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Effect of agroecological practices on cultivated lixisol fertility in eastern Burkina Faso

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ABSTRACT

Conservation and restoration of degraded agricultural soils are in fact two important factors of resilient agrosystems and food sovereignty in the context of global change in the Sudano-Sahelian zone. The objective of this study is to determine the effect of adaptive practices for the conservation and restoration of degraded agricultural lixisol. Soil organic carbon, total nitrogen, pH and soil microbiological activity were evaluated in soils surface layers on cultivated plots developed in zaï (Z) and in stone-rows (SR) with contribution of compost (C) since 2006, traditional practices (absolute witness AW) and uncultivated natural vegetation (NV) soils. The results showed that agroecological practices improve soil pH, organic carbon, total nitrogen, electrical conductivity and available phosphorous compared to the absolute witnesses. There was also a decrease in the C/N ratio on the agroecological field relative to the controls. These practices had a positive effect on soil mineralization potential and the soil microorganism's diversity. Substrate-induced respiration (SIR) for 15 carbon sources using the MicroResp technique under agroecological practices and natural vegetation were much higher than those under the absolute witness. Agroecological practices have a positive effect on the different parameters of soil fertility in the semi-arid zone and can thus restore degraded soils.
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Keywords: Agroecology, stone-rows, zaï, compost, soil microbiology, Burkina Faso.

INTRODUCTION

In the Sudano-sahelian zone, populations are particularly concerned by the climate change and soil degradation generated by lack of residues restitution, tillage and erosion that strongly influence the agricultural production. Like most soils in West Africa, those of Burkina Faso are characterized by poverty of soil nutrients, especially nitrogen and phosphorus (Traoré and Toé, 2008). Others studies have shown that they are also characterized by a richness of silt and fine sand with poor structural stability of soil surface layers, a low clay content together with a low organic matter content (less than

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3% under vegetation and 0.7% under crops) and low nutrients reserves.

Additionally to these intrinsic limiting soil factors, we must add climatic factors (water and wind erosion) (Payet et al., 2011) and agricultural practices which very often lead to a fairly rapid degradation of the physical, chemical and biological qualities of these poored soil. It is estimated that about a quarter of the world's land area is degraded, affecting 1.5 billion people in all climatic zones around the world (von Braun et al., 2013). Over the next 40 years, the annual loss of cultivated land would be in the order of 10 to 12 million hectares (MEA, 2005) i.e. 0.7 to 1% of available capital due to a deterioration in their quality (high decline in productivity) or a change in land use and other forms of degradation if no action is taken to reverse trends. In Burkina Faso, about 20% of the territory is affected by soil degradation (LADA, 2011) and to date 9.234.500 hectares of degraded agricultural land are estimated at an annual growth rate of 105.000 to 250.000 hectares.

The causes of this degradation are varied but often agricultural practices like overgrazed pasture, tillage and fertilizing systems… Hien (2004). Carried out on the soil they cause different forms of physical, chemical and biological degradations but the most extreme of which being erosion. Wind erosion occurs mostly at the starting of the rainy season (May to September) when soil cover by annual plants is minimal from May to half of July before vegetation growth. Hydric erosion occurs throughout rainfall season. However, most of the annual land loss occurs during some particularly intense rain events (Rajot et al., 2009). At the global level, erosion (water and wind) would account for 83% of degraded land. Hydric erosion is reported to be the main form (12%) in most countries with the exception of a few countries in the Sahel (Mauritania, Niger and Mali) where wind erosion occurs (4%) (Pautrot, 2012). In Western Africa, these losses amount to 72% of arable land and 31% of pastoral land. In Burkina Faso, about 24% of arable lands are severely degraded by this phenomenon. Faced to this phenomenon, Western African farmers in the semi-arid zone have developed agroecological practices based on both traditional and modern knowledge and extension initiatives to secure their farms. These include stone-rows, a belt of stones building on contour as an erosion control technique; zaï, a special form of culture in bunches of micro-basins, and production and use of aerobic composting (Sawadogo et al., 2008). Zaï and stone-rows are mainly used on degraded soils to restore them. However there are also many cases where stone-rows are used to prevent the degradation and erosion of agricultural soils.

The effect of these agroecological practices on soil physical and chemical characteristics as well as on crop production (sorghum, maize…) has been demonstrated in the sudano-sahelian context (Bouzou-Moussa and Dan-Lamso, 2004; Zougmoré et al., 2004; Sawadogo et al., 2008; Yameogo et al., 2013) but little has been done in Western Africa on soil microbiology and thus biological fertility. Zougmooré et al. (2004) found that yield increased for stone-rows and compost about 106% and Yaméogo et al. (2013) showed 300% augmentation on sorghum production for Z+SR+C respectively in North and West of Burkina Faso two zones characterized by tropical ferruginous soils. In addition to these funding, several studies on soil microbiology have been carried out in arid, semi-arid and tropical and sub-tropical conditions in other parts of the world (Zhou et al., 2012; Hien et al, 2010; Diakhaté et al., 2016). These studies

globally demonstrated the positive effect of good agricultural practices such as conservation agriculture, crop residues restitution and composting on the characteristics (quantity and diversity) of soil microflora. However, most of these studies on soil microflora were conducted on forest soils. Moreover, a few studies (Doamba et al., 2011) have investigated the characterization of the soil microbial community under these practices. Therefore, little information is available on the effect of both traditional and modern agroecological practices (alone or combined with each other) on the soil microbial community in Western Africa in the semi-arid zone.

