Effect of fallowing on carbon sequestration in a humid tropical sandy soil (Mangodara, Burkina Faso)

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Keywords: fallow, carbon, nitrogen, mineralization, soil particles

Abstract

Although many studies focused on the effect of fallow on soil fertility, the process of soil organic matter recovery following cessation of cultivation remains little understood. This paper examines the relationships between the fallow duration and organic matter pools and their mineralization activities. The effect of fallowing on the dynamics of soil organic matter was studied through the chemical and biological characterization of whole soils and their organo-mineral particles. Soil samples were collected under fallows of different duration (5, 10 and 30 years) in the Mangodara area (Burkina Faso, West Africa), and analysed for their organic C and total N contents, and soil respiration.

The length of fallow did not influence organic C, total nitrogen contents, and CO_2 *production of the whole soils. Fallow only affected the 20-2,000 μm fractions, in which C content significantly increased with the duration of fallow: 24, 32 and 37% higher for the 5, 10 and 30 year-old fallows, respectively. The contribution of coarse fractions to C mineralization was 2 times less in the old (10 and 30 years) than in the young fallow, suggesting that the quantity of easily mineralizable compounds associated with coarse fraction decreases with the age of fallow.*

These results clearly indicate that in sandy soil, soil organic storage is mainly controlled by soil particles larger than 20 μm, but its depletion occurs through fine organo-mineral particles, particularly under old fallows.

1. Introduction

When soil is brought into cultivation there is a progressive decline of organic matter content, and soil becomes quickly infertile (Piéri 1992). Therefore, particularly in Sudanian cropping systems, soil is left uncropped for several years (fallow) to improve soil fertility. The effect of fallow on soil rehabilitation processes, particularly on soil organic matter recovery has been extensively studied and benefits (Somé 1996; Manlay et al., 2002), as well as no significant changes (N'Dour et al. 2000) have been reported. The process of soil organic matter recovery following cessation of cultivation remains little understood, probably because it depends on physical, chemical and biological processes which are influenced by local environmental conditions.

Soil organic matter is made of a physically and chemically heterogeneous mixture of organic compounds at different stages of decomposition. Study of the relationship between the physical environment of soil microorganisms and their activity is useful for a better understanding of the dynamics of soil organic matter (Christensen 1992). Indeed microbial mineralization activities depend on soil organic matter quantity and quality, and may change in response to management practices. Although many studies focused on the effect of fallow on soil fertility, the simultaneous C and N net mineralization of soil fractions under this agricultural management has never been studied. This paper examines the relationships: (i) between the fallow duration (5, 10 and 30 years) and organic matter pools of soil size fractions and (ii) between these organic pools and their mineralization activities.

2. Materials and methods

2.1 Site characteristics and soil sampling

Soil samples were collected in the Mangodara area (9º54′N 4º25′W, Burkina Faso, West Africa). The average temperature is 27°C and annual rainfall

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averages 1,100 mm yr^{-1}. The rainfall is characterized by high intensity and short duration (May to September). Soils are classified as tropical ferruginous soils (FAO-UNESCO 1990?: Acrisols). The vegetation is a typical open savannah dominated by *Isorberlinia doka* and Andropogonea.

Samples were collected in June 2001 from the 0-40 cm depth under three fallow sites from which cultivation had been excluded for 5, 10 or 30 years. In each of the nine sampling areas, ten samples were randomly collected, air-dried, thoroughly mixed, and gently sieved (<2 mm) to disrupt the macro-aggregates. The fraction >2,000 µm was discarded.

2.2 Determination of soil texture and isolation of organo-mineral particles

Soil texture was determined after the destruction of organic matter by $H_2O_{2,}$ dispersion in hexametaphosphate, and shaking for 16 hours, according to Balesdent et al. (1991). The organo-mineral particles of the soil were also separated as above, but without using $H_2O_{2,}$ and hexametaphosphate; only shaking soil samples in water (20 g: 200 ml, ratio soil:water). The resulting 6 fractions were dried at 40ºC: 250 to 2,000 µm (coarse sand), 100 to 250 µm (fine sand), 100 to 50 µm (very fine sand), 20 to 50 µm (coarse silt), 2 to 20 µm (fine silt), and 0.05 to 2 µm (clay). The silt and the sand fractions were gathered; the following three fractions were thus obtained: 0.05 to 2 µm (clay), 20 to 50 µm (silt), and 50 to 2,000 µm (sand).

