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Characterization by solid-state CPMAS ^{13}C NMR spectroscopy of decomposing plant residues in conventional and no-tillage systems in Central Brazil

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ABSTRACT

The Savanna region of Central Brazil is currently the most important area for grain production in the country but intensive agricultural activities are related to high losses of soil organic carbon. No-tillage systems were introduced in the mid 1980's but the use of cover plants in no-tillage systems is poorly studied and there is a demand for selection of suitable species to improve soil organic carbon. This study characterizes the chemical composition of decomposing plant residues of different cover plants (*Crotalaria juncea*, *Canavalia brasiliensis*, *Cajanus cajan*, *Mucuna pruriens*, *Helianthus annuus*, *Pennisetum glaucum*, *Raphanus sativus* and natural fallow, as a control). Cover plants were used in rotation with maize, under conventional and no-tillage systems. Decomposition rates were estimated using litter bags and residues of *C. juncea*, *C. brasiliensis*, *M. pruriens* and *R. sativus* were analyzed by CPMAS ^{13}C NMR. The highest decomposition rates were found for *C. brasiliensis* and *C. juncea*, while the lowest for *M. pruriens*, *C. cajan* and *P. glaucum*. *C. cajan* presented the lowest content of polysaccharides and along with *M. pruriens*, the highest percentage of aromatic C, reflecting the slow decomposition of highly lignified material. The residues of these two species also presented high hydrophobicity, as a consequence of the presence of aromatic groups. Incorporation of plant residues accelerated the decomposition in comparison to no-tillage system. *C. cajan*, *P. glaucum* and *M. pruriens* are more appropriate to increase soil cover due to lower decomposition rates while *C. brasiliensis*, *R. sativus* and *H. annus*, which presented higher decomposition rates, are indicated for an improvement of nutrient availability.

1. Introduction

Savannas of Central Brazil, locally named Cerrado, occupied originally approximately 200 million hectares. Since the 1970's the region has been the focus of intense agricultural expansion, and it is estimated that more than 50% of this area has lost its original vegetation, mainly through conversion to pastures and croplands (Klink and Machado, 2005). Currently, the Cerrado is the most important region for beef and grain production in Brazil and a potential region for expansion of crops related to bioenergy. The regional climate is tropical and seasonal, with a pronounced dry season from May to September. The dominant soils are dystrophic Oxisols, and conventional agricultural practices have led to erosion with losses of organic matter and nutrients (Silva et al., 1994; Mielniczuk, 1999; Bayer et al., 2001). No-tillage systems were introduced to reduce soil losses but soil and climate conditions in the Cerrado do not favor the establishment and maintenance of cover crops and mulch during the long dry season. Modeling simulations for the Cerrado region indicated that soil C and N contents under soybean monoculture with bare fallow decline approximately 30% after 30 years of conversion to agricultural land, even under no-tillage. An yearly C input of about 8.5 Mg C ha^{-1} year^{-1} would be necessary to maintain the native soil C levels. The C input under the soybean-fallow system (assessed to be about 4.2 Mg C ha^{-1} year^{-1}) was clearly insufficient to sustain the original levels of soil C. Simulated soil C and N stocks for cropping systems with two crops per year were comparable to those under native vegetation (Bustamante et al., 2006).

In this sense, cover plants with low decomposability are an alternative for no-tillage systems in the Cerrado region. The decomposition of plant residues involves initial loss of carbohydrates (cellulose and hemicellulose), followed by the slow

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transformation of aromatic structures of the lignin molecules and, finally, of highly recalcitrant carbon (alkyls) (Kögel-Knaber, 2000).

In general, the main differences in the chemical composition of plant residues are associated with differences in signal intensities of the alkyl and *O*-alkyl regions (Alcântara et al., 2004; Mahieu et al., 1999). The relative amount of alkyl-C increases during the decomposition process, mainly in the initial phase, while the amount of *O*-alkyl decreases (Golchin et al., 1995; Gregorich et al., 1996; Hopkins et al., 1997). Considering the influence of carbon compounds on the decomposition process, Baldock et al. (1997) suggested the ratio between alkyls and *O*-alkyls as an index of decomposition dynamics. In addition, other attributes of organic groups can be used, such as the aromaticity ratio (Hatcher et al., 1981) and the hydrophobicity ratio. These ratios have been applied in studies employing solid-state nuclear magnetic resonance (NMR) of ^{13}C with cross-polarization (CP) and magic angle spinning (MAS) (CPMAS ^{13}C NMR) to complement the information of the chemical composition of plant material and soil organic matter (Alcântara et al., 2004).

Studies involving characterization of plant residues and their decomposition are scarce for the Cerrado region. Thus, the objectives of this work were: (1) determine the decomposition rates of residues from different species of cover plants, incorporated or not (no-tillage) to the soil, (2) characterize the chemical composition of cover plant species employing CPMAS ^{13}C NMR, and (3) relate decomposition rates and chemical composition.

