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Effects of Soil and Water Conservation Techniques on Soil Properties under Degraded Lands in Burkina Faso

François Wenemi Kagambèga[1], Salifou Traoré[2], Adjima Thiombiano[3] Anne Mette Lykke[4], & Joseph Issaka Boussim[5]

Abstract:

Land degradation is a major issue in the West African Sahel for human livelihoods. A better understanding of soil and water conservation practices' effects on soil nutrients is necessary for their further development. A study was conducted on encrusted sealed bare Luvisols in Central and Northern Burkina Faso to assess the effects of half-moon (HM), sub-soil tillage (ST) and zaï system (Zaï) on soil physical, chemical and biological proprieties. Soil texture was significantly affected by techniques resulting in fines particles particularly in HM system and in ST in a lesser extend. HM technique followed by ST and Zaï, contribute significantly to enhance total organic carbon, total nitrogen, calcium, magnesium, phosphorus and soil pH as well as soil microbial biomass and basal respiration. Soil microbial biomass and basal respiration were significantly ($p<0.05$) correlated with clay fraction, Soil Organic Carbon (SOC), total N, pH and calcium. These results suggest that the techniques alter soil nutrient and that SOC, pH and phosphorus are mitigating factors that affect the microbial activities. Among the studied techniques, HM system proved to be better in terms of enhancing soil proprieties. Therefore, it may serve as a useful and inexpensive approach to rapidly reclaim degraded soils.

Keywords: Land reclamation; Soil properties; Microbial activity; Soil erosion; Vegetation cover.

1. Introduction

Land degradation has emerged as an environmental crisis, which continues to threaten the lives and livelihoods of many people worldwide. Improper land use, drought, vegetation loss, soil erosion are the principal agents (Lal, 2004; Khanmirzaei et al., 2011; Zhang et al., 2017) and soils play a central role in protection and regulation of land resources. Degradation of soil quality is manifested through water and wind erosion, organic matter and nutrient depletion, soil compaction, soil acidity, and decreased microbial activity (Bezdicek et al., 2003). The African continent is seriously threatened by this phenomenon as mentioned in various studies (Thiombiano et al., 2007). An estimated US $ 42 billion in income and 6 million ha of productive land are lost every year due to land degradation and declining agricultural productivity (UNDP-GEF, 2004).More than half of all African people are affected by land degradation, making it one of the continent's urgent development issues with significant cost. Indeed, Africa is burdened with a US $ 9.3 billion annual cost of desertification (Bationo et al.,2007). Like others Sahelian countries, Burkina Faso is facing significant and continuous degradation of its natural resources (Zombre, 2006; Kagambèga et al., 2011a).

[1] Department of Environment and Forest, Institute of Environment and Agricultural Research (INERA), 03 BP 7047 Ouagadougou 03, Burkina Faso; Corresponding author email: wenemifrancois@yahoo.fr; Tel: (+226)70747578
[2] Laboratory of Plant Biology and Ecology, University of Ouaga I Pr Joseph Ki-Zerbo, Ouagadougou, Burkina Faso
[3] Department of Bioscience, Aarhus University, Aarhus, Denmark
[4] Department of Bioscience, Aarhus University, Aarhus, Denmark
[5] Laboratory of Plant Biology and Ecology, University of Ouaga I Pr Joseph Ki-Zerbo, Ouagadougou, Burkina Faso

The combined effect of low soil fertility, mismanagement of ecosystems, extreme climatic conditions and increasing erosion has ultimately resulted in bare and indurate soils called "Zipellés" in Burkina Faso, or harde soils in Chad (Zougmoré et al., 2003a). Nearly 24% of the soils of Burkina Faso have been reduced to zipellés, most notably in the central and northern regions (Zougmoré et al., 2004). This has major economic consequences for the country, as agricultural and pastoral activities are practiced by 86% of the population. This phenomenon reduces the agricultural potential of the lands, resulting in poverty and immigration. Consequently, land rehabilitation is essential to reverse the trend of degradation and improve the productivity of soils by enhancing their quality and following the life quality in local communities. Traditionally, soil quality has been mainly associated with forest productivity (Hornik, 1992), whereas more recently the definition has been expanded to include the capacity of a soil to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran & Parkin, 1994). Soil quality can be improved by reducing soil erosion through improved infiltration and soil structure, have been reported in several studies.

