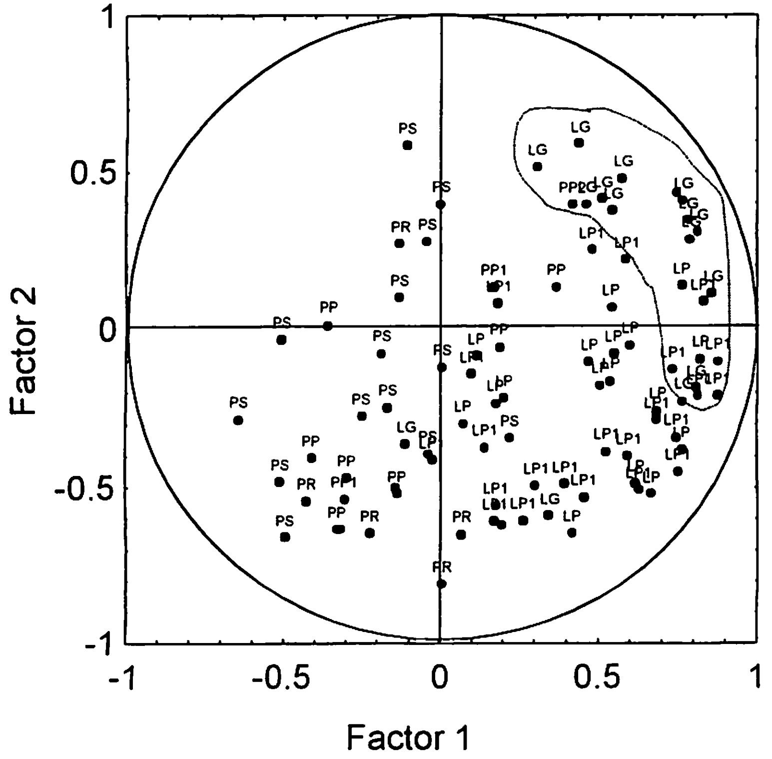

FIGURE 4. Factor loadings of the 90 peaks (variables - V90), considering the whole set of litter and SOM samples (cases - C40), and 3 factors (F3). Obtained from the combination of factors 1 and 2 (F1 and F2).

Legend: See Table 5.

To allow for more detail in the set of soil samples, we repeated the analysis for the extracted OM alone, without litter samples. We found that again three factors explained 41.9% of the total variance of this set of samples. The existent decrease in the percentage of explanation can be due to the large difference between litter and SOM samples. Although there was still 58.1% of variance unexplained by these three factors, the analysis allowed the distinction of a number of interesting features.

The scatter plot of factors 1 and 2, for the 32 extracted organic matter samples, is presented in Figure 5. These factors together explained 34.3% of the total variance. Most of the samples had scores placed around the centre of the scatter plot. This suggested that there were no systematic differences in the relative contribution of each of the 90 pyrolysis peaks. However, most forest topsoil samples (0-5 cm) were clustered in the bottom-right region, and samples from the deepest soil depth of cerrado (10-20 cm) showed an upper left cluster (both regions are highlighted in Figure 5). In figure 6 we present the factor loading of factors 1 and 2 for this data set. Roughly, it was possible to find three distinct regions in the figure (dashed lines): the top-left comprised most of the Ps peaks, the top-right comprised most of the Lp1 peaks, and the bottom-right comprised the majority of the lignin peaks. In keeping with Figure 5, there was a coincidence of the forest topsoil samples in Figure 5 and lignin cluster in Figure 6. Furthermore, the samples from the deepest soil layer of cerrado were clustered at the opposite side of the forest topsoil (Figure 5), coinciding with most of polysaccharide peaks (Figure 6). Therefore, lignin compounds were responsible for separating forest topsoil and, polysaccharides, for separating cerrado subsoil (10-20 cm).

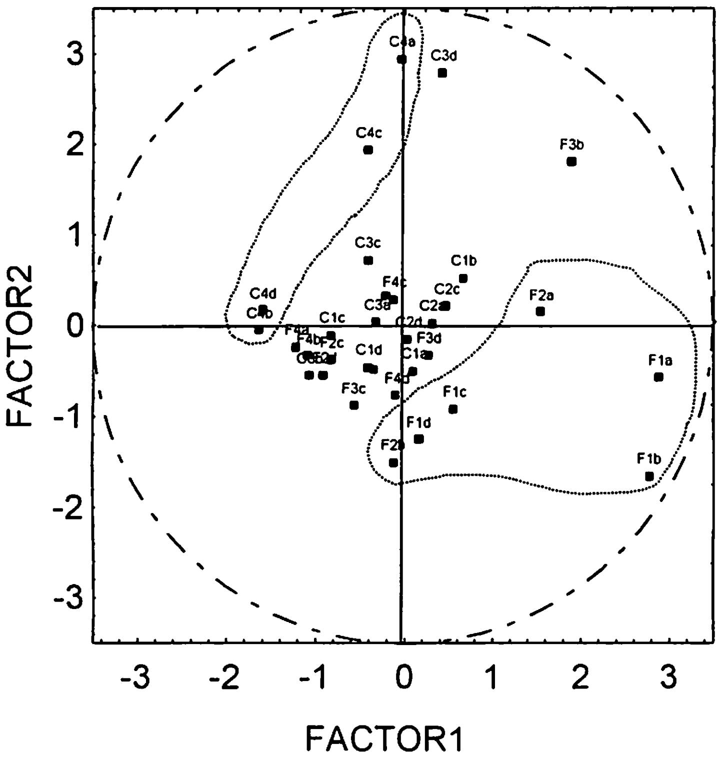

FIGURE 5. Factor scores in F1, F2 space for 32 SOM samples (cases - C32), 90 pyrolysis peaks (variables - V90), and 3 factors (F3).
Legend: See Figure 2.

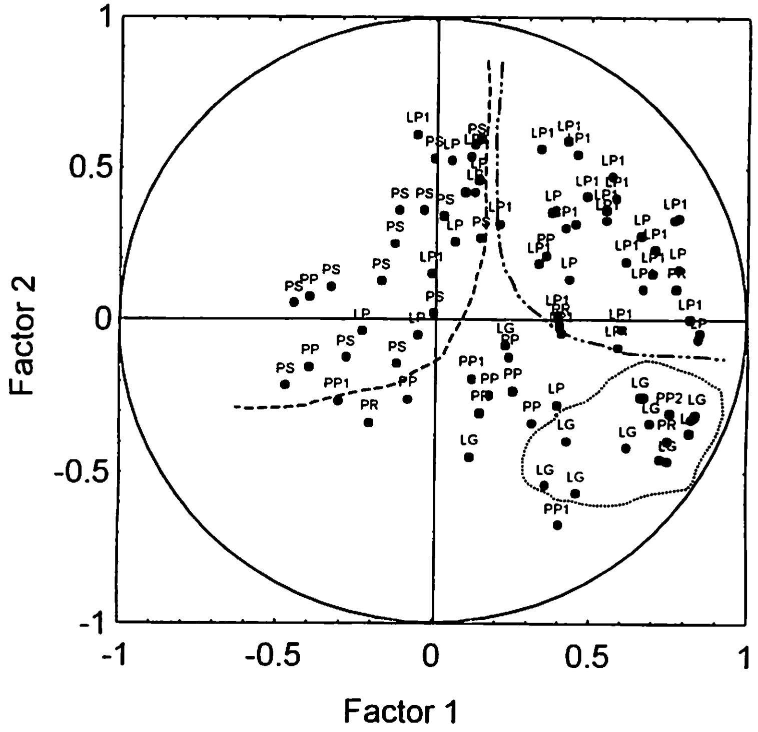

FIGURE 6. Factor loadings of the 90 peaks (variables - V90), considering the 32 SOM samples (cases - C32), and 3 factors (F3). Obtained from the combination of factors 1 and 2 (F1 and F2).
Legend: See Table 5.

4 DISCUSSION

4.1 Carbon and nitrogen distribution

For the total soil we found higher C and N concentrations under cerrado. This phenomenon was previously studied in detail, by the use of soil density fractionation (Chapter 2). and the explanations for it are summarised here. Under cerrado the decomposition process appeared to be more efficient, and much C and N were rapidly transferred to the heavy fraction. The shift from a below-ground carbon input (grassy cerrado) to an above-ground one (riparian forest) promoted a reduction in the carbon and nitrogen stocks in the heavy fraction, which constitutes the major part of SOM. This reduced C and N concentrations and stocks for total soil under forest.

