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Effect of Fallowing on Soil Organic Matter Pools and Associated Microbial Activities in a Humid Savannah (Mangodara, Burkina Faso)

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Abstract: The effect of fallowing on the dynamics of soil organic matter was studied through chemical and biological characterization of organo-mineral particles. Soil samples were collected in fields lying fallow for 5, 10 and 30 years in the Mangodara area (Burkina Faso) and analyzed for the content of organic C and total N, soil respiration and N mineralization. Our study has shown that the effect of length of fallow on SOM content was not significant, contrary to what is generally assumed. Organic C content of the original soil increased slightly from the younger (3005 μg C g^{-1} soil) to the older (3400 μg C g^{-1} soil) fallow. After 30 years of fallowing, the organic matter accumulation remains low: fallowing seems to be ineffective for carbon sequestration in sandy soils. With regard to C distribution, it appears that SOM increases with length of fallow in the coarse fractions and actually decreases in the fine fractions. Soil microbial activities seem to be determined by the coarse fractions in the young fallow and by the fine fractions in the old fallow. Consequently, organic matter entering the soil system seems to be quickly decomposed; as a result, the storage of organic compound is strongly reduced.

Key words: Fallow · carbon · nitrogen · mineralization · soil fractions

INTRODUCTION

When soil is brought into cultivation there is a progressive decline of organic matter content and soil becomes quickly infertile [1]. Therefore, particularly in sudanian cropping systems, soil is left uncropped for several years (fallow) to improve soil fertility. The effect of fallow on soil recovery processes, particularly on soil organic matter recovery has been extensively studied and benefits [2, 3], as well as lack of significant changes have been reported [4]. The process of soil organic matter recovery following cessation of cultivation remains little understood, probably because it depends on interaction between physical, chemical and biological processes which are influenced by local environmental conditions.

Soil organic matter is composed of physically and chemically heterogeneous mixtures of organic compounds at different stages of decomposition [5]. The study of the relationship between physical environment of soil microorganisms and their activity is useful for a better understanding of the dynamics of soil organic matter [6]. Indeed microbial mineralization activities depend on soil organic matter quantity and quality and may change in response to management practices [7]. Although many studies have focused on the effect of fallow on soil fertility, the simultaneous analysis of C content and mineralization of soil fractions under this type of agricultural management has never been studied. This paper examines the relationships (I) between the fallow period (5, 10 and 30 years) and soil organic matter pools in soil fractions and (ii) between these organic pools and their mineralization activities.

MATERIALS AND METHODS

Site characteristics and soil sampling: Soil samples were collected in the Mangodara area (9°54'N 4°25'W, Burkina Faso, West Africa). The average temperature is 27°C and annual rainfall averages 1100 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: Acrisols). The

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vegetation is a typical open savannah dominated by *Isorberlinia doka* and Andropogonea.

Samples were collected in June 2001 from 0-40 cm depth under three fallow lands of 5, 10 and 30 years. In each of the nine sampling area, ten samples were randomly collected, air-dried, thoroughly mixed and gently sieved (< 2 mm) to disrupt the macro aggregates. The fraction > 2000 µm was discarded.

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 shaken for 16 hours, according to Balesdent *et al.* [8]. The organo-mineral particles of the soil were also separated as above, but without using H_2O_2 and hexametaphosphate; soil samples were gently shaken in water (20 g: 200 mL). The resulting 6 fractions were dried at 40°C: 250 to 2000 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 2000 µm (sand).

Analysis: Organic C and total N were determined using an automatic CHN analyzer (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 28°C (±0.5°C) 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.* [9], by comparing the activity of the whole soil to the activity of reconstituted soils without one of the soil fractions (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 Analyzer 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.

Statistical analysis: Analyses were replicated four times for organic C and total N and three times for C mineralization. Data were subjected to an analysis of variance using SAS [10]. Mean values that differed significantly were separated using the Scheffe's test-; all tests were performed at the 95% confidence level of probability.

RESULTS

C and total N distribution: Organic C content of the whole soil increased slightly from the younger (3005 µg C g^{-1} soil) to the older (3400 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). Analysis of variance did not show a significant effect of the length of fallow on organic C nor on total N contents. Still, the C:N ratios of whole soils significantly increased with fallow age (Table 1).

The largest amounts of soil organic matter (69 to 75% of total C) was found in the silt fractions and the C content (2248 to 2264 µg C g^{-1} soil) 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 period. The C content in the sandy fraction increased significantly with fallow age. Regarding total N content, it decreased in the fine fractions and increased slightly in the coarse one (Table 1), but 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.

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 (and to N 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 productions of the whole soils were low (11 µg g^{-1} dry soil) and not influenced by the fallow age. The CO_2 productions 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 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).