2. Materials and methods

2.1. Study area and experimental design

The experiment was conducted at Embrapa Cerrados, Planaltina, Federal District (S 15°36′37.5″ and W 47°44′36.8″), central region of Brazil. The area was cultivated during 6 years with maize, in rotation with cover plants planted at the end of the rainy season, after harvesting the previous maize crop. The soil is classified as Red-Yellow Latosol (Brazilian Soil Classification, Embrapa, 1999) or typic Acrustox (Soil Survey Staff, 2006). Texture and chemical characterization of the soil are presented in Table 1. The climate is Aw (tropical with rainy summer) according to the classification of Köppen. During the study period monthly precipitation ranged from null (July 2002) to 252 mm (January 2003). The monthly mean temperature oscillated between 19 °C (June 2003) and 27 °C (March 2003) (Fig. 1).

At the beginning of the experiment (January 1997), the area was fertilized with 180 kg ha^{-1} of P_2O_5, as single superphosphate, 60 kg ha^{-1} of K_2O, as potassium chloride, and 50 kg ha^{-1} of micronutrient fertilizer (7% of Zn, 2.5% of Bo, 1% of Cu, 4% of Fe, 4%

Table 1
Soil physical and chemical characteristics (mean for $n = 20$ samples) for the 0–20 cm depth of a Typic Acrustox in the Cerrado region of Brazil near Brasilia

Soil characteristics	Mean
Clay (g kg^{-1})	513
Silt (g kg^{-1})	186
Sand (g kg^{-1})	301
$pH_{(H_2O)}$	6.2
Organic matter (g kg^{-1})	23.6
Al (cmol$_c$ kg^{-1})	0.01
Titratable acidity at pH 7.0 (H + Al) (cmol$_c$ kg^{-1})	3.34
$Ca^{2+} + Mg^{2+} + K^+$ (cmol$_c$ kg^{-1})	3.4
$Ca^{2+} + Mg^{2+} + K^+$ + (H + Al) (cmol$_c$ kg^{-1})	6.8
Base saturation at pH 7.0 (%)	50
P (Mehlich-1 extractant) (mg kg^{-1})	3.4

of Mn, 0.1% of Mo and 0.1% of Co). Before sowing the maize, 500 kg ha^{-1} of $CaSO_4$ were applied to the area. The experimental design was randomized complete block in a split plot arrangement with experimental units replicated three times. Cover plants were sown into whole plots (12 m × 30 m) at the end of each rainy season following a maize crop in both conventional tillage (with incorporation of plant residues employing disc plough and harrow) and no-tillage subplots (12 m × 15 m). Plots and subplots were separated by 1-m border. Fertilizers were incorporated with the plant residues before maize sowing using a disk harrow in subplots under tillage or applied on the soil surface under no-tillage.

The following cover plant species were used in rotation with maize: *Crotalaria juncea* L. (Leguminosae), *Canavalia brasiliensis* M. and Benth (Leguminosae), *Cajanus cajan* (L.) Millsp cv. Caqui (Leguminosae), *Mucuna pruriens* (L.) DC (Leguminosae), *Helianthus annuus* L. (Asteracee), *Pennisetum glaucum* (L.) R. Brown (Poaceae) and *Raphanus sativus* L (Brassicaceae). The control consisted of natural fallow. Cover crops were planted in March (end of rainy season). Seeds were distributed (3 cm depth) in rows (spacing 0.5 m) using a no-tillage seeder. Plants per meter varied between 8 m^{-1} (*M. pruriens*) and 40 m^{-1} (*R. sativus*) (Carvalho and Amabile, 2006).

The cover plants were cut when flowering reached approximately 50% and remained over the soil surface until sowing the maize in the beginning of the rainy season. *M. pruriens*, *P. glaucum* and *C. brasiliensis* presented regrowth. In the no-tillage subplots, 3.0 L ha^{-1} of glyphosate was applied to eliminate weeds and individuals of the cover species before sowing of maize. In the plots with *C. brasiliensis*, a mixture of 1.5 L ha^{-1} of glyphosate + 1.5 L ha^{-1} of 2.4-D (2-4 dichlorophenoxyacetic acid) was applied to eliminate weeds and cover crop plants before sowing maize. In the tilled subplots plant residues were incorporated with a disc plough (20 cm depth). Maize was sown

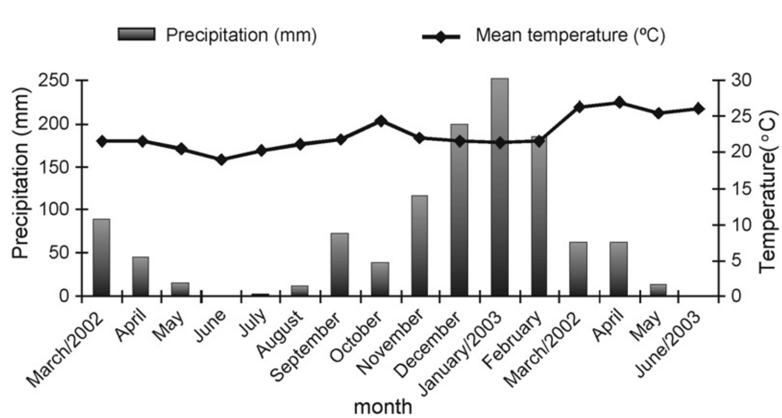

Fig. 1. Monthly rainfall and air temperature from March 2002 to June 2003, measured at Embrapa Cerrados Meteorological Station (Planaltina, Brazil).