4.2 Chemical composition of SOM

4.2.1 Changes during the transformation of litter into soil organic matter

It is well known that the rate of decomposition is influenced by climatic conditions, mainly temperature and moisture. Within one climatic type and working on one soil type, other aspects, such as chemical structure of the litter, become important. It is expected that different litters (plant residues in general) generate soil organic matter with different chemical composition.

Decomposition of organic residues is characterised by gradual changes in functional groups (Gressel et al., 1995). Therefore, soil organic matter will differ in carbon structure, from its native litter. Such changes are noticeable with time and also within soil depth. It is generally accepted (e.g. Baldock et al., 1992; Gressel et al., 1995; Gregorich et al., 1996) that more easily decomposed compounds (substrates easily metabolised by microorganisms) would be utilised and even mineralised at a faster rate than more recalcitrant material. Baldock et al. (1992) proposed a decomposition process model, based on their own results and literature (Oades, 1981; Hatcher & Spiker, 1988), which includes three stages of oxidative decomposition. Since in the soil there are materials in different phases of decomposition, these stages occur simultaneously. They are (1) loss of O-alkyl carbon (hemicellulose, cellulose, and protein), (2) exposure and subsequent decomposition of aromatic carbon (lignin), and (3) loss of the highly recalcitrant alkyl carbon. Therefore, the relative contribution of each carbon type may show the extension of changes in carbon chemistry due to decomposition.

As a similarity between litter and extracted OM, we found that polysaccharides are dominant in both. Mahieu et al. (1999) reviewed published CPMAS ^{13}C NMR data of SOM, comprising a very wide range of soils and land uses (311 soil samples), and found a sequence of O-alkyl > alkyl > aromatic > carbonyl-C for bulk soil. The O-alkyl region contributed 45% of the carbon, in average. For our samples, this contribution was around 65% for litter and 62% for extracted OM. Similar proportions for polysaccharides have been found for litter (Gregorich et al., 1996; Quideau et al., 2000) and OM extracted by NaOH and/or $Na_4P_2O_7$ (Wattel-Koekkoek et al., 2001). Nevertheless, it is very difficult to compare such data because of the effect of different vegetation and local soil and climate influences.

For cerrado and forest litters we found the same sequence mentioned above but for SOM, extracted under both vegetation covers, there is relatively more carbonyl-C than aromatic-C. Thus, although the proportions of carbon types for litter and OM were rather similar, the contribution of carbonyl-C increased upon decomposition. According to Baldock et al. (1992) and their model of oxidative decomposition with time, once the organic material is added to the soil and the O-alkyl carbon associated to the plant material has been degraded, the second step of decomposition is initiated: molecules of lignin (previously surrounded by O-alkyl structures) are exposed to microbial activity, resulting in a decrease in the content of aromatic carbon. While the proportion of O-alkyl decreases progressively from the litter to the SOM, there is an increase in the carbonyl region, which represents oxidative degradation processes (Quideau et al., 2000).

Both systems have a constant addition of fresh material. In the forest, the addition is mainly superficial, and in the cerrado largely below ground due to its grass root system (Chapter 2). Factor analysis of the whole set of samples (litter plus SOM) indicated that the litter samples are a main source for the majority of lignin compounds. In general, the chemistry linked to the transformation of litter into SOM in these systems reflects very active addition/decomposition.

4.2.2 Changes in SOM structure due to the vegetation cover

Because of the large differences between cerrado and forest litter (mainly grasses in cerrado, and trees in forest), as shown by NMR, changes in the SOM chemical composition upon conversion should be expected. Usually such changes are most conspicuous during the first years after the vegetation conversion. Golchin et al. (1997) studied changes after an invasion of grassland by forest. Their NMR results showed a higher alkyl-C contribution during the first 20-30 years after the forest invasion. Nevertheless, the authors emphasise that both the shift in vegetation and management practices might be responsible for such changes.

We found that conversion of cerrado into riparian forest increases the proportions of alkyl-C in the litter (forest), while the original cerrado litter is richer in O-alkyl-C. This change is reflected in the extracted OM. The alkyl/O-alkyl ratio has been proposed by Baldock et al. (1997) as a sensitive index of the extent of decomposition in organic residues. Reviewing data from wood, peat, composts, forest litter and OM in surface layer of mineral soils, they found that the alkyl/O-alkyl ratio can be used as an indicative parameter for decomposition degree, but only in specific conditions. According to the authors, comparison between sites supporting different vegetation should be avoided, because it means that the OM was not derived from the same starting material. Therefore, the alkyl/O-alkyl ratio alone can not be used to compare the degree of decomposition of the different litters.

The conversion also increases the proportion of aromatic-C in the litter. The forest litter has a higher content of potentially recalcitrant material (alkyl-C and aromatic-C). Consequently, this litter presents fewer easily degraded components (carbohydrate and/or proteins, comprised in O-alkyl region). This is indicative of its lower decomposability, when compared with the cerrado litter.

Factor analysis of the pyrolysis data corroborates this difference between systems, since it indicates a trend for increased presence of lignin compounds in the forest topsoil. In addition, it shows that the SOM extracted from forest subsoil (below 5 cm) and cerrado profile is similar. Only at the deepest cerrado depth, where the majority of the grass roots are concentrated, there was an effect of vegetal material richer in polysaccharides. We showed in Chapter 2, by $\delta^{13}C$ study, that eight years after the conversion the forest soil profile retained the C_4-derived C (from cerrado grasses) below 2.5 cm, and that C_3-derived C was predominantly found at the first soil layer (0-2.5 cm), due to mainly above-ground material input in the forest. Among the forest species, there are some species of *Acacia* spp., which are rich in lignin. Field observations indicate a relatively large contribution of these species leaves to the forest litter.

Increase in aromatic-C is not usually well pronounced during decomposition and humification processes (Zech et al., 1997). There are indications that aromatic-C content may increase, decrease or remain constant (Baldock et al., 1997). We found no changes in the aromaticity degree for litter. Despite the higher contribution of aromatic-C compounds to the SOM under forest, the aromaticity index remained unchanged.

The forest litter appears to be more hydrophobic, which was reflected by the higher hydrophobicity index of the SOM extracted under forest. This finding is in agreement with the more recalcitrant nature of the forest litter, compared with that of cerrado. Notwithstanding, it is important to relate that this apparent recalcitrance of the forest litter may be due to differences inherent to the lignin in both cerrado and forest materials. It is likely that the lignin in the cerrado grasses has a much faster decomposition rate.

4.2.3 Changes with soil depth

In ^{13}C NMR we found some changes in SOM carbon types with depth, under both vegetation conversion. Roughly, decreases in O-alkyl are followed by increases in alkyl and aromatic C types, as we have previously discussed. The highest contribution of O-alkyl compounds below 2.5 cm can be explained in the cerrado by the large input of new organic material from roots death/decomposition and by exsudation of polysaccharides in the rizhosphere (considering the layer between 2.5 and 20 cm). In the forest, as this behaviour is not expected, it is possible that the differences between topsoil and subsoil were too slight in order to promote significant interaction vegetation cover x soil depth. It is also likely that that in forest topsoil a higher microbial activity may cause lower percentage of easily degradable compounds, if compared to the soil below 2.5 cm.

4.2.4 CPMAS ^{13}C NMR and Py-GC/MS approach

The combination of CPMAS ^{13}C NMR and Py-GC/MS enables to detect if and how SOM structure changed due to vegetation conversion. Carbon-13 NMR gave us the carbon "framework" of litter and extracted OM, by the semi-quantification of the carbon types. The litter spectra show better separation than those of extracted organic matter do, because they are from pure vegetal material. In the later we can observe much noise, probably due to iron. Pyrolysis, utilised in a qualitative way, provides complementary information for the NMR results. Furthermore, we made an attempt, with the pyrolysis data, to access the semi-quantitative contribution of each source of compounds. Semi-quantification into groups of supposed equal origin does not provide detailed information. According to Saiz-Jimenez (1994), the complexity of the pyrolysates obtained from macromolecular structures makes very difficult the interpretation of the results. However, using the whole data set we could trace important tendencies.

One of the potential problems in interpretation is the large field variability. Further, litter and soil samples were submitted to a large series of procedures, and each procedure by itself includes many steps. At the end, all the possible variability induced by these procedures is added to the sub-sample (milligrams) analysed by Py-GC/MS. We were able to reach around 40% of explanation for the variability between samples, but it is still low. By the statistical treatment that we gave to the pyrolysis results, we found that assumptions usually done in the literature about relative abundance of pyrolysates, for example comparisons between different samples looking for "higher" or "lower" contribution have to be done carefully.

