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Pairwise comparison of soil organic particle-size distributions in native savannas and Eucalyptus plantations in Congo

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Abstract

Conversion of native vegetation into fast-growing tree plantations is known to affect soil organic matter (SOM): soil carbon (C) and nitrogen (N) content and their distribution in particle-size fractions can be modified in various ways depending on numerous factors, such as soil properties, SOM levels prior to conversion, climatic conditions, silvicultural practices and fire occurrence. Since 1978, 43,000 ha of clonal eucalyptus plantations have been established on sandy coastal plains under savannas near Pointe-Noire, Congo. We investigated the effects of afforestation on topsoil (0–10 cm) C and N through the analysis of their distribution in particle-size fractions using a pairwise experimental design that compared adjacent savannas and plantations. The studied plantations were of different ages (2–30-year-old stands) and differently affected by accidental fires. No significant difference in total topsoil C, N or C/N was observed between young plantations and savanna. In old plantations that had not been affected by fire, total topsoil C content was twice as high as in savanna ($p = 0.0016$), on average, mostly involving fractions > 50 μm. By contrast, total topsoil N did not differ significantly at these sites. In old plantations affected by fire, total topsoil C content did not differ significantly from that in savanna, but total topsoil N was 26 % lower in plantations than in savanna ($p = 0.0063$), on average, and the decrease affected fractions < 200 μm especially. Whatever the fire occurrence, total topsoil C/N was higher in old plantations than in savanna, in fractions > 20 μm especially.

Keywords: Soil organic matter; Particle-size fractionation; Savanna; Eucalyptus; Fire

1. Introduction

Soil organic matter (SOM) is an important determinant of soil fertility and productivity, and is a key factor in the global carbon cycle. Indeed, SOM affects soil chemical, physical, and biological processes, and thus fulfils a wide range of functions. It is an ion exchange material, it promotes the formation of soil aggregates and thereby influences water infiltration, water-holding capacity and root penetration, and it is a source of energy and nutrients for many soil organisms (Fernandes et al., 1997; Craswell and Lefroy, 2001). Moreover, SOM is an essential reservoir of carbon (C), including a larger C pool than the combined atmosphere and vegetation pools, and is thus a critical component of the global C balance (Lal et al., 1995). In fast-growing tree plantations prone to nutrient deficiencies (Bouillet et al., 2004), the role of SOM is even more important as it represents a major nitrogen (N) source through litterfall and decomposition cycles (Nzila et al., 2002). Particle-size fractionation has proven to be a valuable tool in studies about SOM dynamics and the effects of land use change (Christensen, 2001). It separates SOM pools that are in different states of decay and have different decomposition rates, fine fractions being generally more decomposed and more stable than coarser ones (Balesdent, 1996).

Land use changes (e.g. conversion of native vegetation into cropland or plantations) strongly affect SOM. Studying conversion of pasture into forest, Paul et al. (2002) outlined

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the following general pattern: an initial decrease in C and N stocks due to the decomposition of pasture-originating SOM, followed by a gradual increase as the forest grows and returns residues to the soil. Paul et al. (2003) ascribed the strong sensitivity of these dynamics (decrease then increase) to numerous factors, such as soil properties, SOM level prior to conversion, silvicultural practices and climatic conditions. Among these factors, fire occurrences appear to have various effects on the fate of soil C. Bauhus et al. (2002) showed that burning slashes in a eucalyptus forest strongly increased topsoil C as a result of charcoal inputs. However, in a meta-analysis covering many forest and climate types, Johnson and Curtis (2001) observed either positive or negative effects of fire on topsoil C. This is not only true for total SOM but also for SOM in particle-size fractions. In sub-humid Zimbabwean savannas, Bird et al. (2000) observed that the decrease in soil C stocks upon regular fires resulted from a strong decrease in C content in coarse particle-size fractions, whereas C content increased in fine fractions. Fire therefore appears to change not only the soil C stocks but also its size distribution and quality.

In south-western Congo-Brazzaville, near Pointe Noire, 43,000 ha of native savannas have been afforested with eucalyptus since 1978. Because of the short rotations, there are concerns about the sustainability of these plantations and a comprehensive study on the whole biogeochemical cycle started 10 years ago. While nutrient cycling has been well documented, few studies have been devoted to SOM despite its importance in such ecosystems (Nzila et al., 2002). Annual savanna burning is a traditional practice in this area (Deleporte et al., 2004) and propagation of fire often reaches the nearby plantations. A local study showed that after 19 years, soil organic C content at 0–5 cm increased from 6.5 to 8.8 g kg^{-1} when savanna was afforested with eucalyptus (Trouvé et al., 1996). Yet, the effect of fire occurrence on soil C or its distribution within the different particle-size fractions of the soil was not fully assessed. The objective of the present study was therefore to compare, through a pairwise experimental design, the distribution and the quantity of topsoil (0–10 cm) C and N in particle-size fractions in savanna and eucalyptus plantations, as affected by plantation age and fire occurrence.

