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Microbial Properties of a Ferric Lixisol as Affected by Long Term Crop Management and Fertilization Regimes in Burkina Faso, West Africa

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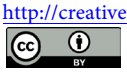

Abstract

We used an ongoing long-term field trial established since 1960 in Burkina Faso, to study the microbial properties of a Ferric Lixisol under various crop management and fertilization regimes. Microbial respiration rate, microbial biomass carbon (MBC) and soil bacteria's number were assessed in soil samples taken at 0 - 20 cm depth. The crop management were continuous cropping of sorghum (*Sorghum bicolor L.*) (S/S) and rotation between sorghum and cowpea (*Vigna unguiculata L.*) (S/C), while the fertilization regimes were: 1) Control (te); 2) Low rate of mineral fertilizer (fm); 3) Low rate of mineral fertilizer + sorghum straw restitution (fmr); 4) Low rate of mineral fertilizer + low rate of manure (fmo); 5) High rate of mineral fertilizer (FM); and vii) High rate of mineral fertilizer + high rate of manure (FMO). The manure is applied every second year. The results indicate that sorghum/cowpea rotation significantly increase MBC and bacteria number as compared to continuous sorghum cropping. MBC ranged from 335.5 to 54.85 µg C g^{-1} soil with S/S and from 457.5 to 86.6 µg C g^{-1} soil with S/C. Application of high level of manure and mineral fertilizer increase microbial respiration rate and MBC. The highest MBC was observed with FMO and the lowest with the control. In general, the metabolic quotient (qCO_2) was negatively impacted by the fertilization and cowpea rotation. For S/S rotation, qCO_2 of the control was 1.5 to 2 times that of the treatments with low mineral fertilizer (fmr, fmo and fm) and 3 times that of the high rate of fertilization (FM and FMO). With S/C ro-

tation, qCO_2 of the control was 2 times of that fmr, FM and FMO and 0.8 times that of fmo and fm. Soil bacteria in the fmr were 63.6 and 12.4 times the control in the S/S and S/C rotations, respectively. In sum, combined application of manure and mineral fertilizer with crop rotation is the best management practices to improve in sustainable way microbial activities in tropical soil.

Keywords

Microbial Respiration, Bacteria Quantification, Compost, Crop Rotation, Sorghum, Cowpea

1. Introduction

The integration of legumes in the cropping systems is known to have positive effects on subsequent cereal yield. This positive effect was attributed to the enhanced soil health resulting from the increase of available nitrogen through biological nitrogen fixation, maintenance of soil structure, increase in soil carbon and physical properties, disruption of pest cycles, and weed suppression [1] [2] [3] originating from the activities of soil microorganisms [4].

In Sub Sahara Africa including Burkina Faso, farmers often produce sorghum [*Sorghum bicolor L.*] in bare soil with little or without fertilization for their own consumption. These cropping systems often include cotton in the rotation as a cash crop in the cotton cropping areas and more generally legume crops like cowpea and groundnut. In such systems, soil fertility management relies on the application of little mineral fertilizers with or without organic amendments mainly composts, crop residues, and farmyards manures [5]. Conflicting results on the effects of mineral fertilizer and organic amendments application on soil microbial activities have been reported. For instance, an increase of soil microbial respiration and enzymatic activities following mineral fertilizer and manure application has been reported [6] [7] [8] and attributed to higher soil carbon, higher nutrient availability, crop roots and, additional microbes from manure. On the other hand, long-term application of mineral fertilizer results in the decrease of microbial biomass probably due to soil acidification and decrease of soil carbon content due to increased mineralization as reported by Geisseler, *et al.* [7].

Soil microbial respiration rate, biomass, metabolic quotient (qCO_2), or enzymatic activity have been used as potential indicators for change in soil quality because they are sensitive to soil management [9]. Geisseler, *et al.* [7] analyze the responses of soil microorganisms to mineral fertilizer using 107 datasets from 64 long-term fertilization trials in cropping systems. Only 3 datasets originate from Africa implying that little evidence is available on soil biological properties under long-term application on mineral fertilizer and organic amendments and crop rotation in tropical soils.