The objective of this study is to evaluate the effect of agroecological practices like zaï, stone-rows and amendments on the evolution of physical, chemical and mainly the microbiological soil parameters on cultivated lixisol. We hypothesized that agroecological practices significantly improve soil microbial activity and the diversity of microorganisms together with soil physical and chemical parameters.

MATERIALS AND METHODS

Site description

The study was conducted in the east of Burkina Faso in the village of Sampieri about 150 km east of Fada N'Gourma city and 20 km west of the commune of Kantchari (border Burkina-Niger). The climate in the study area is Northern-Sudanian. Mean annual precipitation and temperature are 687 mm and 29 °C respectively. On the geological level, Sampiéri is on a basement resulting from the alternation between birrimian furrows and granitic terrains (Sattran and Wenmenga, 2002). Soil from granitic level was subsequently altered leading to the formation of plinthite or petro-plinthite layer.

The main soils inventoried in the village are lixisols (WRB, 2014) from little leached to leached on sandy, sandy-clayey and clayey-sandy and poorly evolved. They are mainly characterized by low levels of nitrogen and phosphorus. Basic soil data for the Sampieri village are given in Table 1. Agriculture (sorghum, millet, maize system) is the main activity and is family-based with a set of small plots (about 3 ha) per farmer. Production is predominantly subsistence, but in recent years cash crops have also been developed, especially cotton and sesame. The fields concerned by our study have been cultivated for years (sorghum, millet, maize) before being gradually developed into zaï and stone-rows and then amended in compost since 2006.

Methods

A preliminary survey carried out in 2014, made it possible to understand the typology of farms and the main farming practices. Thus, practices such as Zaï, stone-rows, production and compost use have been identified. Zaï was consists to hole digging approximately 20-40 cm of diameter and 10 to 15 cm deep (Plate 1). The soil removed from the holes was deposited downstream of the hole to stop the runoff water and allow a better infiltration of the water. We estimated at 12 000 to 15 000 the number of holes on one hectare for a typical zaï field. This was a new practice in the study area since 2006 and about 10 to 20% of farmers in the area have adopted it to date. As for stone-rows, these are stone obstacles (Plate 2) along a contour that cut down run-off speed. The length of the stone-rows depends on the field size. In our case it was in order of 25 meters and the lines were set up according to the contour lines. The implementing of this structure allowed the sedimentation of soil particles (sands, but

also fine elements, organic matter…) in upstream of the bund an increase the infiltration of runoff water. However, these practices were rarely set up individually and were often combined with each other and using the compost. The following treatments had been identified and studied:

1. Stone-rows + compost (SR + C),
2. Zaï + stone-rows + compost (Z + SR + C),
3. Absolute Witness (AW): plots without tillage or compost corresponding to traditional cultural practices
4. Natural vegetation (NV): tiger / savanna bush never or more than 10 years exploited.

Three cultivated plots with different cultural systems (sorghum, millet, maize) per treatment all located on the mid-glacis in the Sampieri watershed were identified for soil sampling. Surface samples were taken in January 2015 for SR + C, Z + SR + C and AW and completed by NV in February 2016 in the 0-10 cm layer. For each treatment, three elementary samples were collected following the field diagonal and then pooled to form a composite sample. All soil samples were dried in ambient air and then sieved to 2 mm and stored for the various analyzes.

The experimental texture kit named Soil Texture Unit (code 1067) developed by LaMotte company (USA) was used for the determination of the various particles size fractions of the soils after sieving at 2 mm. This test was designed to separate fine earth into three basic mineral fractions independently of coarse elements greater than 2 mm: sand from 2 mm to 50 µm, silt from 50 µm to 2 µm and clay less than 2 µm. Determination of total nitrogen content was realized using an elemental flash pyrolyser analyser (Flash 2000, Thermo Fischer Scientific). For this purpose, soil samples were finely ground (diameter less than 160 µm) and then placed in a tin capsule and introduced into a high-temperature furnace (900 °C) crossed by a current of helium, an oxygen supply causing total combustion. The respective contents of nitrogen (N) are quantified by gas chromatography. Total organic carbon content was determined by the Rock-Eval method (Disnar et al., 2003) using a Rock-Eval 6 Turbo (Vinci Technologies, France). It consists in heating successively between 300 and 650 °C (pyrolysis) and 300 and 850 °C (oxidation) 100 mg of soil sample finely ground beforehand.