2. Material and method

2.1. Geographical context

This study was carried out in the Congolese eucalyptus clonal plantations that cover a strip of about thirty by seventy kilometres along the Atlantic coast around Pointe-Noire (04°07′S, 12°00′E). Climate is characterised by the alternation of a dry season (from May to September) and a wet season. Temperature is nearly constant over the year and averages 25 °C. Mean annual rainfall is about 1200 mm with great inter-annual variability (variation coefficient is 30% over a 40-year period). The geological substratum is composed of thick sandy Plio-Pleistocene formations (Jamet, 1975). According to the FAO classification (FAO-ISRIC-ISSS, 1998), the soils near Pointe-Noire are ferralic arenosols, characterised by high sand content and low clay and silt contents (respectively 80–90%, 5–10% and 2–2.5%). In addition, they have limited nutrient availability, a very low level of exchangeable cations and a low level of organic matter and cation exchange capacity (Nzila et al., 2002).

2.2. Sites under study

The native vegetation is savanna dominated by an herbaceous layer of *Loudetia arundinacea* (Hoschst) and *Hyparrhenia diplandra* (Hack). For the past 30 years, this savanna has been progressively planted with Eucalyptus clones, the most commonly used being clone PF1, which originates from a crossing between *E. alba* Reinw. Ex Blume (mother tree) and a poorly identified hybrid (father tree) that probably includes *E. grandis*, *E. robusta*, *E. urophylla* and *E. botryoïdes* (Bouvet, 1995). Tree density is between 625 and 800 stems $ha^{-1}$and no tillage is done prior to replantation. Native grasses are eliminated with herbicide application and trees starter-fertilized 2 weeks after planting. Rotation length is from 7 to 10 years. Two management regimes are used on the industrial plantation: high forest (succession of plantation, harvest and re-plantation after each rotation) and coppice (plantation, harvested after a first rotation and re-grown as a coppice once or twice). For both regimes, out of three lines, one is used for circulation of engines and the slash is taken away (circulation line), one is used for storing the slash of the circulation line (double slash line) and one has a standard slash level (normal line). Five sites, each including a PF1 eucalyptus stand and an adjacent savanna (at least 1 ha each), were chosen throughout the plantation area. The plantations from the five sites differed in age, silvicultural practices and fire occurrence. One was a young stand planted for the first time in 2001, two were old (first plantation in 1983 and 1984) and had undergone fires since their last harvest and two were old and had not been affected by fires (Table 1). Due to social habits (mainly hunting as there is no grazing), the savanna is traditionally burnt every year at the

Table 1
Characteristics of the studied plantations

Site	Group	Replicates	Management	Plant.	Harv.	Last harvest	Fires
Loubou 1	Old burnt	3	Coppice	1983	2	1995	2002/2003
Loubou 2	Old unburnt	3	Coppice	1983	1	1992	–
Loubou 3	Old unburnt	2	High forest	1983	1	1992	–
Kondi	Young	3	High forest	2001	0	–	–
Mengo	Old burnt	3	High forest	1984	2	1997	2001/2002

Plant. is the date of first eucalyptus plantation, Harv. the number of harvests, Last harvest the date of last harvest and Fires the years when fire occurred.

end of the dry season. For the studied eucalyptus stands, data on fire occurrence were recorded by the plantation manager. These fires are always accidental and burn the entire superficial litter layer.

2.3. Soil sampling

In May 2003, three composite soil samples were collected at 0–10 cm depth in a 1 ha area of every eucalyptus stand (except for site Loubou 3 where only two samples were taken in the eucalyptus stand) and adjacent savanna. Each of these composite samples resulted from the mixing of elementary samples collected with a 1 dm^3 cylinder on the sides of a 1-m^2 wide pit. The three pits were situated in a 100 m × 100 m square at a 50 m distance from each other. They were located in the middle of inter-rows (on the normal slash lines) in the eucalyptus plantations and randomly in the savannas. The distance between a eucalyptus stand and the adjacent savanna was around 150 m in order to avoid eucalyptus root occurrence in the savannas.