Various studies conducted in the sahelian area have shown that soil restoration methods using digging pits or furrows conservation tillage and adding manure can improve soil physical properties, reduce wind and water erosion in the sealed bare soils (Zougmoré et al., 2003b; Roose, 2004; Ganaba, 2005). The techniques such as zaï, sub-soil tillage and half-moon are particularly effective in reducing runoff and improving infiltration. Their socio-economic importance and their effect on increasing yield and soil hydrodynamic are well known (Zougmoré et al., 2004; Kagambèga et al., 2011b). However, comparatively little information is available on their effect on the changes in soil organic matter and nutrients, in particular biological activity. A better understanding of their long-term effects on soil organic matter, nutrients and microbial activity is also necessary for their further development in dryland areas. In the present study, we investigated the behaviour of soil parameters related to soil fertility under a well-designed field. The objective was to evaluate the effects of three soil and water conservation techniques (half-moon, sub-soil tillage and zaï) on soil physical, chemical and microbiological properties under realistic conditions in two climatic zones in Burkina Faso and thus contribute to the understanding of soil degradation and sustainable management of encrusted sealed and bare soils.

2. Materials and methods

2.1. Study site description

The study was carried out at two experimental sites (2007 - 2010) located in the central and northern Burkina Faso, in the villages of Gampèla near the city of Ouagadougou (12° 25' N and 1° 21' W) and Baporé near the city of Ouahigouya (13°33' N and 2°20' W). The climate is of Sudano-Sahelianand Sahelian type with 600-700 and 500-600 mm annual precipitation respectively with two contrasted seasons: a long dry season from October to May and a short rainy season from June to September. Phytogeographically, the study sites are located in the following sectors defined by Fontes & Guinko (1995). Temperatures are subjected to high fluctuations ranging from 25°C in December-January to more than 40°C in April-May. In the experimental plots, the soil type is a Gleyic-Luvisol in Gampèla and Leptic-Luvisol in Baporé, according to the FAO/UNESCO soils' classification.

2.2. Experimental design and treatments

Field experiments were established in May 2007 at each study site. Until this date, the fields of the study sites were cropped mainly with cereals and had become since a decade, an extensive pasture ground for wandering livestock and cattle in which the soils are barren and whitish at the surface with a low gradient slope of 1-2%. The surface crust has as consequence a very poor permeability that prevents water infiltration and accentuate run-off. Prior to these experiments, soils were sampled at random locations in each site; the mean results of the soil analysis revealed soils to be acidic with silt loam surface soil texture, and low in organic C, N and cationic exchange capacity (Table 1).
The experiments combined soil restoration methods with plantation of Faidherbia albida and were designed as a randomized completed block with four treatments and three replicates (Figure 1).

Table 1. Soil profile characteristics before treatments application in the two experimental sites, investigated and measured in 2007 (10 samples each, SD = standard deviation)

Soil parameters	Horizon depth (cm)	Gampèla (Mean±SD)	Baporé (Mean±SD)
Clay fraction (%)	0–20	15.8 ± 0.5	29.8 ± 6.6
	0–60	42.8 ± 0.6	31.4 ± 3.5
Silt fraction (%)	0–20	43.7 ± 1.4	31.7 ± 2.6
	0–60	46.5 ± 2.1	32.1 ± 3.4
Sand fraction (%)	0–20	40.5 ± 2.5	38.5 ± 5.2
	0–60	10.7 ± 0.5	35.5 ± 2.1
Useful available water (%)	0–20	8.8 ± 0.9	12.1 ± 1
	0–60	11.6 ± 1.91	13.7 ± 2.1
Soil pH (H_2O)	0–20	5.4 ± 0.4	5.1 ± 0.2
	0–60	6.5 ± 1.2	5.04 ± 0.1
Total carbon ($g.kg^{-1}$)	0–20	4.75 ± 1.1	5.1 ± 1.1
	0–60	3.80 ± 0.8	5.2 ± 2
Total nitrogen ($g.kg^{-1}$)	0–20	0.37 ± 0.1	0.42 ± 0.1
	0–60	0.32 ± 0.1	0.41 ± 0.2
Exchangeable bases ($cmol.kg^{-1}$)	0–20	3.3 ± 1.1	2.8 ± 0.6
	0–60	3.2 ± 0.4	3.3 ± 0.4
Cationic exchange capacity ($cmol.kg^{-1}$)	0–20	4.9 ± 0.7	4.5 ± 0.9
	0–60	9.4 ± 0.6	5.2 ± 0.7