In this study, we investigate the potential of some entry points of integrated

soil fertility management on soil biological properties. Our objectives were to assess the long-term effects of 1) crop rotation (cowpea-sorghum) and 2) application of mineral fertilizer with and without organic matter on soil microbial properties. This was done by measuring soil microbial respiration rates, microbial biomass, and quantification, and assessing the microbial metabolic quotient in soil samples from long-term experiments. We hypothesized that 1) sorghum-cowpea rotation will increase soil microbial biomass compared to continuous sorghum cropping and 2) combined application of mineral fertilizer and manure will result in greater microbial biomass and activity than the only application of mineral fertilizer.

2. Material and Methods

2.1. Site Description

The experiment was conducted in 2012 at Saria agricultural research station (12˚16'N, 2˚9'W) in Burkina Faso. The climate was north-Sudanian with monomodal rainfall and unevenly distributed (Figure 1). The total rainfall during the experiment year was 856 mm; mean daily temperatures vary from 30˚C during the rainy season to 45˚C in April and May. The soil type was Ferric Lixisol. The vegetation type was an open woody savannah and the main species were *Parkia biglobosa*, *Vitellaria paradoxa*, and *Tamarindus indica*. The herbaceous component was dominated by *Pennisetum pedicellatum*, *Andropogon* sp., *Loudetia togoensis*, and *Schoenfeldia gracilis*.

2.2. Experimental Layout

The long-term trial established in 1960 at the research station of Saria (Burkina Faso), which is still ongoing, was used to evaluate the soil microbial properties under different crop management and fertilization regimes. The experiment design is a split-plot with six blocs (replicates), six (06) levels of fertilization treatments and three levels in the rotation treatments.)

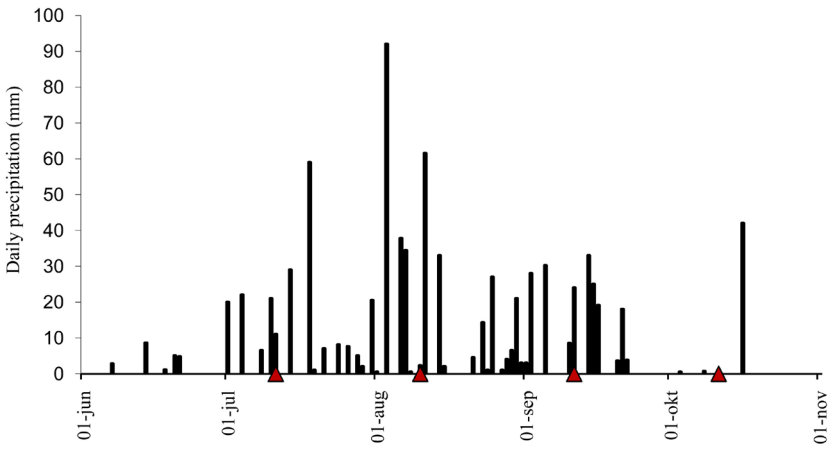

Figure 1. Daily precipitation in 2012 at Saria research station in Burkina Faso. The red triangles indicate the four soil sampling dates.

The Main fertilization treatments are:

- Control, without any fertilizer (te);
- Low rate of mineral fertilizer (100 kg·ha^{-1} of NPK + 50 kg·ha^{-1} of urea) + sorghum straw restitution (fmr);
- Low rate of mineral fertilizer + 5 Mg·ha^{-1} 2 years^{-1} of manure (fmo);
- Low rate of mineral fertilizer (fm);
- High rate of mineral fertilizer (100 kg·ha^{-1} of NPK + 100 kg·ha^{-1} of urea + 50 kg·ha^{-1} of KCl) + 40 Mg·ha^{-1} 2 years^{-1} of manure (FMO);
- High rate of mineral fertilizer (FM).