2.4. Soil analyses

The 29 collected soil samples were air-dried and manually sieved through a 2 mm mesh. The particle-size fractionation of soil organic matter was carried out on 20 g soil samples, using a protocol adapted from Gavinelli et al. (1995). Each sample was pre-soaked overnight at 4 °C in 200 mL deionised water with 0.4 g sodium hexametaphosphate. It was then shaken with ten agate balls (1 cm diameter) in a rotary shaker for 1 h (45 rpm). Next, the soil suspension was wet-sieved through 200-, 50-, and 20- μm sieves, successively. After each sieving, the fraction remaining in the sieve was washed with water and the washing added to the suspension that had passed the screen. The three fractions 200–2000, 50–200 and 20–50 μm were oven-dried at 40 °C and weighed. The suspension < 20 μm was transferred to a 1-L glass cylinder, where water was added to bring the volume to 1 L. Then the cylinder was shaken by hand (30 end-over-end tumblings) and a 100-mL aliquot of the suspension was withdrawn immediately after, oven-dried at 40 °C, weighed, and referred to the cylinder volume. Carbon and nitrogen concentrations were determined on finely ground (< 200 μm) oven-dried (40 °C) aliquots of whole soils and fractions by dry combustion (145 analyses), using an Elemental Analyser CHN Fisons/Carlo Erba NA 2000 (Milano, Italy). In the absence of carbonates, all C was assumed to be organic. These concentrations are given in mg g^{-1} of dry matter. In order to compare fractions originating from different samples, we calculated C amounts as follows:

$$C_{\text{amount}}(\text{Fraction}_i) = \frac{C_{\text{concentration}}(\text{Fraction}_i) \cdot \text{Mass}(\text{Fraction}_i)}{\text{Mass}(\text{Total soil})}$$

Fraction N amounts were similarly calculated. C (and N) amounts are therefore given in mg C g^{-1} soil (respectively mg N g^{-1} soil), whereas C (and N) concentrations are expressed in mg C g^{-1} fraction (respectively mg N g^{-1} fraction). Concentrations are used to compare different fractions within a sample, and amounts to compare a particular fraction between all samples.

2.5. Statistical analyses

Statistical analyses were performed with SAS software (SAS, 1989). Biases in weight, C and N yields (comparison between total soil and sum of soil fractions) were checked using a simultaneous F-test as recommended by Mayer and Butler (1993). Statistical comparisons were performed by means of a two-step procedure: first, a pairwise comparison was performed between savanna and eucalyptus. It was carried out site by site on fraction C and N concentrations and amounts, using a linear model (proc GLM). For this first step, a nested model was used (site effect, and eucalyptus/savanna effect within sites) because eucalyptus stands were not strictly comparable from one site to another, due to differences in clones and silvicultural regimes. Results of these comparisons are given in Table 2. In a second stage, after grouping sites into young, old unburnt, old burnt and savanna, the group effect was tested on C and N (amount and concentrations) for every particle-size fraction, using the non-parametric dissymmetrical Mann and Whitney test (proc Npar1way).

3. Results

Concentrations and amounts of C and N in total soil and particle-size fractions are presented in Table 2, for each site separately (data regarding total soil are included in the lines denoted NF).

3.1. Total soil C and N contents

Total topsoil C and N showed great variability and considering all sites together, neither C nor N contents were significantly different between eucalyptus plantations and savannas (7.8 mg C g^{-1} versus 6.4 mg C g^{-1}, and 0.34 mg N g^{-1} versus 0.37 mg N g^{-1}). Nevertheless, old plantations that had not been affected by fires had significantly higher C content than adjacent savannas (10.9 mg C g^{-1} versus 5.5 mg C g^{-1} in Loubou 2 and Loubou 3). By contrast, in either young plantations or plantations that were affected by fires, soil C did not differ significantly from that in adjacent savannas (6.0 mg C g^{-1} versus 5.8 mg C g^{-1}), except at Mengo where it was significantly higher in the savanna than in the plantation (9.3 mg C g^{-1} versus 7.1 mg C g^{-1}). Old plantations that underwent regular fires (Loubou 1 and Mengo) also had lower soil N content than the adjacent savannas (Table 2). Elsewhere, soil N was greater in plantation (young or unburnt) than in adjacent savanna, but the difference was not significant (0.38 mg N g^{-1} versus 0.34 mg N g^{-1}). The C/N ratio of the total soil was significantly higher for eucalyptus than for savanna over all the studied sites (22.6 versus 17.1, on average). Site by site however, the difference was significant for Loubou 1 only.