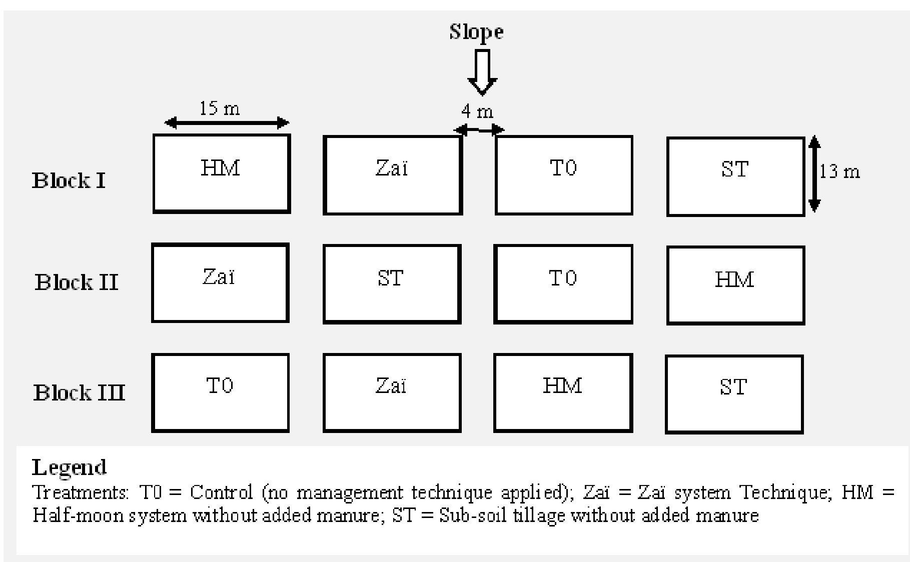

Figure 1. Experimental design of soil management experiments. T0 = control; ZAÏ = zaï system; HM = half-moon and ST = sub-soil tillage.

The four different treatments were applied to the experimental plots since 2007, each with three replicates resulted in a total of 12 plots per site. Each plot was 15 m by 13 m in size, spaced 4 m apart.

The sub-soiling technique involves tilling the soil deeply to break up the sub-soil. In this study a tractor was used to create furrows (5 per plot) of 40-60 cm deep and 15 m long, spaced 3 m apart.

The half-moon technique is designed to collect surface runoff by the excavation of hollows on bare and crusted soils with gentle slopes (Zougmoré et al., 2003a). Each hollow was 10–15 cm in depth, dug with a hoe or a pick with the excavated earth returned to form a mound in the shape of a half-circle. In this study, half-moons (20 per plot) were 2m in diameter, spaced 1 m apart in rows approximately 3 m apart (Figure 2). 'Zaï' is a traditional technique used in the Sahel of West Africa for the rehabilitation of degraded and crusted soils. Zaï Technique involves manually digging pits to collect surface runoff, to which are added some form of organic material, usually manure (300 g per pit). Zaï pits (20 per plots) were constructed with 20 cm in diameter, 10-15 cm deep and 3 m apart.