Microbial communities characterization was carried out by the MicroResp^{TM} technique (Campbell et al., 2003), which allows the study of the functional diversity of a soil in its entirety without the cultivation of the microorganisms present with the risk of selection phenomena. The MicroResp^{TM} technique is a measurement soil respiration through the quantification of the CO_2 emitted. The principle is based on the capture of CO_2 released by the soils incubated in deep well plates (96 wells) by cresol red placed in detection plates. Soil samples (approximately 0.4 g of soil per well) placed in these wells were previously moistened to about 60% of their maximum water retention capacity. In addition to blank (distilled water), 25 µL of the following 15 carbon substrates added at 30 mg C g^{-1} soil water were used to enrich the incubated soils: glucose, galactose, mannose, fructose, trehalose, sucrose, maltose, mannitol, sorbitol, inositol, glycine, proline, arginine, citrate and malate. Substrates were chosen based on their complexity (i. e. length of the C chain) and diversity concerning their role in the metabolism. Moreover, theses substrates are representative of low molecular weight organic compounds released during the decomposition of plant residues and released

in root exudates (Campbell et al., 2003). All the C sources were obtained from Sigma-Aldrich (Saint-Quentin Fallavier, France). CO_2 released by the soil, after six hours incubation in the dark at 25 °C was captured by the gel. A chemical reaction takes place between the CO_2 formed and the HCO_3^- ion to give, inter alia, H^+; the medium thus sees its pH decreasing causing a change of color of the indicator in the detection plate. The change from pink to yellow was measured before adding substrates and following the 6 hour incubation, using a spectrophotometer at the wavelength of 570 nm (Bio-Tek Instrument, Inc., µQuant – MQX 200). This will make it possible to estimate the rate of respiration of each well. The rate of CO_2 respiration expressed per gram of soil per well was calculated using the formula provided in the MicroResp™ manual (Macaulay Scientific Consulting, UK). The amount of CO_2 produced from the water addition wells was subtracted from the respiration in the substrate wells to accurately calculate the substrate induced response (SIR). The determination of the basal respiration (BR) was calculated from data obtained after soil incubation with water added. Results were expressed in µg C-CO_2 g^{-1} soil h^{-1}. The microbial biomass (MB) was calculated from respiration produced from the glucose amended wells using the equation from Anderson and Domsch (1978). The metabolic quotient (qCO_2) was calculated according to the equation (Anderson and Domsch, 1993): qCO_2: basal respiration / microbial biomass. Higher qCO_2 indicated stress or exogenous disturbance (Anderson and Domsch, 1993). Shannon-Weaver index (H') and equitability index (E) were calculated to subsequently characterize the microbial community. All measurements were done in 6 technical replicates.

Statistical analysis

The data was collected into Excel spreadsheet and then analyzed using ANOVA variance of XLSTAT 7.5 software. Means were separated according to the Tukey test at the 5% threshold. For the MicroResp data, principal component analysis (PCA) using a correlation similarity matrix was used to identify separate groups according to different soils treatments applying the XLSTAT 7.5 software. For soil microbial diversity, two indices cited above were calculated.

The functional diversity as measured by Shannon-Weaver index (H') was calculated using the equation: $H'=-\sum Pi(\ln Pi)$, where Pi was the ratio of the utilization rate of each C source to the sum of the utilization rate of all C source for each soil sample (Zak et al., 1994). Evenness (E) or Pielou index was calculated based on the equation of $E = H'/H'_{max}=H'/\ln S$, where H_{max} was the largest H' within a specific sample (Zhou et al., 2012) and S total number of species, represented here total number of substrates tested.

Table 1: Basic soil properties of Sampieri soil (Bunasols, 2008).

Parameter	Clay	Sand	Silt	C	N	C/N ratio	Pa	pH
Unit	%	%	%	$mg.g^{-1}$	$mg.g^{-1}$	-	$mg.g^{-1}$	-
Value	8-10	37-51	39-55	4.5	0.4	10-13	0.0014	6-6.6

Plate 1: Photograph of fields cultivated in zaï (Sampieri 2014) on the mi-glacis of the catchment area.

