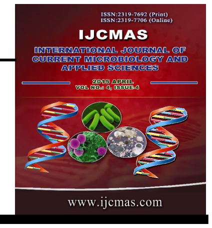
*Int.J.Curr.Microbiol.App.Sci* (2015) 4(4): 375-383




*International Journal of Current Microbiology and Applied Sciences*
***ISSN: 2319-7706*** **Volume 4 Number 4 (2015) pp. 375-383**
**http://www.ijcmas.com**

**Original Research Article**

# Soil Physicochemical Characteristics Under Different Ecosystems in Western Niger

**Boubacar M. Moussa[1]*, Abdoulaye Diouf[2], Salamatou I. Abdourahamane[3], NouhouSalifouJangorzo[2], Ali Mahamane[1], JørgenAagaard Axelsen[4] and Jean-Marie Karimou Ambouta[5]**

[1]Laboratoire GarbaMounkaila, Département de Biologie, Faculté des Sciences et Techniques, Université Abdou Moumouni de Niamey, Niger
[2]Département des Sciences du Sol et Télédétection, Faculté d'Agronomie et des Sciences de l'Environnement, Université de Maradi, Niger
[3]Département de Biologie, Faculté des Sciences et Techniques, Université de Maradi, Niger
[4]Aarhus University, Department of Bioscience, Vejlsøvej 25, 8600 Silkeborg, Denmark
[5]Département des Sciences du Sol, Faculté d'Agronomie, Université Abdou Moumouni de Niamey, Niger
**Corresponding author*

**A B S T R A C T**

**Keywords**

Organic Carbon, Acidity, Texture, Soil fertility, Niger

The soil fertility constraints were assessed through the physicochemical characteristics of agrosystem and silvopastoral system in the western Niger. This study was carried out through a soil sampling and physicochemical analysis in both ecosystems. The results exhibited four homogeneous soil groups in agrosystemand three soil groups in silvopastoral system characterized by specific soil physicochemical parameters. Thus, lowland soils located in agrosystem and those of vegetated plateaus in silvopastoral system have significantly higher values of organic carbon (2±0.2 g $kg^{-1}$; 5.3±0.8 g $kg^{-1}$, respectively), cation exchange capacity (2.7±0.9 kg $cmol_c^{-1}$; 5 ± 0.8 $cmol_c$ $kg^{-1}$, respectively), exchangeable bases (2.1±0.7 $cmol_c$ $kg^{-1}$; 3.5±1 $cmol_c$ $kg^{-1}$, respectively), and pH water (5.8±0.2, 4.8±0.5, respectively). However, the main constraints to the soil fertility of fields and fallow, crusted glacis and bare plateaus are: acidity and low levels of soil organic carbon.

## Introduction

In the semi-arid zone of West Africa, the anthropogenic pressure and the low fertility potential of soil represent the main causes of the soil organic matter and nutrients depletions (Sanchez *et al.*, 1997; Bationo and Buerkert, 2001). This soil degradation phenomenon is reflected in a decline of land productivity causing food insecurity (Martius *et al.*, 2001; Bationo *et al.*, 2007).

In western Niger, several projects and programs such as the Agro-Silvo-Pastoral project (North Tillabéry) and Land Management projects (Filingué, Torodi) were implemented in order to restore degraded soils and hence improve their productivity and livelihood of the local community. However, failure to consider the soil physical and chemical parameters in the management process hindered the restoration of these lands considerably. Soil parameters play a key role in the management of plant nutrition and optimal supply of nutrients depends on their optimization (Troeh and Thompson, 2005). The pH is a synthesising factor in soil fertility due to its influence on the assimilation of soil nutrients by plants. In fact, the absorption of minerals such as phosphorus, potassium and nitrogen by the plant becomes more difficult as the pH decreases (Mathieu and Pieltain, 2003). Land use further affects the physicochemical properties of soil (Masto *et al.*, 2008). In western Niger, land uses are characterized by agrosystems and silvopastoral systems. Agrosystems are dominated by continuous and manual cultivation of millet and sorghum. However, the organic matter content of these soils tends to decline rapidly under such activities (De Rouw and Rajot, 2004). These low values of organic matter are associated with low levels of nitrogen and phosphorus (Bationo and Buerkert, 2001). Furthermore, silvopastoral systems, located on the western plateaus of Niger are commonly called “tiger bush” (Ambouta, 1984). The soil of these formations is characterized by high levels of silt and clay particles (Guillaume *et al.*, 1999). In fact, a high positive correlation is observed between the values of organic matter and the contents of clay (Bationo *et al.*, 2007; Esteban and Robert, 2000). Organic matter is strongly linked to fine soil particles and becomes unavailable for the mineralization. However, wood cutting performed on these formations causes the degradation of plant cover and affects the physicochemical properties of the soil negatively.