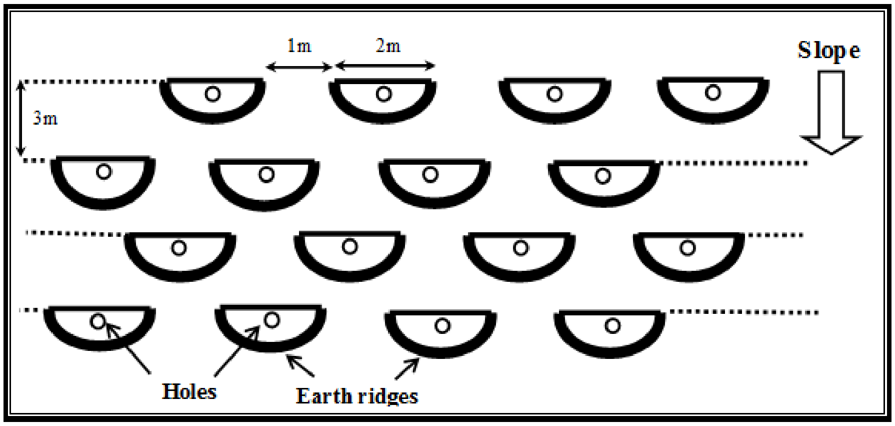

Figure 2.Diagram of half-moon disposition according to the slope

2.3. Soil sampling

Soils were sampled at the beginning of the dry season. In October 2010 (three years after the establishment of the experiments), composites soil samples (0–20 cm depth) were collected with an auger in all treatments (T0, ST, HM and Zaï). A composite sample is a homogenous mixture of three randomly collected subsamples, one from each repeated treatment plot. Five replications were taken from each treatment in the two experimental sites. Thus, a total of 40 soil samples kept in plastic bags on ice were transported to the soil laboratory. After carefully removing the surface organic materials and fine roots, each mixed soil sample was divided in two. One part was air-dried, passed through a 2 mm sieve for the estimation of soil physicochemical properties. The other part of the sample destined to the estimation of soil microbial biomass and soil respiration, was stored in the laboratory at 4°C until analysis. These analyses were conducted in December 2010.

2.4. Soil analysis process

Soil texture was determined with the Robinson pipette method after destruction of soil organic matter with hydrogen peroxide (H_2O_2); the particle size distribution includes percent clays (<2 µm), fine silt (2–20 µm), coarse silt (20–50 µm), fine sand (50–200 µm), and coarse sand (200–2000 µm); Soil pH was measured with a glass electrode using a 1:2.5 soil to water ratio; total organic carbon (TOC) and total nitrogen (N) was determined by Walkley and Black method (Nelson & Sommers, 1982) and by Kjeldahl method (Bremner & Mulvaney, 1982) respectively; available P was measured colorimetric ally; available K by flame photometry; cation exchange capacity (CEC) by extraction with ammonium acetate; available Ca, available Mg were also determinate. Soil microbial biomass was measured with the chloroform-fumigation-incubation (CFI), method suitable for soils with high clay and low organic carbon contents (Kaiser et al., 1992). Then, 200 g of soil were divided into two equal fractions and moistened to 60% water holding capacity (WHC). The first fraction was fumigated for 24 h with ethanol free chloroform.

After removing the fumigant by repeated evacuation, samples were readjusted to 60% WHC and incubated with the unfumigated portion in the presence of NaOH (0.5N) to absorb any CO_2 released from the soil (Wang et al., 2003). To simulate the effects of the temperature increases in the Sahelian area, incubation conditions were set at 28 °C, and the incubation period reduced to 7 days (Chaussod et al., 1986). The soil microbial biomass (Cmic) was calculated by dividing the difference in CO_2– C production between fumigated and unfumigated soils with a conversion factor of 0.41 (Nicolardot et al., 1984). The results were expressed as µg-C.g^{-1} soil.

To measure soil basal respiration (Cresp), 100 g unfumigated dry soil was placed in an airtight glass flask, moistened to 60% water-holding capacity and incubated in the dark at 28 °C. The CO_2 respired was measured every day as described by Traore et al. (2007). The value of CO_2 evolved in a glass flask without soil was subtracted from the value of CO_2 evolved from the soil sample. Metabolic quotient (qCO_2) or respiration quotient defined as the respiration produced per unit of microbial biomass and expressed as (mg CO_2-C g^{-1} per day biomass C), was calculated from the ratio between soil microbial biomass and soil basal respiration.