2.3 Analysis

Organic C and total N were determined using an automatic CHN analyser (NA 1500 Series 2, Fisons). The results were expressed as µg C g^{-1} soil, and µg N g^{-1} soil. Soil respiration was determined by placing 15 g soil in 130 ml closed flasks at 80% of their water holding capacity and incubated in the dark at 28ºC (±0.5ºC) for up to 3 days. The contribution of each size fraction to the total microbial activity in soil was assessed according to the method of Nacro et al. (1996), by comparing the activity of the whole soil to the activity of soils without a soil fraction (soil without coarse sand; soil without fine sand; etc.). Each incomplete soil was prepared by combining 5 fractions in the same proportions as in whole soil. The omitted fraction was replaced by chemical-free sand (particles >20 µm). Soil prepared by combining the 6 fractions was used as reference soil. The CO_2 concentration (µg C-CO_2 g^{-1} dry soil) of each sample was measured on a gas chromatograph (Auto Analyser apparatus, Chrompack CP-2002 P Micro GC) after 1 and 3 days. Gas samples were automatically taken from the flasks with a 250 ml gas-tight syringe.

2.4 Statistical analysis

Analyses were replicated four times for organic C and total N, and three times for soil respiration. Data were subjected to an analysis of variance using SAS (Statistical Analysis System, SAS Institute Inc. 1990). Means that differed significantly were separated using the Scheffe's test-; all tests were performed at the 95% level of probability.

3. Results

3.1 C and total N distribution

Organic C content of the whole soil increased slightly from the younger (3,005 µg C g^{-1} soil) to the older (3,400 µg C g^{-1} soil) fallow (Table 1). A reverse trend was observed for total N (Table 1): the lowest level was observed in the 30 year-old fallow (197 µg N g^{-1} soil), and the highest in the 5 year-old fallow (246 µg N g^{-1} soil). However, the effect of the lenght of fallow on organic C nor total N contents was not significnat. On the other hand, the C:N ratios of whole soils significantly increase with the fallows' age (Table 1).

The C and N contents of the fractions are shown in Table 1. Most of soil organic matter (69 to 75% of total C) was found in the silt fractions (-2,248 to 2,264 µg C g^{-1} soil) and this content was not significantly modified with the age of fallow. The lowest C content was found in the clay fractions and it decreased significantly with the fallow duration. The C content of the sandy fraction increased significantly with the fallow age. Regarding total N content, only the clay fractions were significantly affected by the fallow age. The C:N ratios of the sand fractions were 2 to 8 times higher than in the silt and clay fractions (Table 1), showing the recent origin of organic matter associated with the sand fractions.

3.2 Soil respiration

The CO_2 evolved by whole soils, and the contribution of each fraction are shown in Table 2. The potential contribution of a size class to C mineralization was calculated by subtracting the quantity of C-CO_2 produced by the incomplete soil lacking this class from the quantity of C-CO_2 produced by the completely recombined soil. The CO_2 production of the whole soils was low (11 µg g^{-1} dry soil) and not influenced by the fallow age. The

Table 1. Particles size distribution (percent of dry soil), and its relationship to organic carbon (μg C g^{-1} soil), total nitrogen (μg N g^{-1} soil) content, and C:N ratios of soils after fallows of 5, 10 and 30 years duration

	Age of fallows (years)		
	5	10	30
Texture			
0-2 μm	4.87 ± 0.69^a	4.19 ± 0.59^a	4.61 ± 0.39^a
2-50 μm	9.58 ± 1.03^a	14.7 ± 0.65^b	10.6 ± 0.88^a
50-2,000 μm	84.4 ± 1.12^a	80.4 ± 0.95^b	84.3 ± 0.76^a
Sum	98.9	99.3	99.5
C content (μg g^{-1} soil)			
0-2 μm	83.6 ± 4.73^a	62.2 ± 1.44^b	43.2 ± 0.98c
2-50 μm	2,264 ± 79.6^a	2,248 ± 315.3^a	2,249 ± 105.7^a
50-2,000 μm	529 ± 2,358^a	772 ± 29.1^b	1,024 ± 153.0^c
Sum	2,876 ± 77.7^a	3,082 ± 309.9^a	3,316 ± 103.5^a
Unfractionated soil	3,005 ± 217.7^a	3,089 ± 318.3^a	3,400 ± 106.9^a
N content (μg g^{-1} soil)			
0-2 μm	19.3 ± 3.48^a	12.0 ± 2.30^b	8.29 ± 1.84^b
2-50 μm	183 ± 20.4^a	180 ± 13.5^a	156 ± 6.8^a
50-2,000 μm	21.1 ± 0.62^a	22.4 ± 0.75^a	26.1 ± 3.48^a
Sum	223 ± 24.3^a	214 ± 14.3^a	191 ± 7.85^a
Unfractionated soil	246 ± 40.0^a	210 ± 16.9^a	197 ± 16.5^a
C:N ratios			
0-2 μm	4 ± 1^a	5 ± 1^a	5 ± 1^a
2-50 μm	12 ± 1^a	13 ± 3^a	14 ± 0^a
50-2,000 μm	25 ± 2^a	35 ± 2^b	39 ± 5^b
Unfractionated soil	12 ± 1^a	14 ± 3$^{a, b}$	17 ± 1^b

Means in a row with the same letter are not significantly different (α = 0.05; *t*-test), (n = 36)

CO_2 production of soil fractions varied from 0.30 to 8.78 μg C g^{-1} soil (Table 2). As observed for the C content, only the soil respiration of silt fractions was not affected by the fallow age, whereas that of clay increased after 30 years of fallow. On the other hand, soil respiration of sand fraction decreased with the fallow age (Table 2).