DISCUSSION

Usually soil C content increases significantly during fallow period [2, 3]. This was not observed here, probably

Table 1: Fine and coarse mineral particle size distribution (percent of dry soil), organic carbon (µg C g^{-1} soil), total nitrogen (µg N g^{-1} soil) content of soils and fractions and C:N ratios

	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]	14.74±0.65[b]	10.59±0.88[a]
50-2000 µm	84.40±1.12[a]	80.38±0.95[b]	84.31±0.76[a]
Sum	98.85	99.31	99.51
C content (µg g^{-1} soil)			
0-2 µm	83.58±4.73[a]	62.16±1.44[b]	43.17±0.98[c]
2-50 µm	2263.94±79.59[a]	2248.31±315.31[a]	2248.71±105.65[a]
50-2000 µm	528.86±2358[a]	771.84±29.09[b]	1023.77±153.02[c]
Sum	2876.38±77.66[a]	3082.30±309.91[a]	3315.65±103.54[a]
Unfractionated soil	3005.11±217.73[a]	3089.00±318.31[a]	3400.00±106.93[a]
N content (µg g^{-1} soil)			
0-2 µm	19.30±3.48[a]	12.04±2.30[b]	8.29±1.84[b]
2-50 µm	182.58±20.38[a]	179.90±13.53[a]	156.24±6.80[a]
50-2000 µm	21.12±0.62[a]	22.38±0.75[a]	26.11±3.48[a]
Sum	223.00±24.32[a]	214.32±14.32[a]	190.63±7.85[a]
Unfractionated soil	246.22±40.03[a]	210.44±16.88[a]	197.33±16.51[a]
C:N ratios			
0-2 µm	4.0±1.0[a]	5.0±1.0[a]	5.0±1.0[a]
2-50 µm	12.0±1.0[a]	13.0±3.0[a]	14.0±0.0[a]
50-2000 µm	25.0±2.0[a]	35.0±2.0[b]	39.0±5.0[b]
Unfractionned soil	12.0±1.0[a]	14.0±3.0[ab]	17.0±1.0[b]

Means with the same letter (per line) are not significantly different (α= 0.05; *t*-test) (n= 36)

Table 2: Calculated net contributions of separate size classes to C (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]
50-2000 µm	5.22±0.43[a]	2.57±0.29[b]	2.80±0.36[b]
Sum	13.62±1.39[a]	11.66±1.06[a]	12.19±1.97[a]
Recombined soil	11.35±2.12[a]	10.60±2.59[a]	11.00±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]
50-2000 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 with the same letter (per line) are not significantly different (α= 0.05; *t*-test) (n= 27)

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 plant (standing biomass) than to the soil component [1, 3]. The low capacity for C storage could also be due to the low clay content (only 4 to 5%). Indeed, [11] have shown that the effect of fallow on C content is particularly more important when soils are clayey.

The sum of C and N recoveries after soil fractionation were respectively 96 to 100% and 91 to 102%. The mean C concentrations of fractions larger than 20 µm (31%) was close to 30% as shown in [12] for a large wide of West African savannah soils. The C content of sand fractions increased significantly with the fallow age, indicating that dead plant matter enters gradually into the soil organic matter pool: the more the fallow is old, the more organic matter enters the soil through the sand fractions [12]. This clearly indicates the influence of the sand fractions on variation of total organic C in sandy soils. However, the contribution of sand fractions to soil organic C is 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 one.

No significant effect of the fallow age on soil organic C content was observed. In the same way, the CO_2 released from whole soils and the C mineralization coefficients [13] didn't also varied (Table 2). An opposite result was expected; indeed, plant diversity and composition change considerably in fallow systems [14]. Plant compounds entering the soil organic matter pools are normally different and it may be the case for associated carbon mineralization. Our results probably indicate that in the short term, the overall soil respiration rather depended on the proportion of ready available C than on the origin of organic matter.

Unlike for organic C distribution, the contribution of sand fractions to C mineralization decreased from 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 changes through fallow as observed by [15]. The C mineralization coefficient decreased with the fallow duration for the sand fraction: from 1% in the 5 year-old fallow to 0.3% in the 30 year-old fallow. While it increased in the fine fractions: from 0.3% in the 5 year-old fallow to 4% in the 30 year-old fallow (Table 2). 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. This means that the fine fractions become more and more active with duration of the fallow; as a result, organic matter accumulation is strongly reduced. This sets the problem of the effect of fallow on carbon sequestration in sandy soils. Further investigations are needed to understand this process.

CONCLUSIONS

Our study has shown that the effect of fallow duration on SOM content was not significant, contrary to what is generally assumed. After 30 years of fallowing, the organic matter accumulation remains low: fallowing seems to be ineffective for carbon sequestration in sandy soils. However, with regard to C distribution, it appears that SOM increases with length of fallow duration in the coarse fractions and decreases in the fine fractions. On the other hand, the C mineralization coefficient decreases with the fallow duration for the sand fraction: from 1% in the 5 year-old fallow to 0.3% in the 30 year-old fallow. Hence, soil microbial activities seem to be determined by the coarse fractions in the young fallow and by the fine fractions in the old fallow. Due to the high microbial activities in the coarse fractions, the organic matter entering the soil system is rapidly decomposed. As a result, the storage of organic C is strongly reduced.

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