2.5. Data analysis

The different physical and chemical properties of soil samples mentioned as a depend invariables and soil management practices as independent variable were statistically tested. Data were analysed using one way analysis of variance (ANOVA) and Turkey HSD test to compare soil variables between treatments. Significant levels were established at $p < 0.05$. Pearson's correlation was used to analyse linear relationships between variables. The statistical analyses were computed using the General Linear Model Procedure of JMP 9 (SAS, 2010). These data fulfilled the assumptions of normality and homogeneity of variance.

3. Results

3.1. Soil physical and chemical properties

Variations in soil texture under the treatments plots in the different sites are shown in Table 2. In Gampèla, the soils under HM were considerably higher in clay and fine silt, and slightly higher in coarse silt than the soils under the others treatments. Accordingly, the sand content was the lowest in the soils under HM treatment and the highest under the control. In Baporé, although the differences were not significant, clay content and coarse silt were the highest in HM and ST treatments followed by zaï treatment and the lowest in control; Fine silt and sand content (fine or coarse) followed the same trend as in Gampéla.

Some chemicals properties of the soils are presented in Table 3. In Gampèla, soil total organic carbon (C_{total}) content was significantly higher in HM treatment than that of the others treatments; despite the no significant difference between ST, Zaï and control, the values were the highest in SS followed by Zaï. However in Baporé, C_{total} was significantly higher in HM, SS and Zaï treatments than control. In the two sites, total nitrogen (N_{total}) followed the same trend as the C_{total} variation in relation to treatments. Furthermore, Calcium (Ca), Magnesium (Mg) and pH (H_2O) had the same trend as well as available potassium (K) although the differences were not always significant. But the C/N relation did not follow the trend. Available plant phosphorus (P) amount was the highest under Zaï treatment in the two sites.

Table2. Means (N = 5) and standard deviation (SD) of soil texture under the different treatments in the rehabilitated sites (Gampèla and Baporé) in 2010.

Sites	Gampèla				Baporé			
Parameters	HM	ST	T0	ZAÏ	HM	ST	T0	ZAÏ
Glay (%)	24.7 a	21 ab	18 b	18.1 b	29.5 a	28.8 a	26.6 a	28 a
(SD)	(6)	(1.8)	(0.8)	(3.7)	(2)	(3)	(3.4)	(2.5)
Fine silt (%)	11.3 a	8.6 b	8.4 b	6.8 b	10.6 a	11.2 a	8 b	9.3 ab
(SD)	(1.9)	(1.7)	(1.3)	(1.2)	(1)	(1.8)	(2.4)	(0.7)
Coarse silt (%	23 a	19.6 ab	19.2 ab	18.2 b	13.3 a	11.1 a	9.9 a	10.2 a
(SD)	(4.4)	(3.2)	(0.6)	(2.7)	(3)	(4.5)	(0.5)	(6)
Fine sand (%)	20.2 a	22.8 a	23.4 a	21.1 a	31.9 ab	31.2 ab	35 a	31 b
(SD)	(2.3)	(1.9)	(2.4)	(1.5)	(2)	(3.1)	(2.4)	(4.9)
Coarse sand (%)	20.8 c	28 b	31 ab	35.8 a	14.7 c	17.4 b	20.5 b	21.5 a
(SD)	(7.6)	(5.9)	(2.3)	(7.8)	(2.6)	(4.5)	(1.9)	(3.9)

Letters within a line that are different indicate significant differences in means (p<0.05) between treatments on each site in 2010

Table 3. Means (N = 5) and standard deviation (SD) of chemical soil parameters under the different treatments in the rehabilitated sites (Gampèla and Baporé) in Burkina Faso

