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Effects of Agroecological Practices on Soil Microbiological Activity in Sudano-Sahelian Zone of Burkina Faso

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Abstract: Microorganisms are key actors in soil quality. However, their activity is influenced by various factors including agricultural practices. This study aimed to assess the effects of 4 agroecological practices on soil microbiological activity in the Sudano-Sahelian area of Burkina Faso. These practices involved (a) the use of organic matter (OM) spread over a plot, with and without micro-dose mineral fertilization and (b) the localized application of organic manure in planting pits dug into hard pan land (zaï), with and without cereal-legume rotation. Microbial biomass (MB) by fumigation-extraction and soil respiration by incubation-extraction were measured on 40 soil samples, taken at 0-10 cm depth. The results indicated higher cumulative values of carbon from respiration on plots with generalized application of OM, with and without mineral fertilizers (113 and 111 mg C-CO_2/kg soil respectively), than on plots with localized application, with and without cereal-legume rotation (72.9 and 98 mg C-CO_2/kg soil respectively). MB follows the same trend as soil respiration with lower values (21.9 to 50.9 mg C/kg soil respectively). Generalized application of OM with or without mineral fertilizers was more favorable to soil microbial activity.

Key words: Agroecology, MB, soil respiration, Burkina Faso.

1. Introduction

In Burkina Faso, agricultural production remains one of the main sources of income for most of the population. However, this livelihood activity faces enormous challenges such as the degradation and continuous decline of soil fertility [1, 2]. Soils are deficient in nitrogen and phosphorus, due to their pedogenetic origin [3]. These soils are also poor in organic matter (OM), whose contents are generally lower than 1% [4]. In addition, they are, quite often, subjected to soil mining type agricultural practices. This has accelerated their degradation processes [3, 5]. This degradation is also influenced by various other factors, including biological, chemical, and/or physical. Biological degradation refers to the decrease in biodiversity that can sometimes result in the complete disappearance of certain faunal species, with repercussions on soil fertility. It can also refer to the decrease in microbial activity.

Microorganisms are one of the major biological components of soil fertility due to their diverse functions [6]. They represent the most abundant and diverse of all living organisms [7]. Indeed, fungal cells in a gram of soil are estimated to number up to 10^6 and bacterial cells 10^9 [8]. These microorganisms are strongly involved in how the soil functions within fundamental ecological processes. They also provide many basic ecosystem services [9, 10]. They contribute to the improvement of soil structure by

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enabling the formation of aggregates [9, 11]. They promote water infiltration, purification, and play a role in the soil's water holding capacity [9]. Some microbial populations play a significant role in soil health by regulating the presence and development of human, animal, and plant pathogens [12]. Finally, microbial communities are fundamental players in the biogeochemical cycles of carbon, nitrogen, phosphorus and sulfur [9, 6, 13]. Their agronomic importance is no longer in question. Because of their involvement in ecosystem functioning, microorganisms are good indicators of soil quality [8].

For these reasons, soil microorganisms are often used as indicators to assess soil fertility [14], and more generally, the biological quality of soils [8] as well as the impacts of anthropogenic activities (land use change, pollution, etc.) on ecosystem functioning [10].

In the Sudano-Sahelian zone of Burkina Faso, small-scale family farmers apply some so-called agroecological practices to overcome the problems of soil poverty, and their inability to invest in external agricultural production inputs. These agroecological practices involve the use of integrated soil fertility management (water and soil conservation techniques, minimum tillage, and application of compost or manure). Many authors have shown that these practices have positive effects on soil fertility and agricultural yields [15-18]. However, to better understand the extent to which these practices result in the improvement (or not) of biological fertility, the present study assesses the effects of 4 agroecological practices on microbial biomass (MB) and soil respiration.