5 CONCLUSIONS

The combination of CPMAS ^{13}C NMR and pyrolysis-GC/MS allowed the evaluating of the effect of the establishment of riparian forest on soil previously under cerrado on SOM chemical composition and, in addition, contributed to the knowledge of SOM quality in the studied conditions of climate and soil.

Our data showed that both systems have an active addition/decomposition of organic material. There is a constant addition of new material while the decomposition proceeds. Hence, both products from the vegetal decomposition and from microbial metabolism should be present.

There was an impact of the vegetation conversion on SOM chemical composition during the eight years comprised in this work. The changes were promoted by the addition of litter originated from the planted riparian species, which has a different composition from that one of cerrado. The later, mainly added by a below-ground input, was richer in easily degradable compounds, such as polysaccharides. Conversely, the forest litter presented lower decomposability/higher recalcitrant potential. Thus, the conversion originated a more hydrophobic, richer in aromatic compounds and poorer in carbohydrates-like compounds SOM. Factor analysis of the pyrolysis data gave us a clear separation of forest topsoil, richer in lignin compounds, and also showed that forest subsoil and cerrado profile are quite similar, due to the remaining influence of cerrado material on forest profile. An exception within the cerrado profile is the SOM extracted under cerrado at the deepest soil depth, which is richer in polysaccharides because of the strong influence of grass roots in this region.

Here, we did an attempt to use Py-GC/MS in a semi-quantitative approach. Although we could explain around 40% of the variation between samples using factor analysis, we assume that much more could be assessed. Therefore, more research has to be developed on this aspect, in order to find out not only the most efficient statistical treatment, but also to reach a better understanding about the application of Py-GC/MS for soil organic matter. During the process we found that some peaks have a very slight signature, and it would be possible to reach a better explanation of the total variability if these peaks were not considered in the semi-quantification.

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CHAPTER 4

CONVERSION OF NATIVE VEGETATION INTO RIPARIAN FOREST IMPACTING SOIL ATTRIBUTES

ABSTRACT

ALCÂNTARA, Flávia Aparecida de. **Conversion of native vegetation into riparian forest impacting soil attributes.** Lavras: UFLA, 2002. Chap. 4. 30 p. (Thesis - PhD in Soils and Plant Nutrition)[+]

We compared litter and soil (typical Acric Red-Yellow Latosol) samples of an area converted into riparian forest and another maintained under native vegetation (Brazilian savannah or *cerrado*) in order to (i) search for changes in soil attributes after the conversion; (ii) investigate possible relations between the existing changes in soil attributes and changes in SOM content and quality; and (iii) retract the current situation in the forested area, in terms of soil and environment sustainability. We compiled data of SOM contents and chemical composition from Chapters 2 and 3, and analysed soil physical, chemical, and biological attributes in both areas. Factor Analyses were carried out to detect the data structure and select the variables that contributed to the differentiation of the areas. Such variables were analysed by ANOVA and Tukey's test to compare the treatments. Separation between forest and cerrado litter samples was mainly due to the higher nutrient contents of the first one; and between soil samples, mainly due to fertility parameters and microbial biomass, since physical attributes were slightly affected by the conversion. Although soil organic matter was correlated to several soil attributes, the existing changes in its content and quality have not promoted consistent differences between the areas, indicating no important impacts (positive or negative) of the vegetation conversion on soil sustainability so far: the soil under both covers (in distinct ways) has been able to keep vegetation growth, with no damages to the environment where it is inserted. As for the environmental sustainability, the planted riparian forest proved to be auto sustainable, which is favourable to the re-establishment of a riparian environment in areas surrounding dams, contributing to the recovery of its functions in the future.

[+] Guidance Comittee: Antonio E. Furtini Neto - UFLA (Major Professor), Nilton Curi - UFLA, and Peter Buurman – WU.

RESUMO

ALCÂNTARA, Flávia Aparecida de. **Conversão de vegetação nativa em mata ciliar e seu impacto sobre os atributos do solo.** Lavras: UFLA, 2002. Cap. 4. 30 p. (Tese - Doutorado em Solos e Nutrição de Plantas)*

Foram comparadas amostras de serapilheira e solo (Latossolo Vermelho-Amarelo Ácrico) de uma área convertida em mata ciliar e outra mantida sob vegetação nativa de cerrado, objetivando-se: a) verificar mudanças nos atributos do solo após a conversão; b) investigar relações entre tais mudanças e mudanças ocorridas no conteúdo e na qualidade da matéria orgânica do solo (MOS); e c) retratar as condições atuais da área com relação à sustentabilidade do solo e ambiental. Foram analisados atributos físicos, químicos e biológicos do solo e utilizados dados sobre conteúdo e composição química da MOS provenientes dos capítulos 2 e 3. Utilizou-se a Análise de Fatores (uma forma de análise de componentes principais), com o intuito de detectar a estrutura dos dados e selecionar as variáveis que mais contribuíram para a diferenciação entre as duas áreas. Tais variáveis foram, posteriormente, submetidas à ANAVA e ao teste de Tukey, a fim de comparar os tratamentos. Ocorreu uma separação das amostras de serapilheira do cerrado e da mata devido, principalmente, às maiores concentrações de nutrientes nas últimas. Por sua vez, a separação entre amostras de solo sob cerrado e mata se deu principalmente devido a diferenças na fertilidade do solo e na biomassa microbiana - carbono, já que os atributos físicos permaneceram praticamente inalterados. Apesar de a matéria orgânica ter se correlacionado com vários atributos do solo, as alterações em seu conteúdo e composição química não promoveram, durante o tempo estudado, diferenças consistentes entre as áreas, indicando um baixo impacto (seja ele positivo ou negativo) da conversão de vegetação na sustentabilidade do solo: em ambas as áreas o solo é apto para sustentar a produção vegetal, sem causar danos ao ambiente do qual faz parte. No que se refere à sustentabilidade ambiental, a mata ciliar implantada se mostrou auto-sustentável, o que é favorável ao re-estabelecimento de um ambiente ripário nas áreas marginais aos reservatórios, contribuindo para a futura recuperação de suas funções.

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1 INTRODUCTION

Starting from the 40's, Brazil presented one of the deepest world rates of economical development, which was linked to the exploration of natural resources in a disordered way. At that time, in order to supply electricity and to profit the most promising energy source of the country, water resources, many hydroelectric power plants (HPP) were constructed (Davide & Botelho, 1995). However, it was done with little environmental concern, resulting in great areas deprived of riparian vegetation, and consequently, disappearance of riparian fauna, increase of erosive process (Spera, 1995), and decrease of water quality.

In Brazil, environmental movements acquired political force in the 80's, coinciding with political opening and promulgation of the Federal Constitution. In 1990 the Riparian Forest Project was created as a partnership between CEMIG (Energy Company of Minas Gerais) and UFLA (Lavras Federal University), aiming to obtain technology for vegetation restoration of lakeshores, and two years later, it was implanted in Itutinga/Camargos HPP (Southern region). Although an information database has been generated by the project, it is necessary to carry out a critical evaluation in order to elucidate the current situation of the program in terms of soil and environmental sustainability. So far, most of the studies have focused on forestry aspects (e.g. periodic growth of population), and very little is known about soil processes in such forested areas. Nevertheless, it is already well established (for both agricultural and natural systems) that soil processes, such as nutrient cycling, carbon storage and partition rainfall, are closely linked to soil sustainability. Especially in implanted systems, aiming at environmental restoration, it is important to access possible changes in soil attributes, evaluating their effects on the capacity of soils to sustain vegetation.

It is rather difficult to separate soil attributes in chemical, physical or biological attributes, since they actively interact amongst themselves. In this context, soil organic matter (SOM) has been mentioned as a key indicator of soil quality (Doran, 1997) and a key component of all terrestrial ecosystems (Bartjes & Sombroek, 1997). It plays an outstanding role in several processes, affecting directly or indirectly soil attributes, such as soil structure; aggregates distribution; water infiltration/retention; aeration; ionic exchange capacity; and microbial activity.