Table 2
Pairwise comparisons: means and standard deviations of weight, C and N concentrations and amounts and C/N ratio of topsoil particle-size fractions (200–2000, 50–200, 20–50, 0–20 μm) and of the total soil (NF, non-fractionated soil)

	Site (group)									
	Loubou 1 (old burnt)		Loubou 2 (old unburnt)		Loubou 3 (old unburnt)		Kondi (young)		Mengo (old burnt)	
	Eucalyptus	Savanna	Eucalyptus	Savanna	Eucalyptus	Savanna	Eucalyptus	Savanna	Eucalyptus	Savanna
Particle-size distribution										
200–2000	**63.1 ± 9.7***	**49.8 ± 5.6**	**62.1 ± 0.6***	**57.1 ± 3.5**	54.4 ± 1.5	53.6 ± 5.4	**26.4 ± 1.1**	**30.8 ± 0.6***	64.6 ± 2.1	61.9 ± 2.2
50–200	**32.8 ± 9.3***	**43.2 ± 5.4**	34.2 ± 1.1	36.6 ± 4.0	40 ± 1.6	40.9 ± 4.4	**66.4 ± 0.6***	**63.6 ± 1.0**	**28.2 ± 1.7**	**31.2 ± 2.2***
20–50	1.1 ± 0.1	1.4 ± 0.4	**0.8 ± 0.1**	**1.7 ± 0.4***	1.0 ± 0.1	1.3 ± 0.3	1.8 ± 0.3	1.6 ± 0.3	**1.2 ± 0.2**	**1.7 ± 0.2***
0–20	3.3 ± 0.5	5.0 ± 2.8	3.9 ± 0.6	5.2 ± 0.7	4.5 ± 0.9	5.0 ± 1.3	5.6 ± 0.9	4.2 ± 0.7	5.6 ± 0.6	5.0 ± 0.2
Carbon concentration										
200–2000	2.0 ± 0.4	2.3 ± 0.4	**7.4 ± 1.8***	**1.5 ± 0.9**	4.1 ± 0.0	1.4 ± 0.4	**1.5 ± 0.4**	**1.9 ± 0.4***	1.7 ± 0.4	1.9 ± 0.2
50–200	5.7 ± 2.2	4.0 ± 1.0	**11.8 ± 2.7***	**4.4 ± 1.5**	9.3 ± 2.7	4.1 ± 1.7	2.8 ± 0.7	3.5 ± 0.3	**6.4 ± 2.5**	**8.2 ± 1.1***
20–50	**43.3 ± 6.4****	**27.8 ± 8.0**	**79.5 ± 3.0***	**46.9 ± 4.8**	76.5 ± 19.9	50.3 ± 15.2	34.3 ± 4.7	37.4 ± 2.1	50.1 ± 3.5	48.8 ± 3.6
0–20	**47.8 ± 11.7***	**34.3 ± 6.0**	38.1 ± 8.1	52.8 ± 9.1	51.4 ± 5.1	49.7 ± 8.9	**50.3 ± 5.6***	**44.4 ± 1.3**	52.5 ± 7.8	48.4 ± 1.5
Carbon amount										
200–2000	1.3 ± 0.3	1.2 ± 0.2	**4.6 ± 1.1***	**0.8 ± 0.6**	2.2 ± 0.1	0.8 ± 0.3	**0.4 ± 0.1**	**0.6 ± 0.1***	1.1 ± 0.2	1.2 ± 0.1
50–200	1.7 ± 0.5	1.7 ± 0.6	**4.1 ± 0.9***	**1.6 ± 0.3**	3.7 ± 1.2	1.6 ± 0.5	1.8 ± 0.5	2.2 ± 0.2	**1.8 ± 0.8**	**2.6 ± 0.2***
20–50	0.5 ± 0.0	0.4 ± 0.1	0.6 ± 0.1	0.8 ± 0.1	0.7 ± 0.3	0.6 ± 0.2	0.6 ± 0.1	0.6 ± 0.1	**0.6 ± 0.1**	**0.8 ± 0.1***
0–20	1.6 ± 0.5	1.7 ± 1.1	**1.5 ± 0.2***	**2.7 ± 0.2**	2.4 ± 0.7	2.4 ± 0.5	**2.8 ± 0.2***	**1.9 ± 0.3**	2.9 ± 0.5	2.4 ± 0.1