2. Materials and Methods

2.1 Study Site

The present study was conducted at 4 sites located in the Sudano-Sahelian zone of Burkina Faso. These locations and their geographical coordinates are as follows: Andemtenga in the Centre-East region (12°19′37.2″ N latitude; 0°18′36″ W longitude), Bilanga and Gayéri in the East region with respectively 12°33′00″ N latitude, 0°22′00″ W longitude; and 12°39′ N latitude, 0°29″ E longitude; and Korsimoro in the Centre-North region (13°22′00″ N latitude; 0°01′07″ W longitude).

Due to their geographical position, these sites are characterized by relatively low rainfall. The annual averages over the past 10 years range from 694 to 855 mm of water per year [17].

According to the soil classification of Word Reference Base (WRB), most of the soils in these areas are tropical ferruginous type (C.P.C.S, 1967) and are similar to ferric lixisols [3].

2.2 Choice of Sites and Agroecological Practices

By mutual agreement between the farmers' organizations and the research institute partners, 4 sites were selected for this study. These localities share common features: poor soils, continuous soil degradation, irregular rainfall over time and space, and insufficient material and financial resources for farmers to invest in agricultural production factors.

In these areas, technological practices that do not require large investments in purchased external resources have been proposed to farmers to improve not only the productivity but the sustainability and resilience of their farming system. After several years, an increasing number of farm families have adopted some combination of the proposed agroecological practices in their fields.

The first step in this study was to establish a typology of farmers' plots according to the new agricultural practices adpoted.

The next criterion in the choice of agroecological technologies to assess was that at least a dozen farmers (in the selected villages) applied these practices on at least a quarter of a hectare of their land.

Using these criteria, 4 sets of technological practices were identified:

- the use of OM (compost/manure) spread generally across the plot, and its subsequent burial in the soil using ridge tillage (OM)

- the use of OM buried in the soil using ridge tillage, combined with application of a “micro-dose” of chemical fertilizer at a rate of 2 g/seed pocket of NPK (OM + MD)
- the use of OM in zaï planting pits (i.e. small basins dug into a hard-pan soil)
- the use of OM in zaï combined with cereal-legume rotation (Zaï + Rot).
- The amount of compost/manure used on all plots was approximately 2.5 tons per hectare. The chemical characteristics of the organic substrates used (Table 1) did not differ significantly between the selected farmers. However, they were characterized by low levels of decomposition. All plots were within strips created within permeable rock bunds laid out along the contour (to slow down water run-off and erosion and enable water infiltration).

2.3 Soil Sample Collection

The composite soil samples were made up of 3 samplings per plot, 60 days after planting. These composite samples were analyzed in a laboratory. The assumption was that after 60 days, all the biological or chemical processes within the soil stimulated by the application of exogenous inputs, notably the organic amendments, would have taken place. Samples were taken from the 0-10 cm soil layer between the seed pockets. The soil from these samples were air-dried and then sieved to 2 mm and 0.5 mm for the different analyses undertaken.

2.4 Determination of Total Organic Carbon (TOC)

TOC was determined by the Walkley-Black method [19]. This method consists in oxidizing the soil carbon in cold conditions with potassium dichromate ($K_2Cr_2O_7$) 1 N in the presence of concentrated sodium bisulfate (H_2SO_4). The excess of unreduced potassium dichromate is determined by Mohr’s salt $Fe(SO_4)_2(NH_4)_2$ in the presence of a colored indicator. The carbon and OM contents are obtained by the following formulas:

$$C\ (g/kg) = N(V_1 - V_2) \times 3.9/PE$$

$$OM\ (g/kg) = C \times 1.72$$

where:

V_1 is the volume of Mohr’s salt used for the blank;

V_2 is the volume of Mohr’s salt used to determine the soil sample;

N is the normality of the Mohr’s salt solution;

PE is the weight of the test sample.

2.5 Measurement of Microbial Biomass

Microbial biomass (MB) was determined using the fumigation-incubation method [16]. It consists in treating a soil sample with chloroform vapors in order to kill the majority of microorganisms. After homogenization of the soil sample, this fumigation consisted of depositing 100 g of soil in a desiccator containing chloroform freed from ethanol, after several washings with water. Using a vacuum pump, a vacuum was created in the desiccator to saturate the atmosphere with chloroform vapors.