Native Brazilian savannah or cerrado (in this particular case, grassy cerrado) primarily covered the surrounding areas of Itutinga/Camargos reservoirs. In 1992, selected areas were converted into riparian forest, promoting an important change in the litter origin. This conversion was studied in the two previous chapters. In Chapter 2, we evaluated changes in SOM dynamics and C and N stocks, using density fractionation and $\delta^{13}C$. Both C and N stocks decreased with the conversion due to the change of a below-ground carbon input (from grass roots in cerrado) to an aboveground one (from superficial addition in forest). Delta ^{13}C analysis showed that there was replacement of C_4-derived C (from cerrado) by C_3-derived C (from forest litter) in topsoil, where the new material has been added by aboveground input. In Chapter 3, we worked on effects of the conversion on SOM chemical composition, as revealed by CPMAS ^{13}C NMR and pyrolysis-GC/MS. Soil organic matter quality changed due to the addition of forest litter, chemically different from the cerrado material. The conversion provided a more recalcitrant litter and SOM, while the native material was richer in more easily degradable components. Those results have shown that the conversion of vegetation, as presented in this particular case, promoted changes in SOM contents and quality. We hypothesised that such changes and, in addition, differences in nutritional composition of the distinct litters, may affect some soil attributes, and consequently, cause a positive or negative impact on soil (and environment) sustainability.

Our general objective was to find out whether and how this impact comes out. In order to reach this goal, our specific objectives were: (i) to search for possible changes in soil attributes after the vegetation conversion; (ii) to investigate possible relations between the existing changes in soil attributes and changes in SOM contents and quality (found in previous works); and (iii) to retract the current situation in the forested area, in terms of sustainability.

2 MATERIAL AND METHODS

2.1 Site description

The study was carried out in the Itutinga/Camargos reservoirs, located in southern Minas Gerais State, between 21°15' and 21°50' S and 44°15' and 44°45' W, and at 917 m of altitude. The mean annual temperature is 19.4 °C, and the mean annual precipitation is 1529 mm, with a dry period from April to September (Brasil, 1992). This region is part of Paraná River basin and drained by rivers from Grande River sub-basin. We selected a site in the vicinities of Itutinga/Camargos reservoirs, which was partially submitted to the Riparian Forest Project. The soil (characterised in Table 1, Chapter 2) is a homogeneous Typic Acric Red-Yellow Latosol (Anionic Acrustox) (Chagas et al., 1997).

Two areas within this site were chosen. They are located 200 m apart, in opposite hillsides of the site. The first area was taken as reference because it was maintained under native vegetation (grassy cerrado), which is a grassland with scattered shrubs. The second area was converted into forest in 1992, as part of the above-mentioned project. It was planted with a mixture of riparian species, after excluding native vegetation. The planting was done in pits of 30x30x30 cm. with a spacing of 1.5x3.0m between them. Each one was fertilised with 200g of simple superphosphate (18% of P_2O_5). Sixty days after the planting 15g of KCl (58% of K_2O) plus 60g of $(NH_4)_2SO_4$ (20% of N) were applied following the projection of each plant, on the soil surface.

Both areas were plotted 5 meters from the reservoir margin, in order to discount the depleted area, which is subject to periodic flooding and presents species adapted to such condition. The most important plant species in native and planted areas are named in the Material & Methods section of the Chapter 2.

2.2 Experimental design and material sampling

Sampling was done in May/2000. For that, we used the randomised blocks experimental design in factorial scheme with four replications. Each area was sub-divided into four blocks (replicates), which were defined based on land quotas. The same land quotas were used in both areas in order to plot the blocks. Thus, each block was placed in the same position in the hillside for both areas. One composite sample was taken per block, each one a mixture of ten sub-samples collected in a "zigzag" pattern. Four different soil depths were sampled (0-2.5, 2.5-5, 5-10 and 10-20 cm), resulting in 16 composite soil samples in each area. Litter was collected with a 50 x 50 cm frame, placed on the same sites used for soil sub-samples, resulting in 4 composite samples in each area. The soil samples were air-dried and passed through a 2 mm sieve to remove coarse debris. The aboveground litter samples were oven dried (60°C), weighted, and ground to a fine powder.

2.3 Litter characterisation

Powdered litter samples were submitted to the determination of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn, according to Malavolta et al. (1989). Extracts were obtained by nitroperchloric digestion, except for B (dry extraction).

Phosphorus and B were determined by colorimetry; Ca, Mg, S, Cu, Fe, Mn, and Zn by atomic absorption spectrophotometry; K by flame photometry; S by turbidimetry; and N by Semi-Micro Kjeldahl. Total organic carbon was analysed by flash combustion, using an Interscience Elemental Analyser EA1180. Stocks of carbon and nutrients were calculated based on their respective contents and the dry matter production.

2.4 Soil characterisation

Soil samples were submitted to analysis of pH (H_2O), proportion 1:2.5 (soil: water); total N by the Micro Kjeldahl method (Bremner & Mulvaney, 1982); NH_4-N and NO_3-N by a steam distillation method (Bremner, 1965); exchangeable Ca, Mg, and Al extracted by KCl 1 mol L^{-1} and analysed by titration (EMBRAPA, 1997); $H^{+}+Al^{+3}$ (potential acidity) determined indirectly by SMP solution and quantified by potentiometry (Quaggio et al., 1985); P by the resin method (Raij et al., 1987) and determined by colorimetry; K extracted by Mehlich 1 and analysed by flame photometry (Vettori, 1969); S by turbidimetry (Blanchar et al., 1965); B extracted by hot water and analysed by photocolorimetry (Reisenauer et al., 1973); Cu, Zn, Mn, and Fe, by Mehlich 1 and determined by atomic absorption spectrophotometry (Raij et al., 1987). Fertility parameters, indirectly determined using values of potential acidity, exchangeable bases and Al, were: bases sum (BS); base saturation (B Sat); Al saturation (Al Sat); and effective and potential (or at pH 7.0) cation exchange capacity, respectively eCEC and pCEC.

Analysed physical attributes were: moisture (w) (Uhland, 1951); bulk density (BD) by the paraffin method (Blake & Hartge, 1986); aggregate stability by wet sieving, with subsequent calculation of Geometric Mean Diameter (GMD) and Mean Weight Diameter (MWD) (Kemper & Chepil, 1965); and soil texture by the pipette method (Day, 1965), using NaOH 0.1 mol L^{-1} as dispersant and shaking at 6000 rpm during 20 min. Contents of total clay and water dispersible clay (WDC) were used to calculate the flocculation index (FI) (EMBRAPA, 1997). Microbial biomass carbon (MBC) was determined by the fumigation-extraction method (Vance et al., 1987), and its proportion in relation to the total organic carbon (MBC/TOC) was calculated as percentage.

2.5 Soil organic matter characterisation – data compilation

For the same samples SOM was characterised in Chapters 2 and 3, and full description of the used methods is given therein. Here, we compiled these data in order to verify possible interrelations between them and the attributes coming from soil characterisation (item 2.4). Data used as soil organic matter characteristics, and the respective legends for them, were: total organic C (TOC); carbon content in density fractions: in the light fraction (CLI) and in the heavy fraction (CHE); carbon content in extracted organic matter (alkaline extraction) (CEX); and relative percentage of C types detected by CPMAS ^{13}C NMR (carbonyl, aromatic, O-alkyl and alkyl).

2.6 Statistical Analysis

As a primary step we used multivariate analyses for soil and litter samples in separates, by Factor Analysis procedure, aiming to (i) reduce the number of variables, and (ii) detect structure in the relationships between variables. With these purposes we carried out an extraction of the main factors (or principal components) that are needed to explain the variation between samples, using the STATISTICA version 5.0 software (1997). Factors are "super-variables" made up of highly correlated combinations of the original variables. They are extracted from the correlation matrix, which is done by a combination of cases (in this work, samples) and variables. To extract factors we defined two conditions: (i) three as the maximum number of factors, since usually the first two explain most of the variation, and (ii) Eigen values > 1.0. Eigen values represent the relative contribution of each factor to the explanation of the total variation of the data set. Eigen vectors, or factor loadings, represent the weighting of each original variable on each factor, and their scores are scaled as correlation coefficients ranging from -1 to +1 (Kent & Coker, 1992). In this work, we considered as significantly correlated factor loadings the ones > [0.7]. For the Factor Analysis we did not take into account, as variables, nutrient stocks (litter), ratios and indices (soil).

Upon reduction of variables and assessment of the ones that most contributed for differences between treatments, we carried out univariate analyses to reach more detailed effects of treatments on the variables. For that, analyses of variance (ANOVA) were performed for dependent variables as a function of the independent ones (treatments). We applied Tukey's test (0.05 significance level), in order to compare means of treatments, for those variables that were affected by vegetation cover (litter samples) and vegetation cover or depth (soil samples). For the later, there was no significant effect of the interaction cover x soil depth. Analysis of variance and Tukey's test were accomplished using SAEG version 5.0 software (1993). Pearson correlation was used to access interrelations between SOM characteristics and the studied soil attributes. Only correlation coefficients > [0.80] and significant at $p < 0.05$ (T test) were considered.