NF	6.0 ± 1.1	5.9 ± 0.4	11.9 ± 3.2	5.3 ± 0.4	10.0 ± 1.5	5.7 ± 0.8	6.1 ± 0.3	5.7 ± 0.7	**7.1 ± 0.4**	**9.3 ± 0.8***
Nitrogen concentration										
200–2000	0.08 ± 0.02	0.10 ± 0.01	**0.27 ± 0.04***	**0.07 ± 0.02**	0.18 ± 0.03	0.07 ± 0.02	**0.08 ± 0.03**	**0.12 ± 0.02***	0.08 ± 0.03	0.10 ± 0.02
50–200	0.27 ± 0.15	0.25 ± 0.07	0.46 ± 0.09	0.31 ± 0.13	0.37 ± 0.14	0.26 ± 0.13	**0.21 ± 0.04**	**0.27 ± 0.02***	0.28 ± 0.08	0.52 ± 0.05
20–50	2.53 ± 0.51	1.93 ± 0.61	3.85 ± 0.50	3.21 ± 0.28	3.83 ± 0.93	3.64 ± 1.42	2.49 ± 0.25	2.76 ± 0.21	2.88 ± 0.18	3.04 ± 0.21
0–20	3.72 ± 0.75	3.13 ± 0.63	3.18 ± 0.63	5.16 ± 1.42	4.62 ± 0.75	4.18 ± 0.86	4.32 ± 0.39	4.12 ± 0.28	4.23 ± 0.72	3.60 ± 0.19
Nitrogen amount										
200–2000	0.05 ± 0.02	0.05 ± 0.01	**0.17 ± 0.02***	**0.04 ± 0.01**	0.10 ± 0.01	0.04 ± 0.02	**0.02 ± 0.01**	**0.04 ± 0.01***	0.05 ± 0.02	0.06 ± 0.01
50–200	0.08 ± 0.02	0.11 ± 0.04	0.16 ± 0.03	0.11 ± 0.03	0.15 ± 0.06	0.10 ± 0.04	0.14 ± 0.03	0.17 ± 0.01	0.08 ± 0.03	0.16 ± 0.01
20–50	0.03 ± 0.01	0.03 ± 0.01	**0.03 ± 0.01**	**0.05 ± 0.01***	0.04 ± 0.01	0.05 ± 0.02	0.05 ± 0.01	0.04 ± 0.01	0.03 ± 0.01	0.05 ± 0.01
0–20	0.12 ± 0.03	0.16 ± 0.10	**0.12 ± 0.02**	**0.26 ± 0.06***	0.21 ± 0.07	0.20 ± 0.02	**0.24 ± 0.02***	**0.17 ± 0.04**	0.24 ± 0.05	0.18 ± 0.01
NF	**0.27 ± 0.03**	**0.35 ± 0.01***	0.39 ± 0.07	0.32 ± 0.04	0.38 ± 0.09	0.33 ± 0.04	0.39 ± 0.02	0.36 ± 0.07	**0.34 ± 0.03**	**0.50 ± 0.03***
C/N										
200–2000	26.1 ± 3.5	23.2 ± 4.2	27.0 ± 2.8	21.3 ± 7.8	23.1 ± 3.7	19.7 ± 3.5	20.1 ± 5.4	16.5 ± 1.3	22.1 ± 4.7	19.1 ± 1.2
50–200	**22.8 ± 4.3****	**15.9 ± 1.6**	**25.5 ± 3.0***	**14.8 ± 1.5**	25.9 ± 2.6	16.7 ± 3.1	13.4 ± 0.9	13.0 ± 1.5	**22.3 ± 3.7***	**15.7 ± 0.6**
20–50	**17.3 ± 1.9***	**14.6 ± 1.0**	**20.9 ± 2.3***	**14.6 ± 0.4**	19.9 ± 0.3	14.4 ± 2.7	13.7 ± 0.5	13.6 ± 1.6	17.4 ± 1.7	16.1 ± 0.1
0–20	12.9 ± 1.6	11.0 ± 0.6	11.9 ± 0.4	10.5 ± 1.5	11.2 ± 0.7	12.0 ± 1.2	11.6 ± 0.3	10.8 ± 0.7	12.5 ± 1.5	13.5 ± 0.3
NF	**21.7 ± 1.5***	**17.1 ± 0.7**	29.9 ± 2.7	16.6 ± 0.8	26.3 ± 2.5	17.2 ± 0.7	15.8 ± 1.2	15.9 ± 1.5	21.0 ± 2.1	18.7 ± 1.7