Sites	Gampèla				Baporé			
Soil parameters	HM	ST	T0	ZAÏ	HM	ST	T0	ZAÏ
C_{total} ($g.kg^{-1}$)	6.6 a	4.6 b	3.9 b	4.2 b	5.9 a	5.7 a	4.9 b	6.2 a
(SD)	(1.3)	(0.8)	(0.6)	(1.3)	(0.9)	(1.2)	(0.5)	(0.8)
N_{total} ($g.kg^{-1}$)	0.6 a	0.4 b	0.3 b	0.4b	0.5 a	0.5 a	0.4 b	0.6 a
(SD)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	(0.2)	(0.1)	(0.1)
C/N relation	12 b	12 b	13 a	12 b	12 b	12 b	14 a	12 b
(SD)	(1)	(2)	(1)	(2)	(1)	(2)	(2)	(1)
Ca ($cmol.kg^{-1}$)	702 a	653 a	441 b	631 a	661 a	690 a	419 b	714 a
(SD)	(89)	(29)	(49)	(54)	(90)	(85)	(16)	(81)
Mg ($cmol.kg^{-1}$)	98 a	96 a	76 b	89 ab	66 a	68 a	44 b	64 a
(SD)	(7)	(8)	(11)	(13)	(7)	(11)	(16)	(8)
P ($cmol.kg^{-1}$)	1.1 b	0.9 b	1.3 b	2.6 a	0.9 b	0.8 b	0.7 b	2.4 a
(SD)	(0.2)	(0.1)	(0.4)	(0.6)	(0.2)	(0.2)	(0.1)	(0.6)
K ($cmol.kg^{-1}$)	76 a	71 a	68 a	74 a	58 a	54 a	39 b	54 a
(SD)	(19)	(6)	(22)	(15)	(8)	(9)	(3)	(3)
pH (H_2O)	6.1 a	5.8 a	5.1 b	6.1 a	5.9 a	5.5 a	4.8 b	5.8 a
(SD)	(0.2)	(0.1)	(0.4)	(0.3)	(0.4)	(0.3)	(0.5)	(0.2)

Letters within a line that are different indicate significant differences in means ($p<0.05$) between treatments on each site in 2010. P = available phosphorus; K = available potassium; Mg = Magnesium; Ca = Calcium; C_{total}= Total carbon; N_{total} = Total nitrogen

3.3. Soil Microbiological Properties

The soil microbial biomass-C (C_{mic}) and soil basal respiration (C_{resp}) variation illustrated in Table 4, show significant difference between the treatments in the two sites. In Gampèla, C_{mic} and C_{resp} levels were significantly the highest in HM, followed by Zaï, ST and the lowest in control; at the same time the metabolic quotient (qCO_2) deduced from Cresp and Cmic exhibited a higher microbial metabolism under control than the others treatments. However in Baporé, the C_{mic} and C_{resp} values from Zaï was significantly higher than the ones from both HM and ST. As in Gampèla, the values of C_{mic} and C_{resp} were the lowest in control; Nevertheless, qCO_2 showed no significant difference between the treatments.

Table 4. Means (N = 5) and standard deviation (SD) of Soil microbial biomass-C, soil basal respiration and metabolic quotient (qCO_2) under the different treatments in the rehabilitated sites in Burkina Faso

Sites	Gampèla				Baporé			
Parameters / Treatments	HM	ST	T0	Zaï	HM	ST	T0	Zaï
Soil microbial biomass-C ($\mu g.g^{-1}$)	419 a	198 c	81 d	373 b	317 b	346 b	119 c	529 a
(SD)	(13)	(16)	(15)	(21)	(7)	(26)	(19)	(21)
Soil respiration C-CO_2 ($\mu g.g^{-1}$)	365 a	171 c	138 d	231 b	224 b	241 b	93 c	380 a
(SD)	(5)	(3)	(2)	(4)	(9)	(5)	(3)	(7)
qCO_2 (mg C-CO_2 g^{-1}. per day)	124 b	124 b	251 a	120 b	101 a	100 a	111 a	102 a
(SD)	(3)	(9)	(49)	(9)	(5)	(10)	(6)	(4)

Letters within a column that are different indicate significant differences in means ($p<0.05$) between treatments on each site in 2010.