The rotation treatments are:

- Sorghum/sorghum (*Sorghum bicolor L.*);
- sorghum/cotton (*Gossipium hirsutum*);
- sorghum/cowpea (*Vigna unguiculate L.*).

In our study, we have considered two rotations: sorghum/sorghum (S/S) and sorghum/cowpea (S/C). The study was conducted in 2012 where the sorghum cultivar ICSV 1049 was cropped in all the rotation plots. The dimension of the individual plot was 10.0 m by 8.40 m. Mineral fertilizers were NPK 14.23.14 + 6S + 1B, urea (46% N) and KCl (46% K_2O). One-third of the urea was applied three weeks after sowing together with the total doses of NPK and KCl, and the remaining two-thirds at the time of the flowering stage.

Organic amendments (manure: N = 0.11 g·kg^{-1}, C = 0.20 g·kg^{-1}; and sorghum straw: N = 0.05 g·kg^{-1}, C = 0.39 g·kg^{-1}) were applied on the soil surface on the plots that were concerned and then incorporated into the soil by ploughing at the depth of 15 - 20 cm few days before sowing. Selected soil chemical properties of the trial in 2012 before sowing are presented in Table 1 (Ouandaogo N., unpublished data).

Table 1. Selected soil chemical characteristics before ploughing following crops rotation and fertilizer application at the Saria long-term experiment in Burkina Faso, West Africa; (n = 6). Treatments with the same letter within columns are not statistically different at the 5% level.

Rotation	Treatment	Total-C (g·kg^{-1})	Total-N (g·kg^{-1})	Exchangeable Al^{3+} (cmol·kg^{-1})	P-Bray (mg·kg^{-1})	pH-H_2O
Sorghum-Sorghum	te	1.98a	0.18a	0.00a	4.60a	5.4c
	fmr	2.16a	0.19a	0.11b	18.90b	4.0a
	fmo	3.31c	0.37c	0.00a	33.80d	4.6b
	fm	2.32a	0.28b	0.25c	26.00c	4.0a
	FMO	6.92d	0.61d	0.00a	48.30e	5.9d
	FM	2.42ab	0.21a	0.45d	20.00b	3.9a
Sorghum-Cowpea	te	1.91a	0.19a	0.00a	4.40a	4.8c
	fmr	2.25a	0.20a	0.15b	11.60b	4.0a
	fmo	3.81c	0.31b	0.00a	22.00d	4.4b
	fm	2.60b	0.25a	0.20c	17.60c	4.0a
	FMO	7.80d	0.68c	0.00a	35.10e	5.9d
	FM	2.87b	0.22a	0.26c	16.30c	3.9a

The results in Table 1 indicate that whatever the crop rotation system, soil total-C, total-N and P-Bray were highest with the application of manure (FMO and fmo) and lowest with the control. In the S/S rotation, soil total-C and total-N and P-Bray, varied between 6.92 g·kg^{-1} and 1.98 g·kg^{-1}; 0.61 g·kg^{-1} and 0.18 g·kg^{-1}; 48.30 mg·kg^{-1} and 4.60 mg·kg^{-1} respectively. In the S/C rotation, these parameters varied between 7.8 g·kg^{-1} and 1.91 g·kg^{-1}; 0.68 g·kg^{-1} and 0.19 g·kg^{-1}; 35.10 mg·kg^{-1} and 4.40 mg·kg^{-1} respectively. The soil pH-H_2O was highest (5.9) in the FMO treatments and lowest (4.0) with the low rate of exclusive low mineral fertilization (fm), crop residues restitution (fmr) and the exclusive high mineral fertilization (FM). Exchangeable Al was undetectable (<0 cmol·kg^{-1}) in the control and the manure application (fmo and FMO) and highest in the FM treatments with 0.45 cmol·kg^{-1} and 0.26 cmol·kg^{-1} in the S/S and S/C rotation respectively.