Means are over three replicates except for the eucalyptus stand in Loubou 3 which has two. Particle-size distributions are in % of the total sample weight, concentrations in mg g^{-1} fractions and amounts in mg g^{-1} soil. Asterisks (*) indicate that the value differs significantly between the eucalyptus stand and the adjacent savanna (bold fonts).

3.2. Soil fractions

The cumulative yield of fraction weights ranged from 99.1 to 101.9%. The particle-size distribution of the studied top soils was dominated by sands (>50 μm), which accounted for 93% of the total soil weight. In general, the coarse sand fraction (>200 μm) was the largest, representing 50–65% of total soil, except for the Kondi site where the proportion of fine sands (50–200 μm) reached 64–66%. Soil content in clay plus fine silts (<20 μm) was low, between 3.3 and 5.6% on average. Soil content in coarse silts (20–50 μm) was even lower: 0.8–1.8% on average.

The cumulative yield of fraction carbon was 89.1% (±10.1 %). Fraction C concentrations (in mg C g^{-1} fraction) tended to increase when particle size decreased (Fig. 1a). The 200–2000, 50–200, and 20–50 μm fractions were significantly more concentrated in C in old plantations not affected by fires than elsewhere (savannas, young plantations and regularly burnt plantations). Carbon concentration in the 0–20 μm fraction was not significantly affected by vegetation cover or fire occurrence. Fraction C amounts (in mg C g^{-1}soil) generally ranged as follows: $0-20 \geq 50-200 \geq 200-2000 \geq 20-50$ μm (Fig. 1b). However, in old unburnt plantations, fraction C amounts tended to be the greatest in the 50–200 μm fraction and then in the 200–2000 μm fraction. Carbon amounts in the 200–2000 and 50–200 μm fractions were significantly greater in unburnt old plantations than elsewhere (3.4 mg C g^{-1}soil versus 0.9 mg C g^{-1} soil, on average, in the 200–2000 μm fraction, and 3.9 mg C g^{-1} soil versus 1.9 mg C g^{-1} soil, on average, in the 50–200 μm fraction). Carbon amount in the 200–2000 μm fraction was smaller in young plantations than elsewhere (0.4 mg C g^{-1} soil versus 1.5 mg C g^{-1} soil, on average).