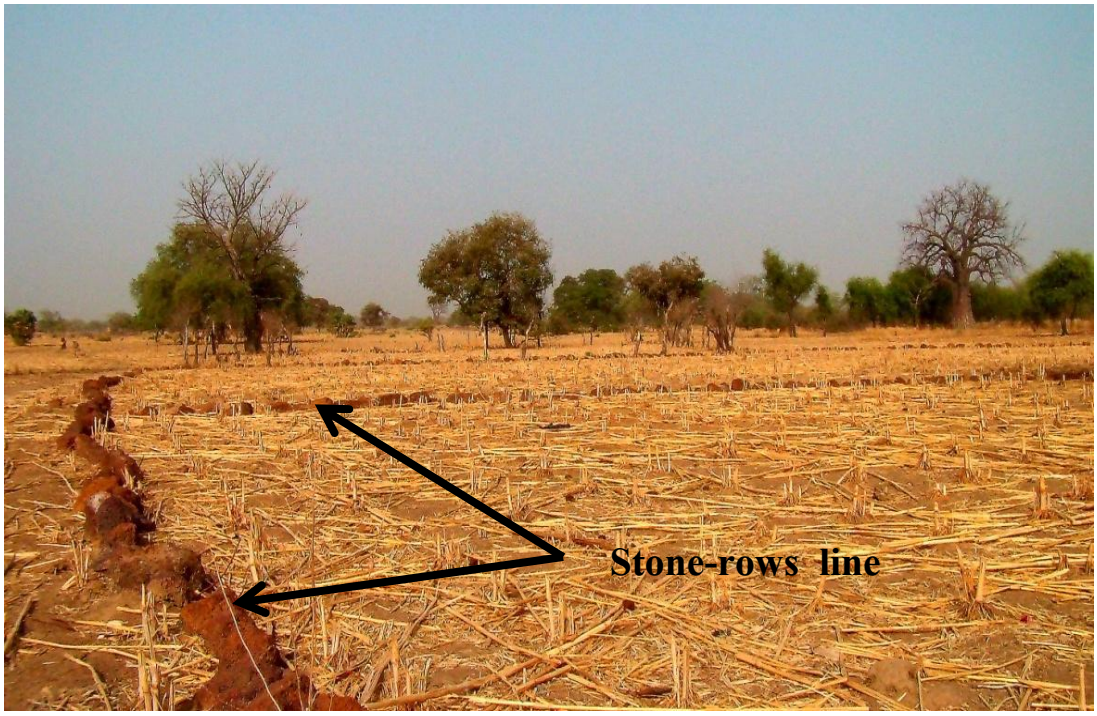

Plate 2: Photograph of stone-rows line on a cultivated field (Sampieri 2014) on the mi-glacis of the catchment area.

RESULTS

Soil physical and chemical properties

Soil fine fraction (0-50 µm) ranged from 29.44% to 60.56% for the controls and for the Z + SR + C treatments respectively in the surface layer and there is significant difference between Z + SR + C, SR + C, NV and AW. No Significant difference was found in soil pH and available phosphorus (Pa) across the treatments. Electrical conductivity (EC), C and N were always higher in the agroecological treatments and NV than for AW. For these parameters, significant differences were found across treatments (Table 2). There was a decrease in the C/N ratio for the agroecological treatments compared to the AW with significant differences between treatments. However the low ratio is obtained on NV treatment with significant difference with other treatments except for SR+C.

Utilization of C sources by soil microorganisms

Catabolic response profiles in all soils showed a difference in the substrates used by microorganisms. The higher respiration rate was found by fructose, mannose and galactose. The lowest values were produced by mannitol, citrate and proline. The low values for these substrates were almost similar to that of water.

Catabolic response profiles were able to establish differences in the soil microbial community under different cultural practices. Therefore, the average of SIR among the agricultural practices increased in order of AW<CP + C<Z + CP + C<NV treatments (Figure 1). There were also significant differences among our four agricultural practices according to the substrate-induced respiration (SIR).

Basal respiration, microbial biomass, metabolic quotients and soil community diversity

Basal respiration (BR: without carbon substrates) showed a low CO_2 release for the control compared to the other treatments. The CO_2 concentration were 0.019 µg C-CO2 $g^{-1}h^{-1}$ for the control to 0.103 µg C-CO_2 g^{-1} h^{-1} for SR + C, with 0.094 µg C-CO_2 g^{-1} h^{-1} for Z + SR + C and 0.090 µg C-CO_2 g^{-1} h^{-1} for NV (Figure 2) with significant differences between control and other treatments. This production of CO_2 was accentuated with the addition of the different carbon substrates. Microbial biomass ranged from 1.779 µg biomass-C g^{-1} in AW to 6.098 µg biomass-C g^{-1} in NV (Figure 3) and there was significant difference across agroecological treatments and AW.

The metabolic quotient (qCO_2) values were always higher under agroecological treatments (Z + SR + C and SR + C) than NV and AW and there was significant difference between agroecological treatments and AW (Table 3). For Shannon-Weaver index (Table 3), which reflects the functional diversity of the microflora by measuring the number of substrates metabolized by the soil microbial community, there was a significant difference between treatments. The equitability index of microbial populations, a measurement of the variability in substrates use, also confirmed the difference between treatments. Indeed, this index varied from 0.302 for the absolute witness (AW) to 0.996 for SR + C (Table 3) and there was significant difference across agroecological treatments, NV and AW.

Our results also showed a positive correlation ($p<0.01$) between the soil microbial biomass, metabolic quotients, Shannon-Weaver, equitability index and total carbon content (Table 4). We also found that the positive correlations between soil nitrogen content and microbial biomass ($p<0.01$), H' and E ($p<0.05$) were significant. Positive

correlations were determined between SIR ratio and microbial biomass, basal respiration, Shannon-Weaver and Equitability index ($p<0.01$) and soil carbon and nitrogen content ($p<0.05$). EC was positively correlated to basal respiration ($p<0.05$) and metabolic quotients ($p<0.01$). C/N ratio was negatively correlated to clay content and ($p<0.05$) almost to all microbiological parameters of the soil ($p<0.01$) in exception of qCO2. There was also positive correlations between soil clay content and MB, BR, qCO_2, C, SIR ($p<0.05$) and H', E ($p<0.01$).

PCA analysis on the microbiology data set showed that two factors F1 and F2 explained 98.5% of the total variability (Figure 4). Three groups (Figure 4) of elements discriminated in the F1–F2 plane represented by the qCO_2 (group 1), SIR and BM (group 2) and E, BR and H' (group 3). Thus, referring to the F1 F2 chemical space (Figure 5), group 1 corresponded to SR+C and Z+SR+C; group 2 corresponded to NV soil and group 3 to SR+C. Analysis of the AW soil are not correlated with any microbial parameters. All these parameters are correlated to agroecological and natural vegetation soils. Figure 5 also shows that microbial communities of soils with agroecological treatments and natural vegetation (SR + C, Z + SR + C and NV) had a significantly different structure compared to soils with absolute witness (AW).