Table 2. Calculated net contributions of separate size classes to C mineralization (μg C-CO_2 g^{-1} soil), and ratio of carbon mineralized to initial organic C (% kc) after 3 days of incubation

	Age of fallows (years)		
	5	10	30
CO_2 (μg g^{-1} soil)			
0-2 μm	0.30 ± 0.08^a	0.31 ± 0.06^a	1.63 ± 0.29^b
2-50 μm	8.03 ± 0.96^a	8.78 ± 1.27^a	7.76 ± 1.37^a
50-2,000 μm	5.22 ± 0.43^a	2.57 ± 0.29^b	2.80 ± 0.36^b
Sum	13.6 ± 1.39^a	11.7 ± 1.06^a	12.2 ± 1.97^a
Recombined soil	11.4 ± 2.12^a	10.6 ± 2.59^a	11.0 ± 2.31^a
kc (%)			
0-2 μm	0.45 ± 0.09^a	0.49 ± 0.10^a	3.77 ± 0.60^b
2-50 μm	0.53 ± 0.09^a	0.31 ± 0.07^b	0.26 ± 0.04^b
50-2,000 μm	1.09 ± 0.09^a	0.31 ± 0.05^b	0.29 ± 0.03^b
Recombined soil	0.38 ± 0.07^a	0.35 ± 0.11^b	0.32 ± 0.06^b

Means in a row with the same letter are not significantly different (α = 0.05; *t*-test), (n = 27)

4. Discussions

Usually soil C content increases significantly during an extended fallow period (Somé 1996; Manlay et al., 2002). This was not observed here, probably because the C input to soil was reduced by fire in the dry season and grazing all year long, or because C “produced” was mostly added to the standing biomass rather than to the soil component (Pieri, 1992; Manlay et al. 2002). It could also be due to the nature of the soil, the crop history, and the land management. Feller et al. (1993) have shown that the effect of fallow on C content is particularly important on soils that are clayey. Soils studied here are very sandy (81 to 85%) with a low clay content (4 to 5%).

The C content of sand fractions increased significantly with the fallow age, indicating that dead plant matter enters gradually the soil organic matter pool: the greater the fallow age, the more organic matter enters the soil through the sand fractions. This clearly indicates the influence of the sand fractions on total organic C variation in sandy soils. However, the contribution of sand fractions to soil organic C was low (10 to 31%) probably because of intense microbial activities leading to high accumulation of by-products in the fine fractions especially in the silt.

Just as fallow age had no effect on soil organic C content, the CO_2 released from whole soils, and the C mineralization coefficients (Dommergues 1960) were also unchanged (Table 2). Since plant diversity and composition change considerably with time in fallow systems, an opposite result was expected. Probably in the short term, the overall soil respiration depends on the proportion of ready available C rather than on plant diversity and composition.

By contrast with its effects on organic C distribution, the contribution of sand fractions to C mineralization decreased with fallow age (from 38% to 28 and 23% respectively for the 10 and 30 year-old fallows). A reverse trend was observed for the silt (59 to 75%) and clay fractions (3 to 13%). This indicates that the quality of organic compounds associated with mineral fractions changed with time during the fallow (Ashman et al., 2003). In the same way, the C mineralization coefficient values (Table 2) showed that 0.3 to 1% of organic C associated with the sand fractions was mineralized, against 0.3 to 4% for the silt and clay fractions. The highest values were observed for the clay fractions from the 10 and 30 year-old fallow; hence, we can hypothesize that in the young fallow (5 year-old), C mineralization activity mainly depends on the availability of C associated with the sand fraction. But later, the C mineralization activity will be determined by the quality of organic compounds and microbial activity associated with the clay fraction. Such activity can lead to losses of soil organic matter, mitigating the effect of fallow on carbon sequestration in sandy soils. Further investigations are needed to understand that process.