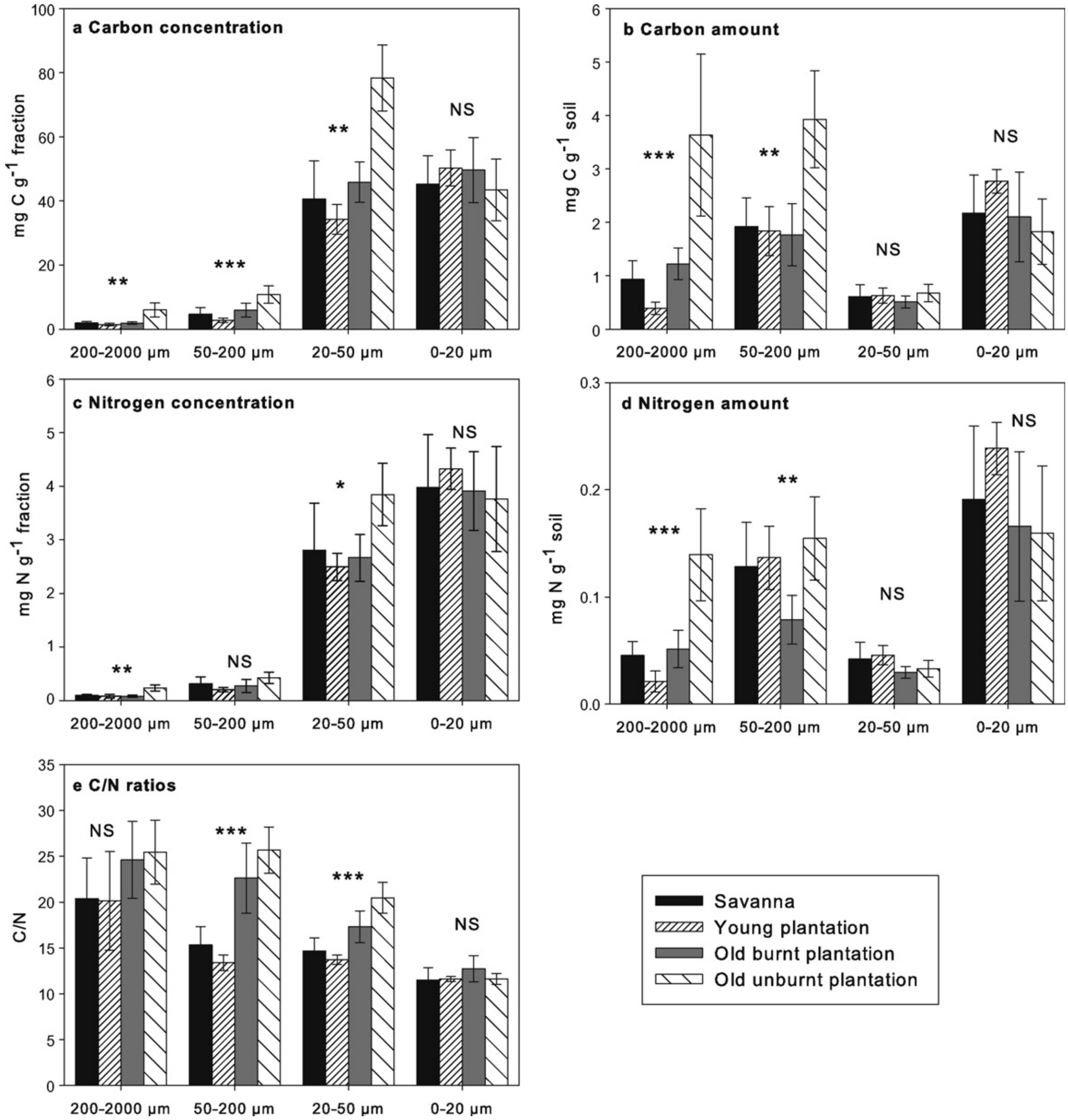

Fig. 1. Group effect: mean carbon concentration (a), carbon amount (b), nitrogen concentration (c), nitrogen amount (d) and C/N ratio (e) of the different particle-size fractions (error bars represent the standard deviations). For each fraction, stars indicate if the group effect is significant. Number of replicates per group: savanna ($n = 15$), young ($n = 3$), old burnt ($n = 6$) and old unburnt plantation ($n = 5$). NS stands for not significant.

The cumulative yield of fraction nitrogen was 112.0% (±17.7%). Fraction N concentration (in mg N g^{-1} fraction) also increased when particle size decreased (Fig. 1c). In the 200–2000 and 20–50 μm fractions, it was significantly higher in old unburnt plantations than elsewhere (0.22 mg N g^{-1} fraction versus 0.09 mg N g^{-1}fraction, on average, in the 200–2000 μm fraction and 3.84 mg N g^{-1} fraction versus 2.60 mg N g^{-1}fraction, on average, in the fraction 20–50 μm), otherwise fraction N concentrations were not significantly affected by vegetation cover or fire occurrence. On the whole, the rank of fraction N amounts (in mg N g^{-1} soil) was similar to that of fraction C amounts: $0{-}20 \geq 50{-}200 \geq 200{-}2000 \geq 20{-}50$ μm (Fig. 1d). Nitrogen amount in the 200–2000 μm fraction was significantly greater in unburnt old plantations than elsewhere (0.13 mg N g^{-1}versus 0.04 mg N g^{-1}, on average). N amount was smaller in the 50–200 μm fraction in regularly burnt old plantations than elsewhere (0.08 mg N g^{-1} versus 0.14 mg N g^{-1}, on average).

The C/N ratio tended to decrease with particle size (Fig. 1e). In the 200–2000, 50–200 and 20–50 μm fractions, it was higher in old plantations than elsewhere (though not significantly in the 200–2000 μm fraction). In these fractions, C/N did not differ significantly between savannas and young plantations on the one hand, and between unburnt and regularly burnt old plantations on the other. In the 0–20 μm fraction, C/N was not significantly affected by vegetation cover or fire occurrence.

4. Discussion and conclusion

In this study, when considering the whole data set, conversion of savanna into eucalyptus plantation significantly changed the C/N ratio, but not bulk soil C or N concentrations. However, despite the low number of replicates for some groups, significant effects for C and N were observed when considering groups. In old plantations where fire had never occurred, topsoil C content was significantly higher than in the adjacent savanna. In eucalyptus plantations where fire regularly occurred, topsoil C content was maintained but N content significantly decreased. In the young plantations, neither topsoil C nor N was significantly different from that in the adjacent savanna. These results are in agreement with the general pattern observed by Paul et al. (2003): no effect for relatively young stands (the initial decrease in SOM after 2 years must have been compensated for by eucalyptus litter inputs) and an increase after a certain time that can be strongly influenced by anthropic events, like fire occurrence. The high sensitivity of the effects of afforestation was previously mentioned by Polglase et al. (2000), Guo and Gifford (2002) and Paul et al. (2002) who showed in meta-analyses that effects of afforestation on soil C could either be positive, neutral or negative, depending on many factors. As far as conversion of savannas into tree plantations is concerned, opposite effects for afforestation can be found in the literature. In the Brazilian Cerrados, for instance, SOM contents in the superficial layer of a clayey and a sandy soil were respectively 13% higher and 16–33% lower in a eucalyptus plantation than in the native sub-humid bush savanna (Resck et al., 2000; Zinn et al., 2002). These authors stated that this was probably due to the low capacity of adsorption of soluble products from decomposition in soils with low clay content.