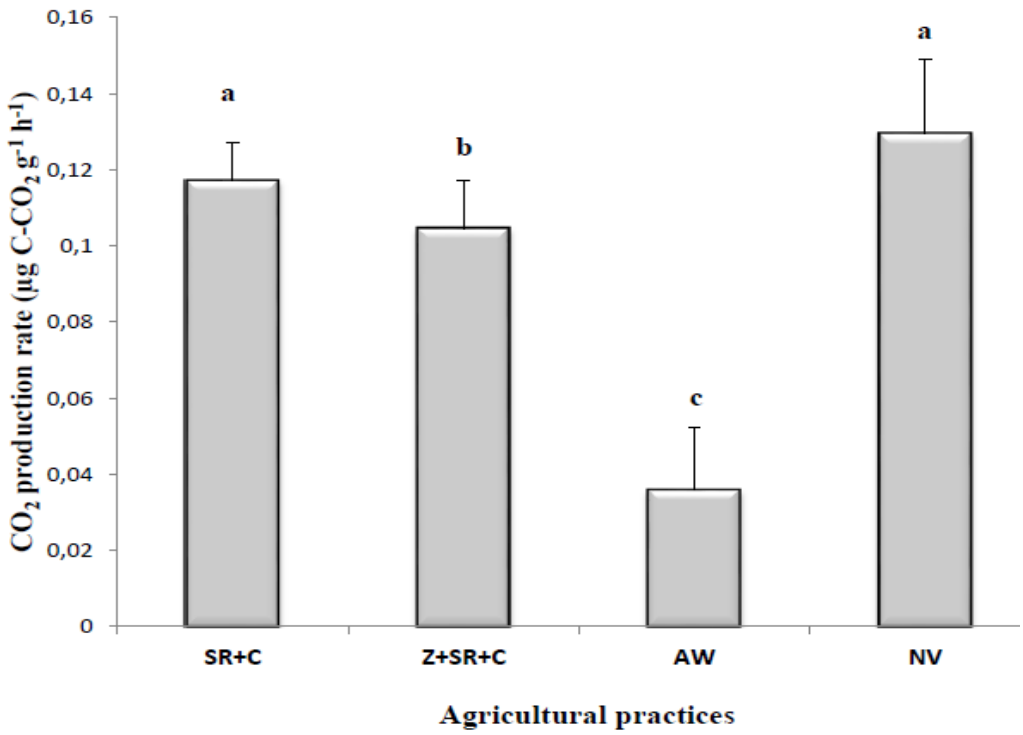

Figure 1: Catabolic response (mean values ± standard deviation n=18) profiles by soil microorganisms under different agricultural practices. Different letters at each sample indicate significant differences at $P < 0.05$ according to Tukey's test.

Table 2: Soil properties under different practices.

Agricultural practices	Soil fine fraction ≤50 µm (%)	Clay (%)	pH	EC (µS/cm)	C (mg g^{-1})	N (mg g^{-1})	C/N	Pa (mg g^{-1})
SR + C	60.56 (6.94) a	5.22 (0.38) b	6.27 (0.46) a	783.30 (40.02) a	6.83 (0.29) a	0.57 (0.04) b	12.07 (1.36) bc	0.05 (0.02) a
Z + SR + C	58.34 (8.33) a	8.66 (0.58) a	6.31 (0.35) a	744.07 (5.74) a	7.30 (1.73) a	0.56 (0.06) b	12.99 (1.93) b	0.031 (0.01) a
AW	29.44 (2.55) b	3.44 (0.19) c	5.56 (0.79) a	292.99 (11.15) b	4.03 (0.81) b	0.17 (0.01) c	23.23 (4.93) a	0.027 (0.01) a
NV	51.67 (2.89) a	7.22 (0.96) a	6.62 (0.31) a	233.03 (8.92) c	5.97 (0.29) ab	1.17 (0.26) a	5.36 (1.63) c	0.027 (0.002) a

Data in the column are mean values and the values in the parentheses represent the standard deviation (n=3). In the same column different letters indicate significant different among practices ($P < 0.05$). EC: electrical conductivity; C: soil total organic carbon; N: total nitrogen; C/N: ratio carbon to total nitrogen; Pa: available phosphorus.

Table 3: Soils metabolic quotient and diversity index.

Agricultural practices	qCO_2(µg C-CO_2 g^{-1} biomass-C h^{-1})	Shannon-Weaver Index (H')	Equitability Index (E)
SR + C	0.020 (0.001) a	2.697 (0.009) a	0.996 (0.003) a
Z + SR + C	0.021 (0.0008) a	2.691 (0.014) a	0.994 (0.005) a
AW	0.011 (0.004) b	0.817 (0.59) b	0.302 (0.19) b
NV	0.015 (0.0001) ab	2.683 (0.009) a	0.991 (0.003) a

Data in the column are mean values and the values in the parentheses represent the standard deviation (n=3). qCO_2 metabolic quotient is the ratio of basal respiration to microbial biomass, H 'reflects the microbial functional diversity; E reflects the richness of the microbial population in terms of substrates utilization.

Table 4: Correlations between soil chemical, physical and microbial properties.