After 24 h of fumigation, 4 to 5 successive vacuums were made to evacuate the chloroform vapors. The fumigated soils were incubated at 30 °C in the dark. Samples were taken after 7 and 14 days for titration of CO_2 release.

Table 1 Chemical characteristics of organic substrates used.

Chemical characteristics	Value
pH_{water}	8.1
Organic matter (%)	22.2
Carbone (%)	12.9
Total nitrogen (%)	0.6
C/N	22.7
Total phosphorus (mg/kg)	1,062.7
Total potassium (mg/kg)	5,629.9
Total calcium (mg/kg)	3,531.1
Total magnesium (mg/kg)	1,175.8

Source: Analysis of organic substrates collected from selected farmers in 2020.

The MB is obtained by the formula below:

$$\mathrm{MB}\ (\frac{\mathrm{mg}}{100\mathrm{g}}\mathrm{ofsoil}) = \frac{F(0-7)\ -\ F(7-14)}{Kc}$$

where: Kc is the proportionality coefficient corresponding to the fraction of microbial carbon mineralized during incubation, and is equal to 0.41 [17]; F(0-7) and F(7-14) represent the C-CO_2 released between 0-7 and 7-14 days of incubation, respectively.

2.6 Measurement of Soil Respiration

Soil respiration activity was measured by the respire-metric test according to the method of Dommergues [18]. The principle is based on the measurement of carbon dioxide (CO_2) released by the soil sample incubated in a closed chamber.

For this purpose, 100 g of soil moistened to 2/3 of its maximum water retention capacity was introduced into a 1-liter glass jar in which a beaker containing 20 mL of 0.1 N sodium hydroxide (NaOH), and a container containing water were placed. The hermetically sealed jar was incubated at the temperature of 30 °C. The CO_2 released and trapped by the soda was determined by titration with 0.1 N hydrogen chloride (HCl) in the presence of phenolphthalein, after prior precipitation of sodium carbonate with 2 mL of 3% barium chloride ($BaCl_2$). The determination of CO_2 released was performed daily for the first 7 d, then every 2 d from the 8th to the 14th day.

The amount of CO_2 released or soil respiration intensity is obtained by the following formula:

$$\text{C-CO}_2(\text{mg/100 gsoil}) = (V_{\text{blank}}\text{-}V_{\text{sample}})\times 2.2$$

where:

V_{blank} = amount of the $\frac{N}{10}$ HCl (in mL) used for the control jars;

V_{sample} = amount of HCl (in mL) used for the jars containing the soil sample; 2.2 g of CO_2 corresponds to 1 mL of $\frac{N}{10}$ HCl [22].

2.7 Calculation of Microbial Yield, Overall Mineralization Rate and Respiration Quotient

The data collected were also used to calculate the microbial yield (MY), the overall mineralization rate (OMR), and the respiratory quotient (QCO_2).

$$\mathrm{MY}\ (\%) = \frac{\mathrm{MB}}{\mathrm{TOC}}$$

The MY is the ratio of MB to TOC.

The metabolic quotient or respiratory quotient is the amount of carbon mineralized per gram of MB per day. It was determined using the following formula [23]:

$$\mathrm{QCO2} = \frac{\mathrm{C\_CO2}(14)}{14 \times \mathrm{MB}}$$

- QCO_2 is the metabolic quotient, expressed as mg/g C-CO_2/day C-Biomass;
- C-CO_2 (14) is the carbon mineralized during 14 d of incubation;
- MB is the carbon of the MB expressed in mg 100 g^{-1} C of soil;
- 14 is the number of days of incubation.