2.3. Soil Sampling and Analysis

Composite auger samples of three subsamples at 0 - 20 cm were taken in 2012 from each plot on four occasions: 1) before ploughing (0DAS); 2) at 30 days after sowing (30DAS), 3) at 60 days after sowing (60DAS) and 4) at 90 days after sowing (90DAS). Soil samples were dried and sieved through a 2 mm mesh for biological properties determination which included 1) soil microbial respiration rate; 2) soil microbial biomass carbon; 3) microbial metabolic quotient; and 4) soil bacteria's quantification.

2.3.1. Soil Microbial Respiration Rate

Heterotrophic microbial respiration was measured using an incubation-alkaline absorption method [10]. Briefly, 20 g of dry soil were weighed, and the water content of the soil was adjusted to 60% water holding capacity and placed in a 1 L vessel. A beaker containing 20 ml of 0.1 mol·l^{-1} NaOH was placed on the moist soil and the vessels were incubated at 30˚C.

Total CO_2-C in the NaOH traps was determined by titrating the excess NaOH with 0.1 mol·l^{-1} HCl after precipitation of carbonates with 3% $BaCl_2$ in the presence of la phenolphthalein as color indicator. CO_2 production was measured daily for the first 7 days and then every 2 days for 14 days more.

Microbial respiration was estimated as µg C-CO_2 kg^{-1} soil according to Equation (1).

$$\text{C-CO}_2\left(\mu\text{g}\cdot\text{kg}^{-1}\right)=\left(V_{\text{blank}}-V_{\text{sample}}\right)\times 2.2/W \quad (1)$$

where: V_{blank} is the number of ml of 0.1 mol·l^{-1} HCl used to titrate the NaOH in the control vessel; V_{sample} is the number of ml of 0.1 mol·l^{-1} HCl used to titrate the NaOH in the sample vessel.

The factor 2.2 is related to the fact that 1 ml of 0.1 mol·l^{-1} HCl corresponds to 2.2 g C-CO_2 [11]; W is the weight of sample in kg.

Then, soil microbial respiration rate expressed as µg C-CO_2 kg^{-1}·d^{-1} was calculated by averaging total C-CO_2 production during the 21 days of incubation.

2.3.2. Soil Microbial Biomass Carbon

Microbial biomass C (MBC) was determined according to the chloroform fumigation method as described by Jenkinson and Powlson [12]. In this method, the microbial cells in soil are killed by fumigation with alcohol-free chloroform, and then subjected to mineralization for 14 days at a constant temperature (30˚C). Controls consist of identically incubated but non-chloroformed soil samples. The amount of MBC is calculated from the difference between the CO_2-C evolved from chloroform-fumigated and non-fumigated samples (Equation (2)):

$$MBC = \left[F_{(0\text{-}7)} - nF_{(7\text{-}14)} \right] / kc \quad (2)$$

where: $F_{(0\text{-}7)}$ representing the total C-CO_2 production between the 0 and 7 days of incubation of the fumigated soil, $nF_{(7\text{-}14)}$ representing the total C-CO_2 production between the 7 and 14 days of incubation of the non-fumigated soil. kc is the factor representing the proportion of C mineralized during the incubation. We used the factor 0.41 according to [13].

2.3.3. Microbial Metabolic Quotient

The microbial metabolic quotient (qCO_2) was calculated as the amount of CO_2-C produced per unit of microbial biomass C.

2.3.4. Soil Bacteria's Quantification

The bacteria's density was evaluated using the suspension-dilution method. Sequential dilution at a ratio of 1-to-10 was realized on an initial solution form with 5 g of soil in 45 ml of sterile water. An aliquot of 100 µl of appropriate dilution 10^{-3}, 10^{-4} and 10^{-5} were spread using balls in the YPGA1/2 (Yeast-Peptone Glucose Agar) medium in Petri dishes. For each of the dilution level, three Petri dishes were prepared and incubated at 25˚C. Bacteria colonies were counted after 3 and 5 days.