	MB	BR	H'	E	qCO_2	N	C	Pa	SIR	EC	C/N	Clay
MB												
BR	**0.893****											
H'	**0.899****	**0.970****										
E	**0.899****	**0.970****	**1.000****									
qCO_2	0.440	**0.767****	**0.727****	**0.727****								
N	**0.711****	0.546	**0.665***	**0.665***	0.171							
C	0.567	**0.791****	**0.760****	**0.760****	**0.833****	0.337						
Pa	0.177	0.299	0.264	0.264	0.390	-0.004	0.241					
SIR	**0.987****	**0.913****	**0.925****	**0.925****	0.500	**0.648***	**0.608***	0.201				
EC	0.186	**0.578***	0.497	0.497	**0.811****	-0.229	**0.648***	0.384	0.291			
C/N	**-0.832****	**-0.737****	**-0.808****	**-0.808****	-0.271	**-0.886****	-0.380	-0.059	**-0.791****	-0.048		
Clay	0.629*	0.705*	**0.731****	**0.731****	0.578*	0.493	0.617*	-0.074	0.641*	0.305	-0.612*	

Mb: Microbial biomass, BR: basal respiration SIR: microbial substrate-induced respiration data obtained with the MicroResp^{TM} system for all substrates in the investigate soils, qCO_2: metabolic quotient, H ': Shannon Weaver diversity index which reflects the microbial functional diversity; E: equitability index which reflects the richness of the microbial population in terms of substrates utilization. *Significant at the 0.05 probability level; **Significance at the 0.01 probability level.

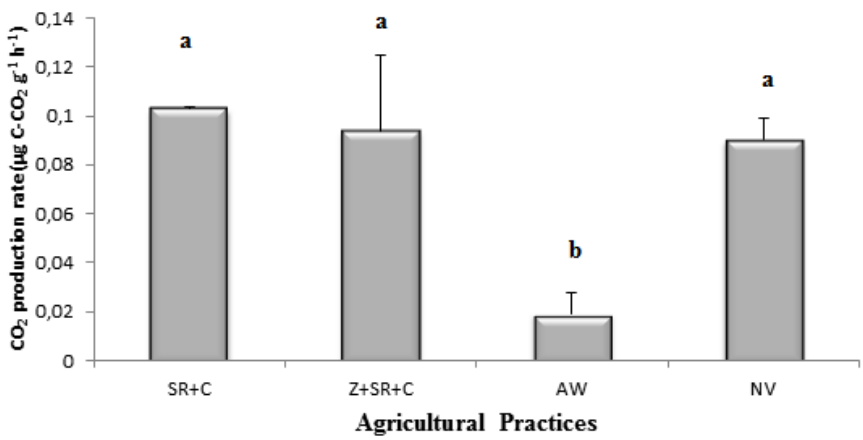

Figure 2: Basal respiration (BR) of the soil for different treatments. These values indicate the rate of evolution of CO_2 from these soils without the addition of organic substrates before incubation. Error bars indicate the standard deviations of the means of replicates (n=18). Different letters at each sample indicate significant differences at $P < 0.05$ according to Tukey's test.

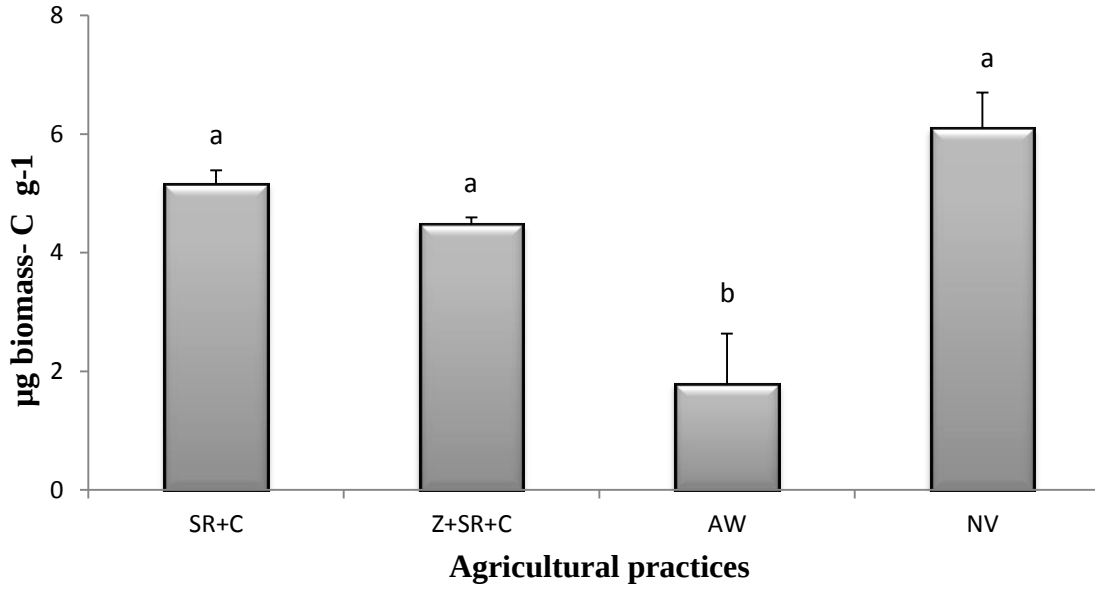

Figure 3: Soil microbial biomass (MB) evaluated from soils with the different treatments. These values indicate the rate of evolution of CO_2 evaluate by respirometry from these soils after glucose addition and 6 h incubation. Error bars indicate the standard deviations of the means of replicates (n=18). Different letters at each sample indicate significant differences at $P < 0.05$ according to Tukey's test.