The OMR is the ratio between the cumulative released C-CO_2 and the total carbon content in the considered treatment. It expresses the rate of mineralization of OM [22]. It enables an estimate of the temporal evolution of organic substrates. It is calculated using the following formula, described by Ref. [19]:

$$\mathrm{OMR}(\%) = \frac{\mathrm{C\_CO2}}{\mathrm{TOC}} \times 100$$

C-CO_2 is the amount of carbon dioxide released, and TOC is total soil organic carbon.

3. Results

3.1 Effects of Agroecological Practices on Soil Respiration

The results showed that the amounts of C-CO_2 released decreased in all practices during incubation (Fig. 1). The highest releases were observed on the first day of incubation, with a rapid decrease starting on the second day. However, statistical analysis did not show significant differences between practices during this time, except on day 5 (*F* pr = 0.005), day 6 (*F* pr = 0.003) and day 7 (*F* pr = 0.002).

Indeed, on days 5, 6 and 7, the plot with generalized application of OM combined with the micro-dose of mineral fertilizers (OM + MD), released the greatest amount of C-CO_2 compared to the other practices.

However, this practice did not differ significantly from the practice of zaï without rotation (Zaï), and the generalized application of manure without micro-dose of fertilizer (OM).

The zaï technique combined with crop rotation (Zaï + Rotation) induced the lowest value (Fig. 1).

Furthermore, the results indicate 3 phases in the evolution of daily C-CO_2 release (Fig. 1). A phase of high C-CO_2 production was observed on the first days of incubation. The amounts of C-CO_2 then decreased steadily until day 7 for all practices, and then rose again between days 7 and 8. Finally, there was a relapse from day 9 to reach a minimum on day 21 (Fig. 1).

However, the cumulative amounts of C-CO_2 were generally low. They ranged from 72.9 to 113.2 mg/kg (Fig. 2). Statistical analysis of the cumulative values of C-CO_2 released indicates no significant difference between practices.

Nevertheless, a comparison of the arithmetic values of released C-CO_2 shows increasing trends on plots where organic manure was applied in a generalized way with or without mineral fertilization by micro-dose.

3.2 Effects of Agroecological Practices on Microbial Biomass and Yield

The results showed that soil MB carbon contents were generally low, with values ranging from 21.9 to 50.9 mg/kg soil (Table 2). They represent less than 1% of TOC.

The highest value was obtained with the generalized application of OM and the lowest value with the practice of zaï.

Compared to the plots with generalized application of OM, those combining generalized OM with the micro-dose of mineral fertilizers (OM + MD) and those with localized application of OM with and without rotation (Zaï + Rotation) induced decreases in MB. However, these differences were not statistically significant.

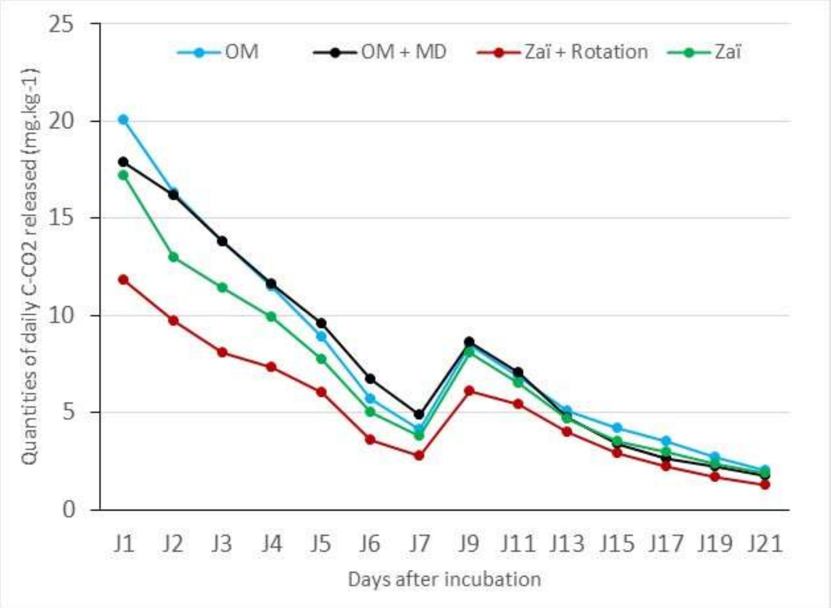

Fig. 1 Evolution of daily CO_2 released by agroecological practices.