This study aimed at identifying the different soil groups of both ecosystems of western Niger and their physicochemical characteristics in other to assess their fertility constraints.

## Materials and Methods

### Study area

This study was conducted in the rural Municipalities of Simiri (13°50' - 14°17' and 01°50’-02° 40') and Tamou (13°50'-14°17' and 01°50’- 02°40') in the Western part of Niger (Figure 1). The semi-arid area of Simiri is situated in the Sahelian climate zone and Tamou is situated in the Sahelo-soudanian zone (Figure 1). The topo-sequence of these two areas is characterized by a succession of plateaus, glacis and lowlands (Courault *et al.*, 1990). The plateaus consist mainly of regosol (Ambouta, 1997), the glacis of tropical ferruginous soil and lowlands, alluvial soil. The natural vegetation is shrub steppe on glacis and shrub or woody steppe in the lowlands while tiger bush or mottled bush are observed on the plateaus (Diouf *et al.*, 2010). The most abundant tree species are *Guierasene galensis* J.F. Gmel, *Combretum micranthum* G. Don and *Combretum glutinosum* Perr.ex DC. The herbaceous layer is dominated by *Mitracar pusscaber*Zucc., *Eragrostistremula* Stend., *Cenchrusbi florus* Roxb and *Microchloa indica* (L. f.) P. Beauv. The main occupation of local populations is agriculture and animal husbandry, and agriculture is widespread on glacis and lowlands. It is mainly rain fed and the crops are mainlymillet [Pennisetumglaucum (L.) R Br.], Sorghum [Sorghum bicolor (L.) Moench.] and cowpea [Vignaunguiculata (L.) Walp.]. The husbandry of cattle and small ruminants is the second most important income generating activity for the populations. The plateaus are only being grazed area during the rainy season.

### Soil sampling

The sampling was done at 49 plots in the agrosystems and 21 plots in the silvopastoral system in July 2013. A sample consisted of a composite sample made up of four subsamples collected at 0-20 cm depth from the corners and one from the centre of the plot. The five subsamples were mixed homogeneously to form one composite sample.

### Soil physicochemical analysis

Soil samples were air-dried and sieved through a 2 mm mesh sieve. Particle size analysis was carried out using the Robinson pipette method. By this method the soil fraction was separate from content of clay (□2 µm), fine silt (2–20 µm), coarse silt (20–50 µm), fine sand (50–200 µm) and coarse sand (200–2000 µm). The organic carbon was quantified by the Walkley and Black (1934) method, while total phosphorus and total nitrogen were determined with Kjeldahl method (Houba *et al.*, 1988). Available phosphorus was assessed by Bray-I procedure (Olsen and Sommers., 1982). Soil pH was determined in soil-water ratio of 1:2.5 using a glass electrode pH meter (Mathieu and Pieltain, 2003). Cation Exchange Capacity and exchangeable cations were determined by silver-thiourea (AgTU) method.

### Statistical analysis

A hierarchical classification based on Euclidean distance and Ward's clustering method was performed on the 70 observations to identify homogeneous soil groups according to their physicochemical characteristics. Then a principal component analysis (PCA) was carried out to highlight the linear combinations of the variables characterizing each of the identified soil groups. Analysis of variance test (ANOVA) (parametric test) and Kruskal-Wallis (non-parametric test) were used to test for differences in physicochemical parameters of the different soil groups. Multivariate analyses were performed with the PCORD software (version 5.0) and univariate analyses with the R software (R development Core T., 2010).

## Result and Discussion

### Identification of soil groups

Seven soil groups were identified by hierarchical classification. These are G1: fields + fallow, Tamou; G2: bare plateaus, Tamou; G3: bare plateaus, Simiri; G4: vegetated plateaus; G5: crusted glacis; G6: lowlands; G7: fields+fallow, Simiri. The physicochemical parameters characterizing each of the groups are analysed using a PCA (Figure 2). The two most significant axes (P□0.05) explain 67.55% of the total variance (Table 1). Axis 1 demonstrates a highly positive correlation with sand content (r = 0.907) and a highly negative correlation with the following variable groups: silt (r = -0.867), clay+fine silt (r = -0.851), organic carbon (r = -0.827) and cation exchange capacity (r = -0.817).This axis can be defined as a gradient of carbon and sandcontent.The soils of vegetated plateaus (G4) have higher carbon content and clay+fine silt content than the soils of fields+fallow of Simiri (G7). Axis 2 shows a high positive correlation with pH (r = 0.700) and can therefore be defined as a gradient of soil acidity. Accordingly, soils of bare plateaus (G3) and those of crusted glacis (G5) are more acid than soil groups of lowlands area (G6).