3 RESULTS

3.1 Litter characterisation

For the whole set of litter samples (08), Factor Analysis gave us three factors (Eigen value >1.0), capable to explain 91.2% of the total variance between samples. Figure 1 (a) shows the scatter plot of factors 1 and 2, which together explain 84.7% of the total variance. There was a clear separation between cerrado and forest litter. All forest samples had negative scores in relation to the factor 1, and consequently, were plotted in the left side of the scatter plot. The cerrado ones had positive scores in relation to this factor, being plotted in the right side. Figure 1 (b) presents the factor loadings of factors 1 and 2 for the same set of samples. Variables significantly correlated to the factor 1 formed two clusters close to the first axis. Their respective factor loadings were DM (-0.97), N (-0.98), Ca (-0.98), Mg (-0.98), S (-0.81), B (-0.97), Cu (-0.95), Fe (-0.96), P (+0.90), Zn (+0.82), Mn (+0.96), O-alkyl C (+0.99), alkyl C (-0.88) and aromatic C (-0.90). In keeping with Figure 1 (a), the separation between cerrado and forest litter samples was strongly affected by these variables. Only K was correlated (+0.73) to the factor 2.

Univariate analysis allowed a better understanding of the existing differences between both litters. Differences in nutritional composition between them are presented in Table 1. We reported only contents and stocks that were significantly different according to ANOVA and, consequently, analysed by Tukey's test. In forest, the material that has been added showed to be richer in most of the studied nutrients (N, Ca, Mg, B, Cu and Fe) and the DM production was higher. On the other hand, cerrado litter had higher contents of P, Zn, and Mn. Forest presented higher stocks of C and all nutrients, except P, of which stocks did not differ between litters. These results confirmed the trends shown by Factor Analysis, demonstrating that differences in dry matter production and nutrient contents were responsible for the spatial separation of cerrado and forest litters.

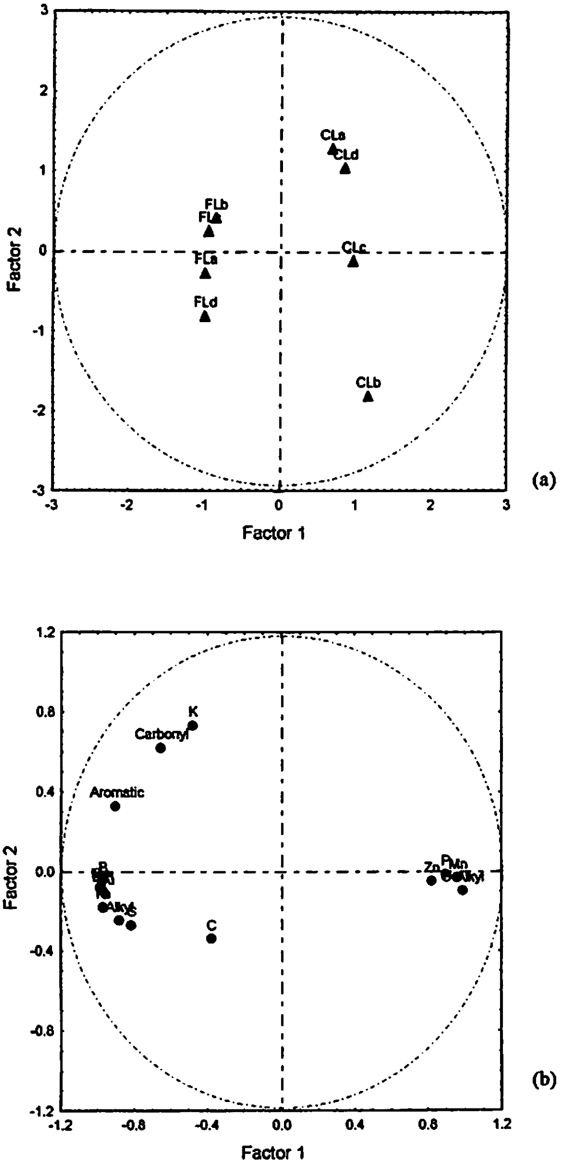

FIGURE 1. (a) Factor scores in F1, F2 space for cases (litter samples) (C8), 17 variables (V17), and 3 factors (F3). (b) Factor loadings of the 17 variables (V17) for litter samples (C8), and 3 factors (F3), obtained from the combination of factors 1 and 2 (F1 and F2). Percentage of the total explanation for factors 1, 2 and 3, respectively: 76.7, 8 and 6.5%.

Legend: C = cerrado, F = forest, L = litter samples, a to d = replicates.

TABLE 1. Litter nutritional composition, dry matter production (DM) and carbon and nutrient stocks[1].

	Contents								
	N	P	Ca	Mg	B	Cu	Zn	Mn	Fe
	.... g kg^{-1}	....			.... mg kg^{-1}	....			
Cerrado	6.5b	0.5a	0.9b	0.4b	5.4b	5.6b	20.6a	398a	4510b
Forest	11.9a	0.4b	10.4a	2.0a	17.1a	12.4	16.5b	184b	7800a

	DM	Stocks									
		C	N	K	Ca	Mg	S	B	Cu	Zn	Fe
	.... kg ha^{-1}	....					.... g ha^{-1}	....			
Cerrado	353b	145b	2.3b	1.6b	0.3b	0.1b	0.2b	1.9b	2.0b	7.2b	1600b
Forest	699a	298a	8.4a	3.5a	7.3a	1.4a	0.5a	11.9	8.6a	11.5a	5424a

[1] Means in the same column followed by the same letter are not significantly different at $p<0.05$ according to Tukey's test.

3.2 Soil characterisation

3.2.1 Changes in soil attributes due to the vegetation cover

For the whole set of soil samples (32), Factor Analysis was carried out for chemical and physical variables, as well as microbial biomass C. We found three factors (Eigen value >1.0), which explained 58.7% of the total variance between samples. Factors 1 and 2, together, were able to explain 49.2% of the total. Figure 2 (a) shows the scatter plot for the cases. There was, similarly to the litter, a clear separation of cerrado and forest soil: forest samples were grouped in the left side of the scatter plot since they presented negative scores in relation to the factor 1; the cerrado ones, with positive scores, were grouped in the right side. This factor was related to the vegetation cover. Conversely, factor 2 was related to the soil depth, promoting a separation between topsoil (depths of 0-2.5 and 2.5-5 cm) and subsoil (depths of 5-10 and 10-20 cm) for both areas, but especially for forest. All the forest samples of the first two layers had positive scores in relation to the factor 2, while all the ones of the deeper layers, negative scores.

Figure 2 (b) presents factor loadings of the first two factors for this data set. Variables significantly correlated to the factor 1 and their respective factor loadings were pH (-0.75), Ca (-0.87), Mg (-0.81), S (-0.81), B (-0.76), Zn (-0.71), BS (-0.84), BSat (-0.92), Cu (+0.73), Al (+0.96), H+Al (+0.75), and Al Sat (+0.96). In keeping with Figure 2 (a), the separation between cerrado and forest soil samples was likely promoted by differences in these variables between the two areas. Factor 2 was significantly correlated to P (+0.72), K (+0.90), Mn (+0.82), Fe (+0.75), pCEC (+0.73) and TOC (+0.88). Consequently, the separation between top and subsoil, for both cerrado and forest samples, was probably caused by differences in P, K, Mn, Fe, TOC, and pCEC with soil depth.

Physical variables were not correlated to the extracted factors, showing the lowest factor loadings (mostly < 0.5). Therefore, in order to check more accurately if these soil attributes were or not affected by vegetation conversion, we performed ANOVA and Tukey's test. Results of the later are reported in Table 2. In fact, physical variables were slightly affected by conversion. Differences were found for moisture content, higher in forest, and for two size classes of aggregate (0.5-0.25 and 0.25-0.105 mm) that presented higher percentages in forest. Macroaggregates > 0.5 and microaggregates <0.105 mm were not affected, as well as the MWD and GWD indexes.

The clear separation between cerrado and forest samples, as shown in Figure 2 (a), indicated that existing differences could be due to several attributes (Figure 2 b), but not to the physical ones. Thus, to allow for more detail about possible differences between cerrado and forest soil samples, we carried out a new Factor Analysis, this time discounting physical variables.