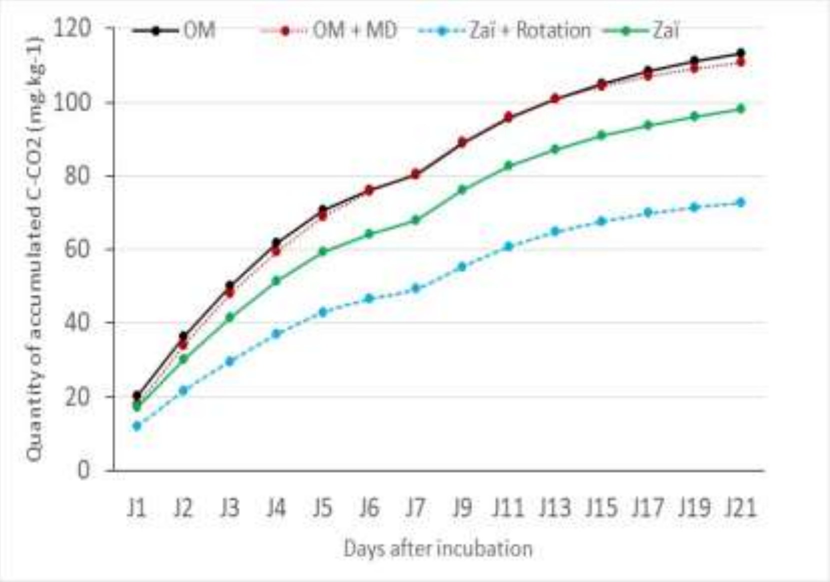

Fig. 2 **Variation in the quantity of $C\text{-}CO_2$ accumulated by different agroecological practices.**

Table 2 **Variation in microbial biomass, the metabolic quotient and microbial yield as a function of agroecological practices.**

Practice	$C\text{-}CO_2$ (mg/kg)	QCO_2(mg/g C/jr MB)	MB (mg/kg)	TOC (g/kg)	MY (%)	OMR (%)
FO	113.2 ± 14.96	0.005^a	50.9 ± 7.75	5.82 ± 0.73	0.95^a	2.14^a
FO + MD	111 ± 12.65	0.004^{ab}	33.5 ± 6.55	5.80 ± 0.62	0.54^b	1.92^{ab}
Zaï + Rot	98 ± 15.99	0.003^{ab}	34.3 ± 8.29	5.75 ± 0.78	0.54^b	1.69^{ab}
Zaï	72.9 ± 15.99	0.001^b	21.9 ± 8.29	4.86 ± 0.78	0.43^b	1.60^b
Fp	0.118	0.039	0.234	0.517	0.003	0.019
Significance	NS	S	NS	NS	HS	S

$C\text{-}CO_2$ = carbon from soil respiration, MB = microbial biomass carbon, QCO_2 = respiration quotient, OMR = overall mineralization rate, TOC = total organic carbon.

Microbial yields (MR = MB/TOC) were also low (0.43% and 0.95%). However, the value obtained with the plots with generalized application without micro-dosing of chemical fertilizers (OM) differed significantly from the other practices.

3.3 Effects of Agroecological Practices on the Metabolic Quotient (QCO_2)

The metabolic quotient or respiratory quotient represents the amount of carbon mineralized per gram of MB per day. Results showed extremely low quotients regardless of practice (Table 2). Statistical analysis indicated significant differences between practices. Like MB, the respiration quotient was higher on plots with widespread application of OM and lower in the zaï practice.