2.4. Statistical Analysis

The effect of crop rotation and fertilization on soil chemical and biological properties was subjected to analysis of variance (ANOVA). We used General Linear Model (GLM) univariate implemented in Minitab (V. 14) statistical software for Windows (Minitab Inc.). Means that showed differences at $p < 0.05$ were compared using Tukey's pair-wise tests.

3. Results

3.1. Soil Microbial Respiration Rate

Soil microbial respiration rate of soil samples before (0DAS) and after (30, 60 and 90 DAS) sowing and applications of manure and mineral fertilizers are shown in **Figure 2**.

In the S/S rotation, the respiration rate was highest at 0DAS and then decreased and remain constant at 30DAS 60DASand 90DAS except for treatment with manure application (fmo and FMO) where it increased at 90DAS. The highest respiration rates were observed with FMO and varied between 46 ± 0.9 and

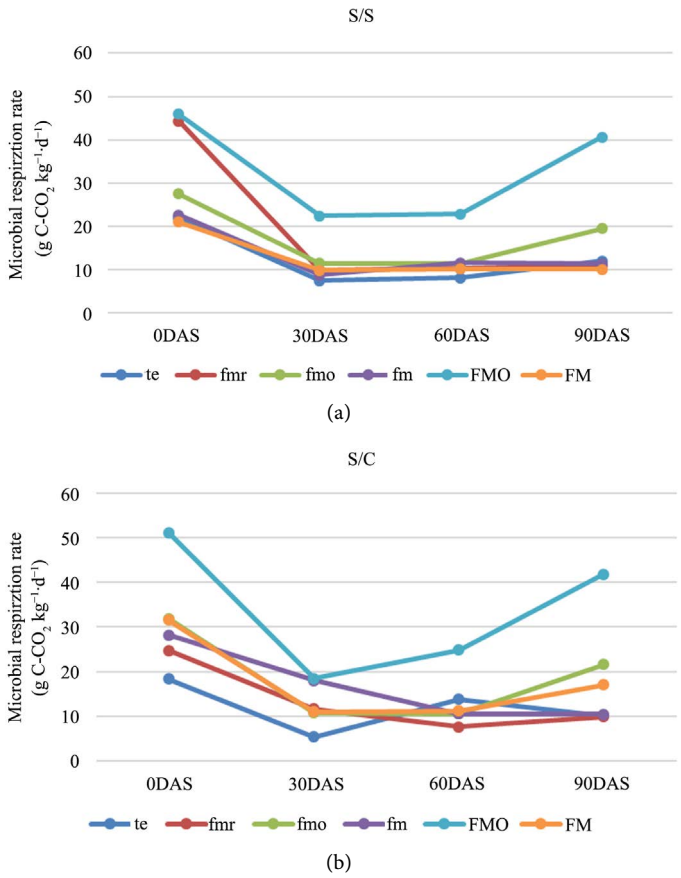

Figure 2. Microbial respiration rate of soil sampled at 0, 30, 60 and 90 days after sowing as affected by crop rotation and fertilization regimes at the Saria long-term experiment in Burkina Faso, West Africa. Each point represents an average for the three field replicates.

41 ± 0.3 µg C-CO_2 $kg^{-1}·d^{-1}$ recorded at 0DAS and 90DAS respectively. The lowest respiration rates were observed with the control 22 ± 0.3 and 12 ± 0.4 µg C-CO_2 $kg^{-1}·d^{-1}$.