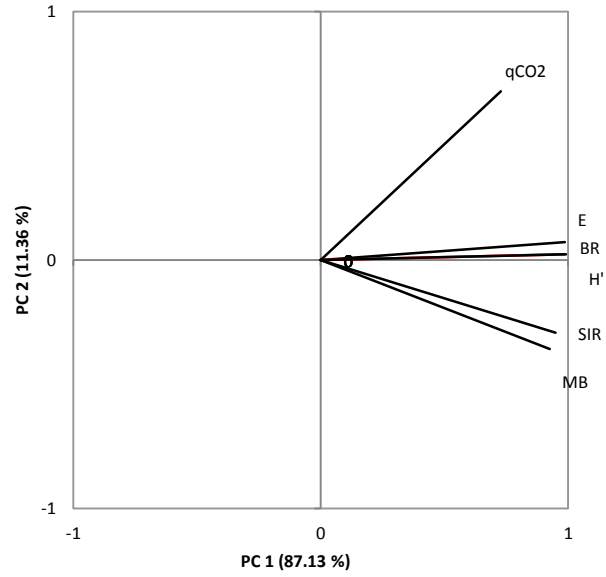

Figure 4: Correlation circle of variables of principal component analysis of soil microbial activities data. BR: basal respiration; MB: microbial biomass; qCO_2: metabolic quotients; H': Shannon-Weaver diversity index; E: equitability index; SIR: respiration induces by substrates.

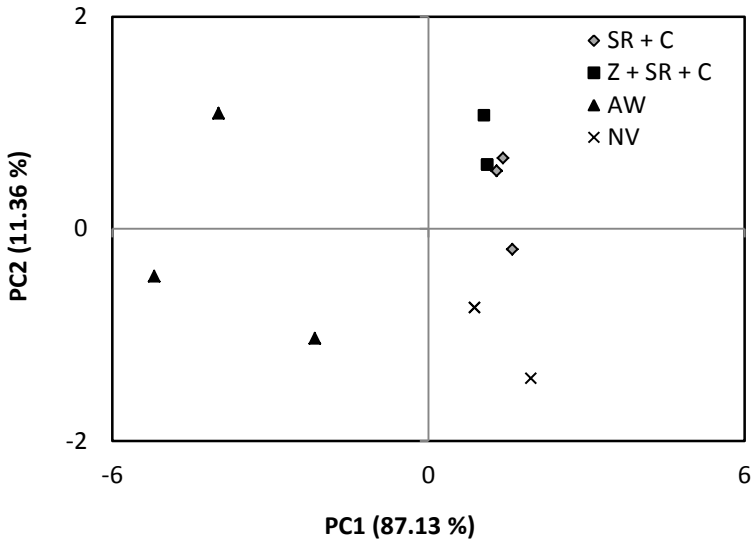

Figure 5: Projection of the samples on the first factorial plane according to the different treatments. SR + C: stone-row plus compost; Z + SR + C: zaï plus stone-row and compost; AW: absolute witness; NV: natural vegetation.

DISCUSSION

Compared to AW, there was a clear increase in the fine elements content for the agroecological plots (SR + C and Z + SR + C) and Natural Vegetation (NV) for the surface layer. This is due to the fact that all agroecological treatments use stone-rows or zaï pockets. Stone-rows, which can be assimilated to physical barriers, favor sedimentation of fine soil particles. Moreover, it has been shown that zaï and assimilated techniques reduced run-off water, thus save water and to avoid land losses. Compared to traditional techniques, run-off and erosion can be reduced by 10 times (Bouzou-Moussa and Dan-Lamso, 2004). There is no significant difference between the treatments for soil pH but the results showed that cultivation without addition of organic matter is characterized by a decrease in soil pH. Although there is no significant difference for pH, its increase in agroecological fields can be explained by the addition of organic matter (compost). Bambara et al. (2012) had found the same results on fields laid out in zaï and bunds of 9 to 10 years. Additionally, the levels of organic carbon and total nitrogen (N) are improved for Z + SR + C and SR + C treatments compared to the AW. It is well established that in these agrosystems, except the organic matter from the roots, exogenous organic matter are the main sources of nitrogen on the soil. The contribution of large quantities of compost (6 tons ha^{-1} $year^{-1}$) makes it possible to explain this figure. The sedimentation of solid particles transported in run-off water due to stone-rows may also contribute. Owing to these various elements of soil fertility, although the retention of the particles contained in the run-off water plays an important role in raising their level, we must recognize that these techniques for water and soil conservation alone without the addition of organic substrates (manure or compost in particular) would not achieve these results (Sawadogo et al., 2008). We also observe that restoration of organic C seemed to be faster than the restoration of N contents. The same trend was observed by N'Dour et al. (2000) in Senegal on fallow-land of 20 years. This can be explained by the quality of the material supplied, but also by the fact that nitrogen is quite volatile and is widely used during the plant growth campaign on the one hand, but

also by microorganisms on the other. In addition, there is a decrease in the C / N ratio for the soils with agroecological practices compared to AW. This can be assimilated to an improvement in the status of the organic matter brought to the soil. The evolution of organic matter incorporated in the soil is accompanied by a progressive decrease of the C / N rate. According to the latter, the contributions of compost, mainly repeated, make it possible to substantially increase parameters such as pH, organic carbon and total nitrogen. Good agricultural practices for soil fertility management significantly improve physical and chemical characteristics of soils (Nacro et al., 2010; Somé et al., 2015). Generally speaking, intake of organic manure is a source of energy and food for soil microbial communities, which promotes nutrient availability (Yaméogo et al., 2013).