5. Conclusion

While fallowing is generally expected to increase soil organic matter, long-term fallow (up to 30 years) did not significantly affected the soil organic C content of a sandy tropical soil. However, the C content of sand fractions was significantly affected by the age of fallow, suggesting that in sandy soil, soil organic matter storage is mainly controlled by soil particle larger than 50 µm. But when considering soil microbial activity, most of the CO_2 was potentially produced by the particles smaller than 50 µm, particularly in old fallows. Therefore, if soil organic matter increases through plant residues entering the soil, its depletion occurs through fine organo-mineral particles. This paradox can be explained by the fact that most heterotrophic soil micro-organisms (Kandeler et al. 1999) and most of easily metabolisable compounds were associated with the fine particles. It seems that soil microbial activity is controlled by the coarse fractions in the young fallow, and by the fine fractions in the old fallow. Fallow is an efficient tool for improving soil fertility, but in line with the findings of Manlay et al. (2002), our results show that long fallows are potentially constrained in their accumulation of soil organic matter content on sandy soils.

Acknowledgments

The authors thank the International Foundation of Science (IFS) and the French Institute for Research and Development (I.R.D.) for providing a grant to HB Nacro. They also gratefully acknowledge the support of Mrs Danièle Benest from Ecole normale Supérieure (Laboratoire d’Ecologie, Paris, France) for her efficient help during laboratory experiments.

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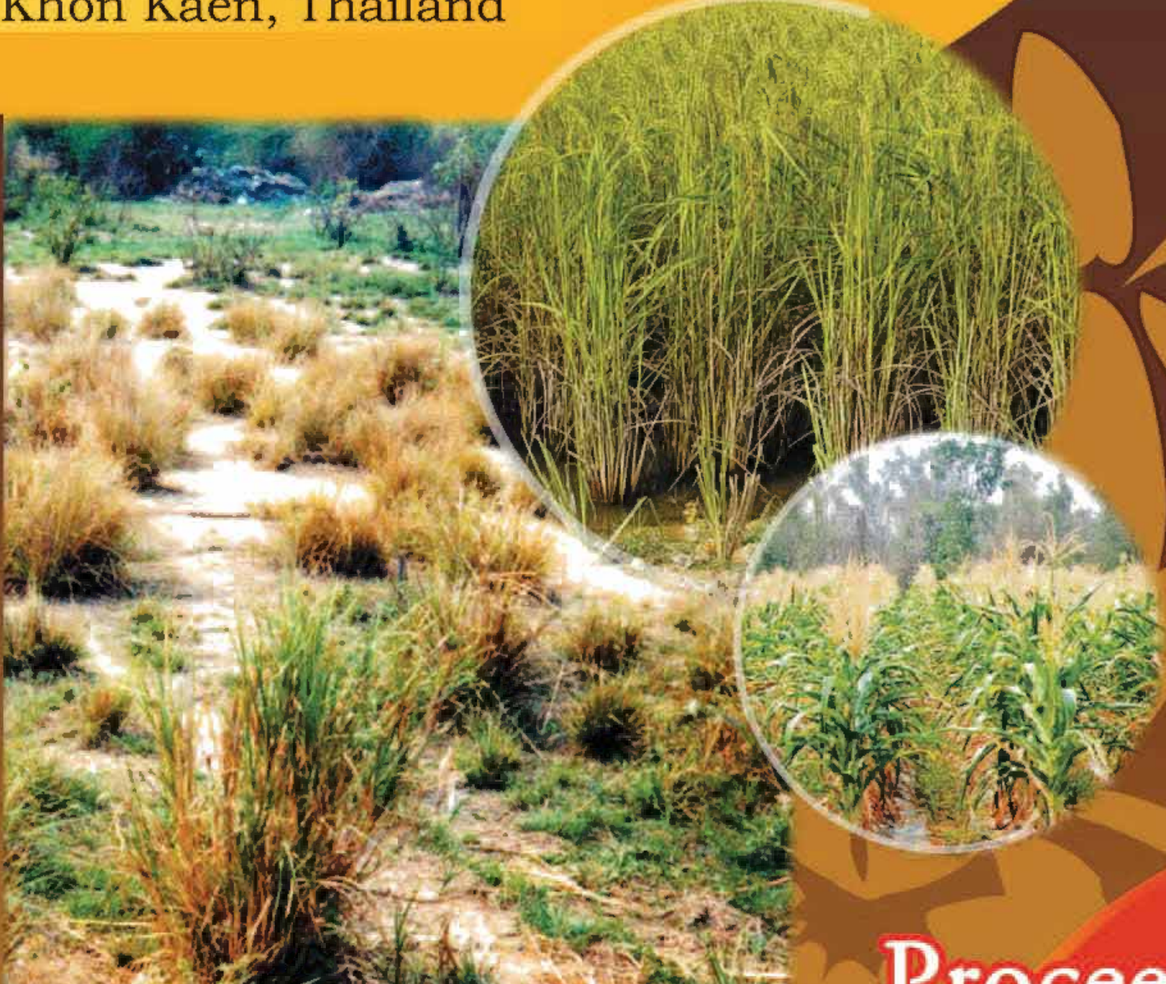

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ISBN 978-974-7946-96-3

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