3.4 Effects of Agroecological Practices on the Overall Mineralization Rate

The OMR or carbon mineralization coefficient expresses the rate of mineralization of OM. OMR makes it possible to estimate the temporal evolution of organic substrates. The results showed OMR values between 1.6% (zaï + rotation) and 2.14% (OM) (Table 2). The generalized application of OM without mineral fertilizers is the most efficient practice on the mineralization rate, compared to the other practices.

4. Discussion

4.1 Effects of Agroecological Practices on Soil Respiration

The release of $C\text{-}CO_2$ results from mineralization of organic substrates. Study results show low basal soil respiration in general, ranging from 72.9 to 113.2 mg/kg soil.

Several factors may be responsible for these low C-CO_2 values. Among these factors, the initial state of soil fertility and the quality of the organic substrates provided could play a major role in biological activity by providing the necessary nutrients and energy to microorganisms [24]. In this regard, it should be noted that the soils of the study area, like the vast majority of soils in Burkina Faso, are deficient in nitrogen and phosphorus, with OM contents generally below 1% [3, 4].

These results are in line with those of several authors [15, 25, 26] who have shown that soil respiration is a function of different factors including total carbon and nitrogen contents. In addition, the organic substrates used are poorly decomposed and low in nitrogen. They can hardly provide the necessary nutrients and energy to the microorganisms on their own. This set of factors could justify the low quantities of C-CO_2 produced.

Overall, the results obtained are in line with the work of Refs. [23, 27, 28]. Both showed that the amount of C-CO_2 released depends strongly on the quality of the OM that can be easily mineralized and, on the nutrients, available or released by the mineralization of organic substrates.

Finally, the great variability that generally characterizes soil fertility in the farming environment in this region of Burkina Faso, is another major factor to consider.

The higher C-CO_2 values on plots with generalized application of organic substrate with and without mineral fertilizers could be explained by the method of application of organic substrates. In these plots, the OM was spread over the entire area and plowed into the soil by ridge tillage. This type of tillage brings the OM from the inter-ridge under the ridge. It thus enhances the organic status of the soil under the ridges. This would explain the higher levels of basal respiration.

The localized application of micro-dose mineral fertilizer (near the seed pockets in the ridges) does not appear to have a beneficial effect on the mineralization of OM because of the way the soil samples are taken (between the ridges). This likely explains why the plots where the applied OM is buried and the plots combining generalized application of OM and micro-dose of chemical fertilizer showed identical values of basal respiration. These values are also the highest compared to the other treatments.

The high C-CO_2 values observed during the first days of incubation would indicate a higher mineralization of the OM at the beginning of incubation. This would correspond to the degradation of the weak compounds of the fresh OM, called “primary mineralization”. Several authors have made the same observations on the evolution of C-CO_2 release in more intensive market gardening areas [29].

The 3 phases observed on the evolution curve of C-CO_2 quantities would thus refer to different types of OM or rather to different compounds of OM [29]. Indeed, OM is made up of different types of compounds whose mineralization is more or less rapid. The decrease in microbial activity could result from the decrease in OM that is easily degradable by soil organisms.

Analysis of cumulative C-CO_2 amounts and daily amounts showed that the induced effects of agroecological practices are not significantly different during incubation, except for 3 days.

All practices involved application of OM. This likely explains the similarities between them.

The exceptions found on the 5th, 6th and 7th days of incubation could be explained by the method of OM application (generalized and localized), the quality of the OM compounds (variable quantities of easily mineralized compounds) and the method of soil sampling (between patches).

4.2 Effects of Agroecological Practices on Microbial Biomass and Microbial Yield, Respiration Quotient and OMR

MB is an important indicator of change in OM quality and quantity [24]. Under comparable soil and climatic conditions, MB is directly related to the carbon available (soil carbon, more or less biodegradable and especially the carbon of inputs of plant matter) to satisfy the energy needs of microorganisms [23].