In the S/C rotation, similar patterns were observed as for S/S rotation. The highest respiration rates were observed with FMO and the lowest with the control (te). At 0DAS, respiration rate varied between 51 ± 0.7 and 19 ± 0.8 µg C-CO_2 $kg^{-1}·d^{-1}$; at 90DAS was 42 ± 0.3 and 10 ± 0.3 µg C-CO_2 $kg^{-1}·d^{-1}$.

3.2. Soil Microbial Biomass C

Microbial biomass C (MBC) was significantly different among treatment and crop rotation (Table 2).

MBC was higher in the S/C rotation as compared to S/S rotation in all treatment except for fmo. The highest MBC were observed with FMO treatment while the lowest one's with the control. MBC ranged from 335.5 µg C g^{-1} soil to 54.85 µg C g^{-1} soil and from 457.5 µg C g^{-1} soil to 86.6 µg C g^{-1} soil with S/S and S/C rotation respectively.

Within the low rate of mineral fertilizer without (fm) or with organic matter addition (fmr and fmo) fmr had the highest MBC.

Table 2. Microbial biomass (μg C g^{-1} soil) following crop rotation and fertilization regimes at the Saria long-term experiment in Burkina Faso, West Africa; (n = 3). Treatments with the same letter within line are not statistically different at the 5% level.

Rotation	Treatment					
	te	fmr	fmo	fm	FMO	FM
Sorghum-Sorghum	54.8a	166.5d	122.6b	111.4b	335.5e	140.6c
Sorghum-cowpea	86.6a	244.0c	89.1a	103.7b	457.5d	237.5c

In the S/S rotation, MBC content was ranked as follow: FMO > fmr > FM > fmo ≥ fm > te and as FMO > fmr > FM > fm > fmo ≥ te in the S/C rotation.

3.3. Microbial Metabolic Quotient

In general, the metabolic quotient (qCO_2) was negatively impacted by the fertilization and cowpea rotation (Table 3). For instance, with the S/S rotation, qCO_2 decreased drastically as the rate of mineral fertilization increased. The qCO_2 of the control was 1.5 to 2 times that of the treatments with low mineral fertilizer (fmr, fmo and fm) and 3 times that of the high rate of fertilization (FM and FMO).

Regarding the S/C rotation, the decrease in qCO_2 was clearly observed with the high rate of fertilization (FM and FMO) and the restitution of sorghum straw (fmr). The qCO_2 of the control was 2 times of that fmr, FM and FMO. In opposite, there was an increase of qCO_2 with low rate of mineral fertilizer with (fmo) and without (fm) manure. The qCO_2 of the control was 0.6 and 0.82 times that of fmo and fm respectively.

3.4. Soil Bacteria's Quantification

The cowpea rotation induced higher soil bacteria with the control and fm treatments. For both rotations, soil bacteria were highest in the low rate of exclusive mineral fertilizer (fm) and low exclusive mineral fertilization plus crop residues restitution (fmr) and lowest with low rate of mineral fertilizer plus manure application (fmo) as indicated in Table 4.

In the S/S rotation, the soil bacteria count gave 91.3, 6.4 and 0.83 × 10^7 g^{-1} soil in the fmr, fm and fmo treatment respectively. In the S/C rotation, it was 84.0, 48.10 and 1.05 respectively in the fmr, fm and fmo treatment. In the S/S rotation, soil bacterial with fmr were 14.3 times fm and 63.6 times the control (te). In the S/C rotation, soil bacterial with fmr were 1.8 times fm and 12.4 times the control. In the S/S rotation, soil microbial ranked as follows: fmr ≫ fm > FMO ≥ te > fmo while in the S/C rotation, treatments were ranked as fmr ≫ fm ≥ te > FMO > fmo ≥ FMO.