Substrates used in this study can be classified into different groups namely sugars, amino acids, organic acids and polyol compounds. The use of these substrates characterized by CO_2 production testifies to the diversity that can be found in our soils. Results have shown that SIR was lower compared to those of Jiang et al. (2012) but similar to Diakhaté et al. (2016) even if the substrates used were somewhat different from ours. In addition, unlike the results from others studies, fructose and mannose had a greater level of SIR in all treatments (Diakhaté et al., 2016) funding. Additionally the lowest values that were almost similar to water are proline and citrate used as carbon substrates. This variation in C substrates used supposes diversity in the microbial communities (Jiang et al., 2012) in the different soil samples. This variation in C sources used by microorganisms was confirmed by the microbial biomass for different agricultural practices. Dabré et al. (2017) have found the same results regarding zaï with or without the addition of the amendments compared to the control

Metabolic quotient (qCO_2) can be used to understand the effect of external changes on the soil microbial community. Although the values of qCO_2 were low in general, there still was still a significant difference between agroecological fields' values and other treatments. The values were lower for AW and NV than for agroecological treatments. This may well be understood given the external contribution of compost and fine soil particles generated by the practices that have induced drastic changes in the habits of these soils.

Moreover, the equitability and Shannon-Weaver indices were functions of the applied treatments and the values of these 2 indices were better for the agroecological field compared to the absolute witness. As a result, agroecological practices showed a better distribution of soil microorganisms. For those indexes, our result was conformed to Doamba et al. (2011). Campbell et al. (2008) showed in a similar experiment that agricultural land-use practices could have significant effects of the same order as ours in this study.

In addition, unlike Austin et al. (2009) results in the Southeastern United States, there were positive correlation between soil carbon content and soil microbial biomass, metabolic quotients, Shannon-Weaver, equitability index. Moreover, it was found a negative correlation between C/N ratio and to almost all microbiological parameters of the soil ($p<0.01$) in exception of qCO_2. This was in opposite to a previous study (Spohn, 2015) that reported a positive correlation between litter layer C/N and qCO_2. In addition, PCA analysis confirmed this by showing and separating groups between agroecological practices and absolute controls. These results showed that agricultural practices affect soils both physical and chemical characteristics which in turn will influence soil micro-organisms with consequences on their biological functioning (Lienhard et al., 2013).

In addition, a positive correlation between SIR and soil total N content was found. This result was confirmed by Lagomarsino et al. (2007) founding's. It is therefore obvious that the activity of soil micro-organisms depends on the physical and chemical conditions. This is confirmed by our results as there was an improvement in soil microbial activity with or without the addition of carbon substrates for soils under agroecological practices compared to the absolute witness (AW). The placement of the stone-rows combined with the compost and the zaï may help to improve these characteristics. In addition, to allow the sedimentation of fine particles, stone-rows also made it possible to slow down the run-off of rainwater and thus reduce the phenomenon of erosion (Zougmoré et al., 2004). This results in an increase in water infiltration, an improvement in the organic status of soils (OM in these waters) upstream of stone-row lines. All this contributes to creating favorable conditions for the development of soil micro-organisms, hence shown by the strong biological activity recorded at these soils relative to the absolute witness. There is strong evidence that stony cords would enhance the potential for mineralization of agricultural soils (Doamba et al., 2011). However the stone-rows alone could not lead to a depletion of the soil in organic compounds if the technique is not accompanied by a supply of manure or compost to compensate for the deficit that could be created by the acceleration of processes of mineralization (Douamba et al., 2011). Hence the combined effect of compost and stone-rows contribution observed on our soils. This resulted not only in an improvement in the levels of different fertilizing elements of the soil but also in the biological activity of these soils. Moreover, the improvement of these soil qualities could even be the explanatory and determining elements of the biological activity recorded on the level of the modified soils compared to the controls.

Conclusion

This study was conducted in Eastern Burkina Faso in an area of high climatic contrast and advanced state of soil degradation. It proved that agroecological practices of water and soil conservation are important for the maintaining and fertilization of agricultural soils. Thus the practice of zaï and stone-rows combined with the application of compost made it possible to raise soil physical and chemical properties (pH, organic carbon, total nitrogen, C/N ratio, EC and Pa) levels compared to absolute witnesses. Additionally, these practices had positive effect on soil mineralization potential and the diversity of microorganisms present as confirmed by substrate-induced respiration (SIR), basal respiration, metabolic quotients (qCO_2) and the associated indexes. Therefore it's absolutely necessary to combine these techniques to optimize their agroecological more value. The efficiency of the components of these practices could allow the improvement of the productivity of degraded soils in the Sudano-Sahelian zone.

COMPETING INTERESTS

The authors declare that they have not competing interests

AUTHOR'S CONTRIBUTIONS

AC designed and carried out the work, EH and MM-H designed and supervised the work, SB designed and supervised microbiology part of the work and provided some literature information and also read and approves the final manuscript.

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