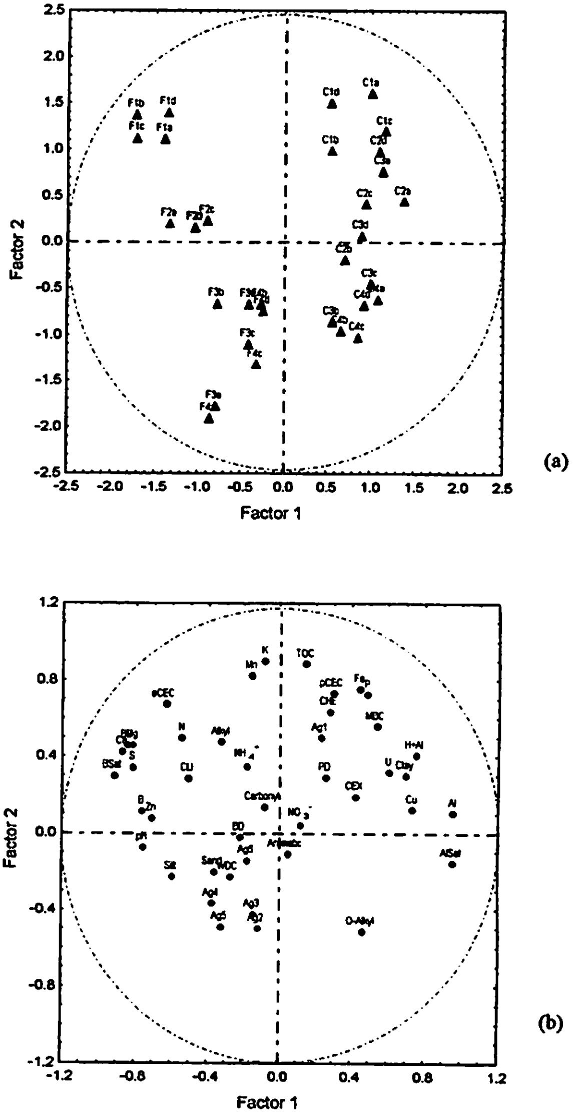

FIGURE 2. (a) Factor scores in F1, F2 space for cases (soil samples) (C8), 43 variables (V43), and 3 factors (F3). (b) Factor loadings of the 43 variables (V43) for soil samples (C8), and 3 factors (F3), obtained from the combination of factors 1 and 2 (F1 and F2). Percentage of the total explanation for factors 1, 2 and 3, respectively: 29.3, 19.9 and 9.5%.

Legend: C = cerrado, F = forest, 1 to 4 = soil depths, a to d = replicates. Ex.: C1a (cerrado OM from the soil depth 0-2.5 cm and replicate a).

TABLE 2. Changes in physical attributes as a function of vegetation cover, independently of the soil depth[1].

W	Texture			WDC	FI	BD	Aggregate stability							
							Size classes						Indexes	
	Clay	Silt	Sand				Ag1	Ag2	Ag3	Ag4	Ag5	Ag6	MWD	GMD
%	.... $g\ kg^{-1}$			....	%	... $g\ dm^{-3}$...	....................%....................						....mm....	
							Cerrado							
3.0b	410	230	360	120	70	1.38	99	0.29	0.14	0.10b	0.14b	0.10	4.9	4.8
							Forest							
3.6a	380	250	370	136	64	1.37	99	0.33	0.20	0.19a	0.23a	0.16	4.9	4.9

[1] Means in the same column followed by the same letter are not significantly different at $p<0.05$ according to Tukey's test. Means not followed by letters were not analysed by Tukey's test, since ANOVA did not point out differences between treatments. Calculations: W = (weight of wet soil – weight of oven-dry soil (at 105°C))/weight of oven-dry soil (at 105°C) and FI =((total clay – WDC)/total clay)*100. Legends: Ag1, Ag2, Ag3, Ag4, Ag5, and Ag6 represent, respectively, the following size classes (mm): 7-2, 2-1, 1-0.5, 0.5-0.25, 0.25-0.105, and <0.105.

We obtained three factors (Eigen value >1.0), able to explain 68% of the total variance. Factors 1 and 2 explained together 61.6% of it. Therefore, we could increase explanation percentages by removing physical variables. Scatter plot for cases (Figure 3 a) shows again the separation of cerrado and forest soil samples, following a similar pattern to that seen in Figure 2 (a). Also here, factor 2 was related to depth. For forest, samples of the first 2.5 cm depth had positive scores in relation to this factor and were clustered in the top-left region. For cerrado, most of the samples between 0 and 10 cm were located in the top-right.

Factor loadings for factors 1 and 2 are presented in Figure 3 (b). The following variables showed significant correlation to the factor 1: pH (-0.70), Ca (-0.96), Mg (-0.91), S (-0.88), B (-0.77), Zn (-0.71), BS (-0.94), eCEC (-0.80), B Sat (-0.96), Al (+0.89) and Al Sat (+0.97). In keeping with Figure 3 (a), the separation between cerrado and forest samples was probably caused by differences in these variables between the two areas. Factor 2 was significantly correlated to several variables: MBC (+0.74), P (+0.79), K (+0.87), Mn (+0.79), Fe (+0.90), pCEC (+0.79), TOC (+0.93), and CHE (+0.80), which might be responsible by the distribution of the different soil depths in Figure 3 (a).

Aiming to verify trends shown by Factor Analysis, we carried out univariate analyses for chemical attributes and MBC. Table 3 presents existing changes in these variables, caused by conversion of cerrado into forest, independently of the soil depth effect. Microbial biomass C diminished after conversion, but its proportion in relation to TOC was not changed. In addition, conversion increased N, S, Ca, Mg, B, and Zn, and decreased P, Cu, and Fe contents. Although K content did not differ between cerrado and forest soils, increases in Ca and Mg contents were followed by increase in BS, eCEC, and B Sat. However, pCEC decreased. As for acidity parameters, soil pH increased after conversion, while Al content, H + Al, and Al Sat diminished. Therefore, differences between cerrado and forest chemical attributes, responsible for the separation observed in Factor Analysis, were verified: conversion promoted higher fertility, characterised by increase of nutrient contents (Ca, Mg, S, B and Zn), and decrease of acidity (higher pH, lower Al and Al Sat).

As the vegetation cover was the main studied factor (soil depth had a characterisation purpose), we focussed on the changes occurred as a function of conversion, which were described above. Nevertheless, we found changes in MBC, TOC, and fertility with soil depth that were independent of the cover (data not shown), which confirmed trends with depth shown by Figures 2 (a) and 3 (a). Microbial biomass C, TOC and N, P, Ca, Mg, S, B, and Fe contents diminished towards 20 cm. In most of cases, values were higher in the first 5 cm. The same happened with CEC (both effective and potential). Conversely, Al content and Al Sat increased with depth.

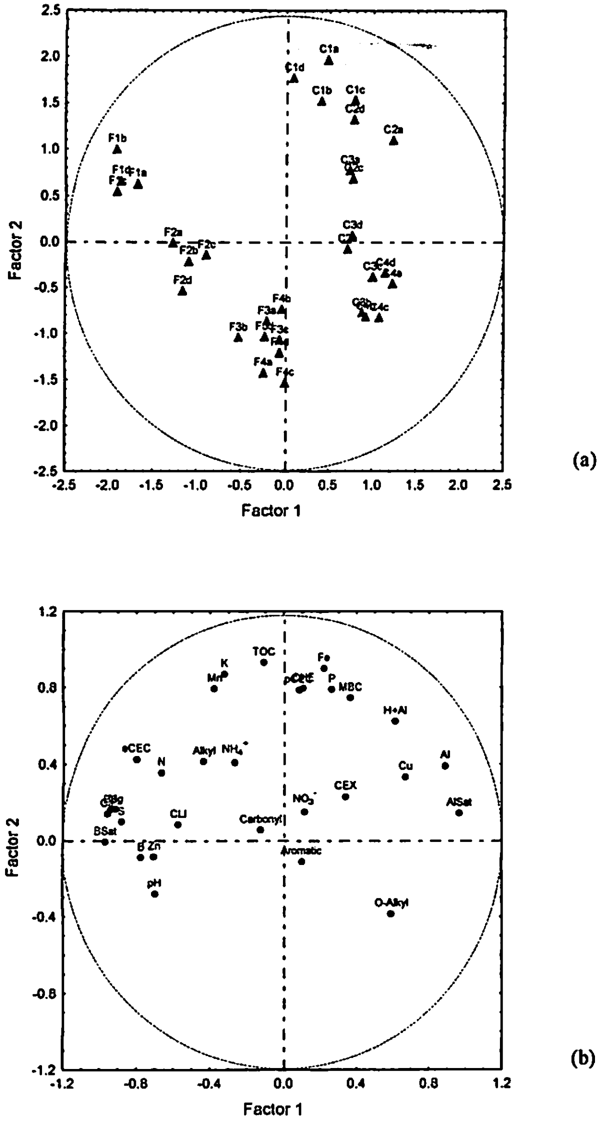

FIGURE 3. (a) Factor scores in F1, F2 space for cases (soil samples) (C8), 30 variables (V30), and 3 factors (F3). (b) Factor loadings of the 30 variables (V30) for soil samples (C8), and 3 factors (F3), obtained from the combination of factors 1 and 2 (F1 and F2). Percentage of the total explanation for factors 1, 2 and 3, respectively: 37.4, 24.2 and 6.4%.