4. Discussion

The results of our study conducted on continuous long-term (52 years) crop rotation and application of mineral fertilizer either alone or in combination with manure or sorghum straw added strong evidence of the benefit of integrated

Table 3. Microbial metabolic quotient (μgC-CO_2 μg-microbial biomass-C $kg^{-1}\cdot d^{-1}$) following crop rotation and fertilization regimes at the Saria long term experiment in Burkina Faso, West Africa; (n = 3). Treatments with the same letter within line are not statistically different at the 5% level

Rotation	Treatment						p-level
	te	fmr	fmo	fm	FMO	FM	
Sorghum-Sorghum	401c	266b	224b	203b	137a	149a	***
Sorghum-Cowpea	211b	101a	358d	272c	112a	133a	***

Table 4. Soil bacteria count ($\times 10^7 \cdot g^{-1}$ soil) following crop rotation and treatment repeated applications at the Saria long-term experiment in Burkina Faso, West Africa; (n = 3). Treatments with the same letter within line are not statistically different at the 5% level.

Rotation	Treatment						p-level
	te	fmr	fmo	fm	FMO	FM	
Sorghum-Sorghum	1.43	91.30	0.83	6.40	3.37	1.45	***
Sorghum-Cowpea	6.77	84.00	1.05	48.10	3.12	1.03	***

soil nutrients and crop management on soil biological and microbiological properties [1] [9] [14]. These results support our hypothesis that combined application of mineral fertilizer and manure result in greater microbial biomass and activity than only application of mineral fertilizer.

4.1. Long Term Fertilization Effects on Soil Microbial Biomass and Activity

Soil microbial respiration rate (SMR) is assessment tools for soil organic matter quality and quantity induced by crop management practices [15] which include our study crop rotation, application of organic amendments and mineral fertilizer. This implies then SMR is related to active fraction of carbon. Repeated combined application of both manures and mineral fertilizers is widely recognized as key factors to increase soil biological, chemical and physical properties [2] [14] [16] [17] which result in sustainable increase and/or maintain crop productivity [18]. In our study, there was clear indication that soil respiration rate increased with levels of manure application which is in line with several studies [19]. The observed data could be related to the greater amount of soil organic matter and nutrients. In fact, manure contains huge amount of dead and alive microorganisms, and are energy sources that stimulate higher microbial activities and respiration. As SMR is controlled by availability of C-content, a greater amount of organic matter provided more labile C that leads to more SMR in soils receiving organic amendment [20]. Lower SMR might indicate limited availability of C-sources and/or actives microbial biomass pool or unfavorable soil conditions for microbial activities.

A meta-analysis based on long-term trials from around the world revealed

that mineral fertilizer application led to a 15.1% increase in the microbial as compared to unfertilized treatments [7]. In our study, the increase was much higher, up to 160% and 510% when mineral fertilizer is applied without (FM) and with manure (FMO), respectively. The magnitude of the increase observed in our study is attributed to the duration of the experiment, since it has more than 20 years [7]. Our results also revealed that application of organic amendments with mineral fertilizer increased considerably MBC as compared with application of mineral fertilizer alone, which is in accordance with other long-term experiments [21] [22] [23] [24] and short-term experiments [19] studies. In addition, higher crop yield reported in previous studies [25] support evidence that better crop yield generates high root biomass and exudates which combined with the readily C-sources added through organic amendments are the key factors contributing to higher build-up of microbial biomass [22]. Straw inputs with mineral fertilizer (fmr) also increase MBC as compared to only mineral fertilizer (fm) even at high rate (FM). In contrast, [26] regular and long term-term mineral fertilization led to a decrease of MB compared to the control and explained by the decrease in soil pH. The lower MBC in the control unfertilized treatment was consistently reported by several studies synthetized in the review paper [7] and explained by the lower soil quality due to negative soil nutrient balance. Our results were similar to those reported by Pallo, *et al.* [27] and Li, *et al.* [28]. However, our results were up to 10 times higher than that reported by Diallo-Diagne [23] who work in a long-term tillage experiment in the same site and could be explained by the rapid carbon mineralisation following tillage and subsequently less availability of soluble carbon.