The microbial carbon obtained is less than 1% of TOC (0.43% to 0.95%). According to several authors, microbial carbon represents 1% to 3% or 1% to 5% of total soil OM [20, 21]. With respect to these previous studies, the MB in our study (21.9 to 50.9 mg/kg soil), appears low. Compared to the biomass obtained by Some *et al*. [22] and Fotio *et al.* [23] which are 312.0 to 544.5 mg/kg soil and 458.0 to 739.0 mg/kg soil respectively, it is very low.

These microbial carbon levels would suggest soils in the samples taken were very poor in OM. Indeed, our study sites recorded low OM levels. The organic amendments applied, whether generalized or localized, were intended to raise the carbon level. The highly degraded state of these soils is likely a contributing factor explaining the results obtained.

The MY (or MB/TOC) is an indicator to estimate the dynamics of OM in the soil [34]. In this study, the different practices resulted in low MYs compared to those found by other authors such as Chaussod *et al*. [23] and Fotio *et al*. [23] which are 1.01% to 1.96% and 1.35% to 1.65% respectively. The differences with these studies would be explained by the soil-climate context in which the work was conducted, and agricultural practices used.

In addition to the low values of MB and yield, the comparison of practices shows that these values are better with generalized inputs of OM, whether associated or not with a micro-dose of mineral fertilizer than those obtained with localized input of OM.

There are two possible reasons for these results: the ridge plowing of the broadcast plots and the areas where the soil samples were taken. Ridge tillage probably increased the quantity of OM within the ridges by bringing in the OM from between the rows. In addition, the soil samples were taken between zaï patches. This made it impossible to account for the induced effects of OM and mineral fertilizer applied to the zai patches and to the plants in the broadcast plots, respectively.

Statistical analysis showed that practices had significantly different effects on respiration quotient (QCO_2), MY and OMR. Generalized applications of material with or without micro-doses of mineral fertilizers were found to be better than localized applications of OM. The reasons for this were the conservation of OM in the ridges, which decomposed over time to release nutrients to the microorganisms. In contrast, in the case of localized application of OM, the soil samples were taken outside the application areas, which would explain the lower efficiency of these practices.

While other studies indicate that in the upper horizons of cultivated soils the respiration quotient can vary from 0.5 to 10 mg $C\text{-}CO_2$/g/h/MB [25], our results gave extremely low metabolic quotients (QCO_2) in the range of 4.1×10^{-4} to 1.3×10^{-4} mg C/gMB/h.

High QCO_2 values would reflect poor substrate quality and low metabolic efficiency, while low values would express a favorable response of the microorganisms to the supplied substrate [27, 34].

The results of this study could therefore reflect either good metabolic efficiency as claimed by these authors, or low quantities or poor quality of the organic substrates provided.

5. Conclusion

The objective of the study was to evaluate the effects of different combinations of agroecological practices on MB and basal soil respiration in a farming environment in various districts of Burkina Faso. Other indicators associated with these parameters like the overall mineralization rate (OMR), the microbial yield (MY), the respiratory quotient (QCO_2) were also calculated.

The results revealed that both MB and soil respiration were low, regardless of the agroecological practice considered.

MB, an active component of soil, with rapid turnover, represented less than 1% of total carbon.

These results raise questions about the quality and quantity of the organic substrates provided.

The respiratory quotient indicated a good metabolic efficiency but also a very fast level of mineralization.

From all these results, it appears that the practice of a generalized application of OM whether associated or not with a micro-dose application of mineral fertilizer, enabled the highest values in all cases, even though the difference was not statistically significant for some parameters such as MB, basal soil respiration and total carbon.

The role and management of OM on the life and activity of microorganisms remains a paramount issue in Burkina Faso's pedoclimatic context.

Finally, there is a need to increase the awareness of small-scale farmers in Burkina Faso to produce good quality compost and to apply the quantities recommended by research studies, in order to improve biological activity and thus the productivity of their soils.

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