3.4. Relationships between Soil Chemical and Microbial

Simple linear correlation analysis was carried out between selected variables across treatments (Table 5). Soil microbial biomass (C_{mic}) and basal soil respiration (C_{resp}) were significantly correlated each other (r = 92); however, the metabolic quotient (qCO_2) was negatively correlated with (C_{mic}(r = -46). Soil microbial biomass (C_{mic}) and basal soil respiration (C_{resp}) were significantly correlated with total organic carbon (C), total nitrogen (N) and soil texture (clay and fine silt fraction). It can also be seen in Table 5 that C_{mic} and C_{resp} were positively correlated with calcium content and soil pH but negatively correlated with C/N. However, the metabolic quotient (qCO_2) was positively correlated with coarse sand and available potassium but negatively correlated with clay, fine silt, total organic carbon, total nitrogen and calcium. This suggests that variation in soil microbial biomass and basal respiration in this study could largely be explained by the levels of soil total C, N, and these results also indicate that soil microbial properties should be addressed to assess the effects of management practices on degraded soil quality.

Table 5. Correlation coefficient (r) between soil microbial biomass (C_{mic}), soil respiration (C_{resp}), some soil chemical and soil texture (N = 40)

	C_{mic}	C_{resp}	qCO2
soil microbial biomass (C_{mic})	1	0.92*	-0.57*
Clay fraction	0.37*	0.32*	-0.45*
Fine silt fraction	0.27	0.38*	-0.09
Coarse sand fraction	-0.18	-0.17	0.32*
Total carbon (C_{total})	0.60*	0.63*	-0.36*
Total nitrogen (N_{total})	0.70*	0.69*	-0.44*
C/N relation	-0.50*	-0.46*	0.27
Calcium (Ca)	0.72*	0.71*	-0.43*
Ph (H_2O)	0.57*	0.56*	-0.29

* Correlation is significant ($P < 0.05$).

4. Discussion

Results from this study illustrate how the three techniques used in degraded land alter soil texture, chemistry and microbiology. Based on three-years' observation in bare land, Zougmoré et al. (2003b) reported a severe degree of soil and water loss in control plot comparatively to the plots in which soil and water conservation were applied. Moreover, the different used restoration techniques resulted in remarkable differences in soil physical, chemical and biological properties (Table 2, 3 & 4). Previous studies that have compared the proprieties of soils managed with several soil restoration techniques have produced conflicting evidence of enhanced soil organic material, diversity and activity of soil microbial that may be attributable to management practice (Zhang et al., 2015; Hishe et al., 2017; Dutta & Gokhale, 2017). In the present study, we have found that the difference in soils parameters under the management practice were dramatic, and varied barely between the two main sites studied. Then, in soil at both Gampèla and Baporé, HM technique, ST technique and Zaï in a lesser extent contribute significantly to enhance pH, total organic carbon, total nitrogen, calcium, magnesium, phosphorus amounts as well as soil microbial biomass and basal respiration. The improvements in total organic carbon and other nutrients could be attributed mainly to the quantity and quality of litter fall and fine root decomposition (Manlay et al., 2000; Kaur et al., 2000). The degree of accumulation of organic matter in soil depends on the relationship between organic carbon inputs and the decomposition rate (Sagar et al., 1999).

The decomposition rate of organic matter is complex and involves many factors including substrate quality, soil matrices, soil biota, and climatic parameters (Traore et al., 2007). Termites and ants are known to be the most efficient organisms in reallocating soil organic matter and increasing its availability for mineralization. According to Floret et al. (1993), roots are reported to be the main providers of carbon to the subsoil of savannahs. Our results do not provide much evidence for a significant contribution of fine roots to soil organic carbon content but the close association between both soil organic carbon and nitrogen with above herbaceous biomass are convincing. The higher organic carbon and nitrogen amounts recorded in the upper (0 - 20 cm) soil layer of HM and ST in a lesser extent compared to the control can be related to an increase in herbaceous species cover, root biomass and larger litter inputs on the two sites.

As regards to the higher amount of C and N under Zaï treatment as compared to the others treatments in Baporé site, this can be attributed to the manure incorporation at the beginning of the experiment with probably low decomposition rate in comparison to the other site (Gampèla). The high available potassium, magnesium and calcium amount under the treated plots are due to a nutrient transfer by roots from the subsoil to the upper soil may occur in regenerated vegetation. However, the high content of phosphorus under Zaï only could be related to manure incorporation (Zhang et al, 2015).