Legend: See Figure 3.

3.2.2 Interactions between soil organic matter characteristics and the studied attributes

We found only few significant correlation coefficients between physical attributes and organic matter characteristics (data not reported). Bulk density was negatively correlated to the heavy fraction carbon in cerrado. Also in this area the percentage of microaggregates < 0.105 mm was positively correlated to O-alkyl C, and negatively, to alkyl C type.

Several chemical attributes were closely related to the variables linked to soil organic matter (Table 4). Total organic C was negatively correlated to Al Sat in cerrado, and also to Al content in forest, but positively correlated to most of nutrients (including many micronutrients in cerrado), and consequently, to fertility parameters, such as bases sum and saturation. Carbon content in density fractions was correlated to some soil attributes. In cerrado, light fraction carbon was positively correlated to MBC, and in forest, to S content. As for heavy fraction carbon, there was a negative correlation with Al, and positive with some nutrients, eCEC, bases sum and saturation, and MBC in forest. In cerrado, CHE was positively correlated to N, NH_4-N, P, S, and B, bases sum and eCEC. Organic matter extracted by alkaline procedure had its carbon mass not correlated to any variable. Nevertheless, carbon types studied in this extracted organic matter presented some interesting correlations. In cerrado, aromatic C was negatively correlated to Al Sat, and positively to some nutrients, bases sum and saturation. In forest, this carbon type was positively correlated to MBC, NO_3-N and P contents. Alkyl C, in cerrado, was positively correlated to Cu, Zn and Mn; and in forest, to pH, some nutrients, CEC, bases sum and saturation. However, it was negatively correlated to Al and Al Sat. Conversely, O-alkyl C had positive correlation with Al and Al Sat, and negative with several nutrients and most of fertility parameters (BS, B Sat and eCEC) in both areas.

TABLE 3. Changes in microbial and total organic carbon, and soil fertility as a function of vegetation cover, independently of soil depth[1].

MBC	TOC	MBC/TOC	pH	N	P	S	Ca	Mg	Al	H+Al	B	Cu	Zn	Fe	eCEC	pCEC	BS	B Sat	Al Sat
g kg^{-1}		%		g kg^{-1}	.. mg dm^{-3}..		.... cmol$_c$ dm^{-3}..........				.... mg dm^{-3}.......				.... cmol$_c$ dm^{-3}........			...........%..........	
										Cerrado									
0.95a	23a	4.1a	4.9b	1.4b	8.0a	2.3b	0.5b	0.2b	1.0a	8.0a	0.1b	1.7a	0.3b	62a	1.8b	8.8a	0.8b	9b	55a
										Forest									
0.59b	20b	2.9a	5.3a	1.7a	5.9b	5.4a	1.1a	0.8a	0.2b	5.1b	0.3a	1.1b	0.9a	30b	2.2a	7.3b	2.0a	30a	9b

[1] Means in the same column followed by the same letter are not significantly different at $p<0.05$ according to Tukey's test. Calculations: MBC/TOC = (MBC/TOC)*100; and fertility parameters: eCEC = $Ca^{+2}+Mg^{+2}+K^{+}+Al^{+3}$, pCEC (at pH=7) = $Ca^{+2}+Mg^{+2}+K^{+1}+H^{+1}+Al^{+3}$, BS = $Ca^{+2}+Mg^{+2}+K^{+}$ (cmol$_c$ kg^{-1}), B Sat = (BS/ pCEC)*100, and Al Sat = (Al^{+3} / eCEC) * 100.

TABLE 4. Correlation between SOM characteristics and MBC, and chemical soil attributes.

	MBC	pH	Al	Al Sat	N	NH_4^+	NO_3^-	P	K	Ca	Mg	e CEC	pCEC	BS	B Sat	S	B	Cu	Zn	Mn	Fe
											Cerrado										
TOC				-	+	+		+	++	++	+	++		++	+	+	++		+	+	+
CLI	+																				
CHE					+	+		+	+			+		+		+	+				+
CEX																					
Carbonyl																					
Aromatic				-	+	+				+	++			+	+	+	+				
O-alkyl	-			++	-				-	-	-	-		--	--	-	-				
Alkyl																		+	+	+	
											Forest										
TOC			--	-	+			++	++	++	+	+	+	+	+	+					
CLI																+					
CHE	+		-		++			++	++	++		+		+	+		+				
CEX																					
Carbonyl																					
Aromatic	+						+	+													
O-alkyl			++	+	--			--	-	-	-	-		-	-		-			-	
Alkyl		+	-	-				+		+	+	+	++	+	+						+

Legend: (-) negative correlation significant at p<0.05; (--) negative significant correlation at p<0.01; (+) positive correlation significant at p<0.05, and (++) positive correlation significant at p<0.01 (T test).

4 DISCUSSION

4.1 Data structure

Factor Analysis detected the structure of the data, showing that some changes, which occurred during the period comprised in this work (eight years), were responsible for differentiating the forested area from the original one. Starting from this analysis, we could select variables that should be studied more carefully, due to their significant contribution for such differentiation. Alterations in these variables are discussed in the next sub section.

4.2 Nutritional composition of the litter

Although the forest litter is richer in most of the studied nutrients, the cerrado one has higher concentrations of P, Zn and Mn. This may be due to the much higher dry matter production of the forest litter, promoting a "dilution" effect of these nutrients, which have high mobility in plant tissues. In addition, the much higher production of DM is responsible by higher stocks of almost all nutrients in the forest litter.

4.3 Changes in soil attributes and their relationship with SOM

4.3.1 Physical attributes

We observed that the time comprised in this work was not enough to cause considerable changes in soil physical attributes. In fact, static soil physical properties, as texture, are expected to change little through time for a given soil (Schoelnholtz et al., 2000). As changes in percentages of clay, silt, and sand are only (and slightly) modified by cultivation or other practices that might cause mixing of different layers (Arshad et al., 1996), changes in granulometry after vegetation conversion are not expected. Water dispersible clay and flocculation index can be related to the soil susceptibility to suffer losses by erosion. As the conversion do not affect total clay and water dispersible clay contents, flocculation index in both soils is steady. Moisture content, one of the few changed physical attributes, is more easily preserved in forest, where we observed in the field a noticeable deposition of litter on soil surface.

Bulk density is a much more dynamic property and varies among soils of distinct texture and structure, but hardly within a given soil type, which can happen, for instance, when soil compaction (caused by machinery or animals) is active. In general, our findings point out favourable aggregate stability in both areas. There are very high percentages of macroaggregate in the size class 7-2 mm, followed by high values of WMD and GMD. Weight mean diameter strongly depends on the amount of macroaggregates retained by sieves of larger mesh, and geometric mean diameter estimates the size of the aggregate class that mostly occurs. As for SOM effects, aggregate stability is the dynamic physical attribute most affected. When changed, it can indirectly influence other properties, such as bulk density, porosity, aeration and water retention/infiltration (Bayer & Mielniczuck, 1999). Several studies have established connections between aggregation and SOM, discussing organic matter as a binding agent (Tisdall & Oades, 1982; Oades, 1984), or relationships erodibility x carbon content (Angulo et al., 1984), and comparing different systems (Castro-Filho et al., 1998; Silva & Mielniczuk, 1998). Although no significant changes in aggregation were found with conversion, we can establish some interesting relations between microaggregates and C types. According to Baldock et al. (1992), relative contribution (%) tends to decrease for O-alkyl C, and increases for alkyl, while the decomposition process takes place. In cerrado, decreases in O-alkyl C, as well as increases in alkyl C, are followed by decreases in microaggregate percentage. It is likely due to the presence of grasses in this area, leading to a high amount of thin roots, in close contact with the soil, and an intense biological activity in the rhizosphere. Mucilage (mostly polysaccharides), produced *in situ* by roots or organisms in this zone, effectively act as aggregators (Oades, 1984). For cerrado clayey Oxisols Neufeldt et al. (1999) affirmed that aggregation is preferentially promoted by bonding of mineral particles with polysaccharides and electrostatic forces between metals and negatively charged organic matter and kaolinite. They indicate the reduction in polysaccharides as one of the greatest disaggregating agents for such soils.