The qCO_2 provides a measure of specific metabolic quotient and describes microbial stress indicators. It is interpreted as "microbial efficiency" or "carbon used efficiency" since it is a measure of the energy necessary to maintain catabolic activity *i.e.* microbial respiration, in relation to the energy necessary anabolic activity *i.e.* for synthetizing microbial biomass. The more soils are under stress, the more the qCO_2 value would be higher. Some studies have shown that qCO_2 varies among ecosystems, soil fertility management [29] [30]. In our study, unfertilized soil had the highest and the FMO had the lowest qCO_2. Similar trends have been reported by various studies [19] [31] and imply that in unfertilized soil, microbial population lives under starvation stress. Application of manure (with mineral fertilizer) would increase nutrients content and availability resulting in favorable conditions for microbial growth and microbial diversity [8]. However, the magnitude qCO_2 as highlighted by our results (100 - 400 μg $C\text{-}CO_2$. μg-microbial biomass-C. $kg^{-1}\cdot d^{-1}$) is five times higher than that commonly reported [9] [22] [32]. One explanation would be the long duration of the experiment (52 years) implying long soil disturbance due to agricultural practices.

Bacteria quantification showed similar number for unfertilized treatment (te) than that of fmo, FMO and FM indicating that only normal mineral fertilization with/without straw restitution increased bacteria number. It is generally expect-

ing that bacteria numbers will be proportional to microbial biomass and respiration. In our study, the figure is opposite suggesting that in these treatments, bacteria are mostly dormant and/or constitute minor pools of soil microorganism community. Francioli, *et al.* [33] reported that organic fertilization increased bacterial diversity and stimulated microbial groups that are known to prefer nutrient-rich environments. In contrast, unfertilized soils exhibited distinct microbial communities enriched in oligotrophic organisms adapted to nutrient-limited environments.

4.2. Crop Rotation Effects on Soil Microbial Biomass and Activity

The impact of long-term crop rotations or relay crops and nutrient management on soil properties including microbial activities have been extensively studied [34], [35] [36]. The results indicated an improvement of soil fertility and subsequently an increase of cereal yield in the cereal/legume rotation as compared to continuous cereal cropping. As we hypothesized in the present study, crop rotations increased microbial biomass (by 36% - 70%) excepted in the fm treatment where there is no effect and fmo treatment which exhibited a decrease of 27%. The overall biomass increase is consistent with many reports in tropical soil [34] [36] [37] and attributed to higher biomass roots input due to higher yield and higher enzyme activity. Lack of effect of rotation on microbial biomass has been reported by [38] and attributed to similar amount of soluble carbon used as energy sources to support microbial growth

In the present study, long-term sorghum-cowpea rotation significantly increases MBC and bacterial number and could be explained by the fact that microorganisms used as energy sources water-soluble carbon which originate from organic matter decomposition, microbial metabolites but also by roots exudates [39]. In the review paper, [3] reported that legume roots secrete more enzymes than cereal roots and that enzymes suppress soil fungi and limit their activity [39]. Hence, since we did not quantify fungi, we could speculate that continuous sorghum cropping would favor fungi pool and detrimental for bacteria pool while the reverse would be observed for sorghum-cowpea rotation. This assertion is supported by Yusuf, *et al.* [34] who report that continuous maize cultivation may favor the establishment and maintenance of fungi community in comparison with legume-maize or fallow-maize rotation in an Alfisol in Nigeria.

5. Conclusion

We used a long-term experiment to assess the effect of crop rotation and nutrient management practices on soil microbial activities. The results indicated that sorghum/cowpea rotation significantly increases soil microbial biomass and bacterial number as compared to continuous sorghum cropping. Repeated application of high levels of manure and mineral fertilizer increased carbon mineralization, microbial biomass, and efficient use of carbon. Hence, combined application of manure and mineral fertilizer with crop rotation is the best management practice to improve in a sustainable way microbial activity in tropical soil.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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