As regard to soil texture (Table 2), the difference between treatments is related to their susceptibility to erosion through soil and water loss. Then, the relative clay and silt enrichment under the HM treatment and a lesser extend under ST treatment could be explained by the loss of fine particles through soil erosion and this is more marked in the control plot than the managed plots. A close linear relationship total organic carbon, total nitrogen, fine silt content and clay content were found (Table 5). This is in agreement with the finding that organic matter in strongly related to fine particle content (Bechtold &Naiman, 2000; Six et al, 2002). More, total organic carbon associated with biological activity plays an important role in clay aggregation (Watts et al., 2005) that reduced clay runoff.

Management practices which involve differential inputs of organic materials into soils might therefore be predicted to modify soil microbial populations (Shannon et al., 2002). In this study the trends of microbial biomass carbon and basal respiration was consistent with that of total organic carbon under the different treatments. These observations were in conformity with various other studies. Then, as a function of soil nutrients and texture, greater soil microbial biomass and basal respiration under treatments (HM especially, Zaï and ST in a lesser extent) than control was due to larger enrichment in total organic carbon, total nitrogen and higher clay content as these soil parameters were positively correlated. Similar close relationships have been reported by other authors (Traore et al., 2007; Adeboye & Iwuafo, 2007). Apart from C and N inputs that potentially determine the size of the soil microbial biomass, according to Teklay et al. (2005), available phosphorus can also limited microbial activities. Greatest C_{resp} and C_{mic} observed in Zaï at Baporé were distinguished by optimal organic carbon and environmental conditions stimulating microbial activity (lower C/N, higher phosphorus). Then, with no significant C and N variation between HM, ST and Zaï treatments in Baporé site, higher available P stimulated more microbial activity in Zaï than both HM and ST. Furthermore, soil pH is one of the mitigating factors that can suppress the growth and activity of the native micro flora (Smith &Paul, 1990).

Low soil pH can impose a stress factor on the microbial biomass thereby increasing its maintenance energy requirement which will reduce the yield efficiency of the biomass and increase their death rate (Witter etal., 1993). This is consistent with our result where C_{resp} and C_{mic} had a significant ($P<0.05$) positive relationship with soil pH with correlation coefficients of $r = 0.56$ with C_{resp} and $r = 0.57$ with C_{mic}. The variation of the metabolic quotient (qCO_2) demonstrated the efficiency of soil microbial communities in substrate utilization (Insam, 1990). An increase in qCO_2 has been interpreted as a microbial response to adverse environmental stress or disturbance (Wardle &Ghani, 1995). In our results, a relatively low qCO_2 was observed under the managed plots (HM, ST and Zaï) comparatively to the control, indicated that labile C content was improved gradually from treatments. In other words, gradually decreased qCO_2 under treated plots resulted from the fraction of substrate C, which was incorporated into biomass so that less carbon per unit biomass was lost through respiration. Then, low qCO_2 reflected a more efficient use of organic substrates by microbial biomass (Anderson, 2003) and higher microbial activity. Alternatively, efficiency of substrate utilization could be due to the fungal dominated microbial biomass as shown by the investigations of Sakamato & Oba (1994). The results (with $pH < 7$ in all treatments) may be a confirmation of the dominance of fungi in the soil that will tolerate acidic condition (Adeboye & Iwuafo, 2007).

5. Conclusion

This study demonstrated that the used soil and water conservation techniques greatly influence variability in soil organic materials, nutrients and microbial activity. In general, the reduced erosion and the higher surface residues maintained under managed plots increased soil qualities attributes. After three years, the three techniques alter soil microhabitat and consequently influence the activity of soil microorganisms. Their beneficial effects on chemical characteristics of the topsoil undoubtedly rely on the biologically induced increase in the soil organic carbon content.
Globally, among these techniques, the soil qualities amounts attributed to treatments had greater under Half-moon systems than both Zaï and sub-soiling, apart in flat area.

Thus, soil chemical properties were improved under the managed plot (Half-moons especially) creating a favourable environment for soil microbes, as their high biomass and activity levels reflected. Then, Half-moon Technique could be one of the potential technical options for remediation of degraded lands. This method of reclamation, if implemented successfully on a large scale, will play an important role in reclaiming the "Zipellés" (degraded bare soils).

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