4.3.2 Biological attributes (microbial biomass C)

Microbial biomass C responds rapidly to alterations in SOM levels, indicating its degradation or aggradation in a short-term period (Sparling, 1992). When in favourable conditions, SOM turnover is mainly controlled by the size and activity of the microbial biomass (Martens, 1995). Substitution of grassy cerrado by riparian species seems to have a negative effect on MBC. The much higher MBC under cerrado is in agreement with the important role that grass roots system plays in soil activity, by supplying organic material (dead roots) and exuding mucilages. Fernandes et al. (1997) compared MBC contents in natural forest and open cerrado in the surrounding areas of the Itutinga/Camargos reservoirs. They found higher MBC in forest, but higher MBC/TOC in open cerrado. This indicated more labile SOM under cerrado, which was related to the presence of grasses in the later area, during the sampling period, exercising a "rhizospheric effect". Microbial biomass can represent 1 to 4% of TOC (Jenkinson & Ladd, 1981). In both areas, MBC/TOC is comprised in this range. Although it was not affected by conversion, its value is rather higher in cerrado, likely influenced by the higher MBC content under this cover. Comparing different land uses, Moreira et al. (1999) found higher MBC values in pasture (0.32 g kg^{-1}) than in agroforestry systems (0.21 g kg^{-1}). According to the first author (personal communication), planted riparian forest, eight years after planting, can be considered closer to the agroforestry systems than to a natural forest.

Decrease in MBC under forest indicates that it is a sensitive parameter, showing to be affected by decreases in carbon content, since C stocks for bulk soil were reduced with conversion (Chapter 2) due to the decrease in the stocks of the heavy fraction. In cerrado, increases in light-fraction C promote increases in MBC, probably due to the fact that increases in C content in this fraction, which is much less decomposed and similar to the litter material, could mean greater supply of carbon for the microorganism's community. In forest, MBC is not linked to light fraction C, but to the heavy one. In this area C contents and stocks were higher in light fraction (Chapter 2). It appears that, since carbon is well supplied by the less decomposed fraction, increases in the heavy one could mean more efficient decomposition, and hence, improvement in microbial activity.

As microbial biomass is an active component of soil, it can be involved in nutrient transformations and storage, acting as nutrient reservoir or source. In soils under nutritionally poor vegetation, it will work as reservoir. In this case, the amount of nutrients supplied via biomass cycling is lower than that one entering the system. Nevertheless, under the same soil, but covered by richer vegetation, it will act as catalyst or source. Thus, the supply of nutrients via biomass cycling will be equal (if catalyst) or higher (if source) than the one entering the system (Gama-Rodrigues, 1999). In this sense, higher MBC in cerrado does not represent gain of nutrients, since its litter is poorer in nutrients than the forest one.

4.3.3 Chemical attributes

The original area presents very low fertility, being characterised by high acidity and low nutrient availability. In general, cerrado vegetation is known to develop in such conditions (low fertility and approximately six months of dry season), covering large area of Brazilian Oxisols. In order to establish the riparian forest in 1992, it was necessary to apply fertilisers to provide the minimum conditions for seedlings development. We consider that such fertilisation was responsible for most of the positive changes in chemical attributes. This previous fertilisation and probably, a more efficient nutrient cycling by forest trees, lead to the addition of a nutritionally richer litter in forest. The decomposition and mineralization of this material has contributed to the maintenance of the forest trees.

Through improvement of nutrient contents, there were positive effects on bases sum, base saturation and effective CEC. The first two parameters allow inferring about the exchange complex. Parameters as Al saturation and base saturation are important as indexes of cation availability in soils that are naturally more extensively leached (Schoenholtz et al., 2000). Effective CEC is more realistic than potential CEC, since it considers only the exchangeable cations Al^{+3}, Ca^{+2}, Mg^{+2} and K^{+}, while the later includes H^{+}, corresponding to the soil total negative charges. In both areas, increases in TOC were related to decreases of soil acidity. This is an indirect effect of improving base contents (increases in base contents are followed by decreases in Al saturation). In addition, Al can form complexes with organic acids, which are products of the metabolism of roots or rhizospheric microorganisms. As for the pH, changes can be promoted by the exudation of H^{+} or OH^{-} by vegetation and microorganisms, in order to keep the cells electrochemical balance (Marschner, 1986).

Increases in heavy-fraction C are correlated to increases in nutrient contents in cerrado and forest, and to decreases of Al content in forest. It seems to be a secondary effect of the decomposition process. Relationships between carbon types, detected by CPMAS ^{13}C NMR in the extracted organic matter, and chemical attributes are also an indirect effect of the decomposition: while O-alkyl components are degraded (and aromatic and alkyl C are "concentrated"), acidity diminishes and nutrient availability increases. A probable explanation is that during the decomposition/humification, there is a positive effect on the CEC due to the presence of more humified material, and therefore, richer in charges.

5 CONCLUSIONS

Conversion of cerrado into riparian forest has changed soil chemical attributes by improving soil fertility. However, such change was unleashed by the previous fertilisation of the soil in order to establish the riparian species. The maintenance of the tree growth, even without further addition of fertilisers, has been a result of an effective nutrient cycling via addition/decomposition of the forest litter. As for the other soil attributes, during the time comprised in this work, there was a reduction in microbial biomass C and practically no effect on the physical ones. Moreover, the high aggregate stability for both cerrado and forest suggests protection against soil losses by erosion.

According to our hypothesis, not only differences in the nutritional composition of the litters, but also in SOM characteristics, could affect some soil attributes, impacting the ability of the soil in maintaining vegetation and behaving within the environment. Although we had previously found differences in SOM chemical composition between cerrado and forest, and in addition, there were relationships between SOM characteristics and several soil attributes for both areas, there were no consistent changes in soil conditions that could be caused by the vegetation conversion by itself. Both soils (in different ways) are sustainable, in the sense that they are able to keep the vegetation growth, with no damages to the surrounding environment. As for the recovery of the riparian forest form and function, in a long term the forestation might bring about the total re-composition of the lakeshores, making possible to restore the biodiversity in the future.

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FINAL CONSIDERATIONS

This research showed that even in a relatively short time (eigth years), the plantation of riparian vegetation on soils originaly under grassy cerrado promoted important alterations in soil organic matter dynamics and chemical composition. We hypothesised that those changes would occur based on the dynamic process of organic material decomposition in tropical conditions. Each single study on SOM in such conditions is important for elucidating its behavior, since most of the works on soil organic fraction are carried out in temperate climate, and especially in Brazil, soil science has focussed mainly on the mineral fraction.

Considering the results of this research as a whole, the establishment of the riparian forest has not effectively improved soil sustainability. The soil under cerrado (standard) is also capable to maintain the vegetation growth, presenting a good carbon storage (addition by root system), and furthermore, high aggregate stability and microbial biomass C. Although in the planted forest, the addition of organic material on soil surface is large, in the cerrado area the predominance of grassy vegetation also promotes a large C addition by its root system. High presence of thin roots in close contact with soil leads to an efficient decomposition process, transferring much C to the more decomposed fraction of SOM and contributing to higher C stocks under cerrado vegetation. In addition, in the later area, more easily degradable C compounds, such as polysaccharides compose the organic material added to the soil. Conversely, the forest litter originates a more hydrophobic, richer in aromatic compounds, and poorer in carbohydrates-like compounds SOM. Much C remains in the less decomposed fraction of SOM in forest. Nevertheless, as the forest is quite young, it is likely that in a long-term its soil carbon storage can be considerably improved by the above-ground biomass addition. As for C storage in vegetal biomass, obviously the forest stocks much more carbon.

The only positive effect of the forest plantation, in terms of soil attributes, was the improvement of soil fertility. Nevertheless, this change was mainly due to the fertilisation done during the planting. An additional effect is the nutrient cycling via decomposition/mineralization of the organic material, which is quite efficient in the forest (no more fertilisers were added after 1992).

Regarding environmental sustainability, as the planted forest showed to be auto sustainable, we may expect the complete re-composition of the lakeshores with time. The future benefits of it would be the recovery of both form and function in such areas, contributing to the preservation of the riparian flora and fauna, and restoration of the environmental scenery. Brazilian forestry laws ensure the preservation/re-establishment of riparian forests. However, the reduction of the preserved margins (in length) by changing the current code has been recently proposed by some politicians and widely discussed. In order to support the maintenance of the current code and its compliance, the scientific community plays an important role by developing knowledge on reforestation and divulging its suitability.