Land use prior to conversion (uncultivated savanna), soil texture (i.e. clay plus fine silts / sand ratio) and genetic material used for afforestation (full brothers of hybrid PF1) were the same for all the studied sites. Moreover, the soil was not tilled (either before or after plantation) and no slash was burnt at harvest. We therefore considered that the factors affecting the different levels of C and N in the soil were afforestation time, forest management and fire occurrence. It could be argued that, as burnt plantations are precisely those that had been harvested twice (Loubou 1 and Mengo), topsoil C decrease could be due to repeated harvests rather than fire occurrence. However, Epron et al. (2006) showed in a nearby stand that 1 year after clear-cutting, total C losses by heterotrophic respiration during the year were 32% lower than the initial C inputs from harvest residues left on the soil, suggesting that initial losses by mineralization had been compensated. Another study (Nouvellon, personal communication) additionally showed, for the plantation area under study, that soil disturbance prior to plantation or re-plantation had no significant effect on soil CO_2 efflux and soil C balance. It is therefore more likely that the low levels of soil C in the old burnt plantations were due to fire rather than to repeated harvests, especially as these stands had received around 20 years of litter input. As far as N is concerned it is less obvious that the observed changes were due to fire rather than exportation by harvest. Previous studies in these plantations Laclau et al. (2005) showed that soil N balance after one rotation had a 140 kg N ha^{-1} deficit. However, N volatilisation by burning might have also had an influence on this negative N balance, as suggested by Deleporte et al. (2004).

Cumulated yields of fraction weights were considered satisfactory (Gavinelli et al., 1995). The relatively low recoveries for C could be attributed, at least partly, to soluble fractions: Christensen (1992) reported that SOM dissolved during the particle size separation could account for more than 10% of total SOM. The excess observed for the cumulative yield of fraction N might come from the aliquot method used, which probably emphasized measurement uncertainties. However, when excluding five samples for which N concentration was very high in the 0–20 μm fraction, the recoveries fell to 107%, which lies within what can be found in the literature (Tchienkoua and Zech, 2004), albeit seldom.

In the sandy soils under study, C and N concentrations in particle-size fractions tended to increase with decreasing particle size. This could be attributed to the SOM dilution effect (Amelung et al., 1998): in coarse textured soils, SOM tends to be diluted in the coarse fractions and concentrated in the fine fractions. Considering that SOM existed in a size continuum, Zinn et al. (2007) suggested that the dilution effect resulted from the relatively constant distribution pattern of SOM between particle size fractions.

Particle-size distributions of C and N were also affected by afforestation time and occurrences of fire. We clearly showed that organic fractions most affected by conversion into plantation were coarse fractions (200–2000 μm, and to a lesser extent, 50–200 μm). This agrees with Feller and Beare (1997) who reported that, in coarse-textured soils, coarse fractions were the most affected by land use change. These authors also noticed that after land use change, the accumulation of new SOM in a given size fraction tended to decrease with particle size, whatever the soil texture. Eucalyptus litter has high tannin and soluble polyphenol contents that can inhibit nitrogen mineralization capacity and lignin degradation (Corbeels et al., 2002; Bernhard-Reversat and Schwartz, 1997). It might therefore be assumed that accumulation of eucalyptus-derived SOM accumulated in the coarsest compartments because of its low decomposability, possibly leading to little SOM transfer to the fine fractions.

Topsoil C and N in fine organic fractions (0–20 and 20–50 μm) were not significantly affected by plantation age and fire occurrence, and therefore by land-use change and land-use. According to the isotopic signature of topsoil (0–5 cm) fraction C in a neighbouring eucalyptus stand of the same age, SOM in the clay fractions (0–2 μm) originated from both the plantation and the former savanna (Trouvé et al., 1994). This suggested that the apparent stability of C and N in fractions < 50 μm actually resulted from the mineralization of savanna-originating fine SOM and its compensation through the humification of plantation-originating coarser SOM.

As a conclusion, a shift in SOM happened after a certain afforestation time and this change was highly dependent on local conditions (fire occurrence) and silvicultural practices (stand age, number of harvests). It mainly concerned the coarsest particle-size fractions of the soil as a result of a possible decomposition inhibition and, in any case, led to an increase in the soil C/N ratio. In these fast-growing plantations where SOM plays a major role in soil fertility, prevention of fire is therefore an essential issue in terms of C and N budget. In terms of plantation sustainability, however, fire prevention should be associated with silvicultural practices that counterbalance the relative plantation-induced N depletion, either by soil fertilization or association with legume species, as suggested by Bouillet et al. (2004).

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