**Agrosystem soils**

Sand classes are significantly dominant in agrosystems found in Simiri and Tamou (Table 2). This could be explained by wind erosion that takes away sand particles of plateaus and deposit them on glacis and lowlands. In addition, manual cultivation mainly based on consistent turn up of soil leads to loss of clay and silt from the topsoil (Barthes *et al.,* 1998; De Rouw and Rajot., 2004; Kouassi, 2009). The crusted glacis soil group (G5) demonstrated the highest (P□0.001) contents of clay and clay+fine silt (Table 2). These values of fine particles associated to the low organic carbon content (1.2 to 2 g $kg^{-1}$) for all agrosystem soils (Table 3) indicate a physical degradation through surface crusting (Pieri, 1989). These low organic carbon values are close to those reported by De Rouw and Rajot (2004) in semi-arid Niger. Indeed, in most tropical soils, decreasing soil carbon content is one of the consequences of crop residues removal and rapid turnover rate of organic matter (Pieri, 1989; Feller and Beare, 1997; Bationo and Buerkert, 2001). Low values of the carbon/nitrogen ratio (<14) confirms the high mineralization activity of organic matter in these sandy soils. In addition, the low total nitrogen measurements recorded in these agrosystems (0.1 to 0.3 g $kg^{-1}$) are probably due to low organic matter content. The sandy texture of these soils associated with low organic carbon cause loss of exchangeable cations resulting in low values of exchangeable bases (S <2.3 $cmol_c$ $kg^{-1}$).This leaching leads to an increase in hydrogen ions on the soil particles that could explain the high acidity of these soils (pH<5.8).In addition, a low value of phosphorus is available for plants (≤8.1±1.7 mg $kg^{-1}$). Effectively, with low pH values, iron oxide particles of these tropical ferruginous soils react with phosphate to form an insoluble component that is unavailable to plants (Busman *et al.*, 2002).However, lowland areas have recorded significantly higher organic carbon content (2.0±0.2 g $kg^{-1}$), nitrogen (0.3±0.07 g $kg^{-1}$) and pH (5.8±0.2) compared to other soil. In fact, the geomorphological position occupied by these formations promotes the formation of woody vegetation with a percentage cover of 20.8±9% (Moussa *et al.,* 2013). Humidity and high degree of aeration of these sandy soils could also favour the mineralization of litter by microorganisms.

**Soils of silvopastoral systems**

The vegetation type called "tiger bush" is found on plateaus made of clay and sandstone of the Continental Terminal which covers a large part of the Niger Basin (Ambouta, 1984). The low slope (□1%) of these plateaus allows a laminar runoff that carry's away fine particles towards the vegetation areas. Thus, measures of fine particles (clay+fine silt) obtained on vegetated areas (34±6%) were significantly higher than those in denuded areas of Tamou (20±3%) (Table 2). The soil organic carbon follows the same trend, probably due to the availability of organic matter and finer soil texture. In fact, litter is more available at vegetated plateaus than at bare plateaus (Hiernaux and Gérard, 1999). Regarding soil texture, a strong positive correlation was observed between the values of organic matter and the contents of clay. Several authors have obtained the same trend (Bationo *et al.,* 2007; Esteban and Robert, 2000). The significantly highest level of cation exchange capacity (5.0±0.8 $cmol_c$ $kg^{-1}$) and exchangeable bases (3.5±1$cmol_c$ $kg^{-1}$) was obtained in the vegetated plateaus (Table 3). These values could be derived from the high carbon measurements (5.3±0.8g $kg^{-1}$) and content of fine particles (34±6). In fact, clays and organic matter through their colloidal properties favour the presence of charges on their surface (Brady *et al.*, 2002). However, the low pH values obtained on bare plateaus would be a limiting factor for plant growth in these soils. Phosphorus, potassium and nitrogen are absorbed even more difficultly as the pH is lowered (Mathieu and Pieltain, 2003). Indeed, micro-organisms activity is reduced and a large part of the organic matter remains inactive with low pH (Kemmitt *et al.*, 2006).

**Table.1** Eigen value, percentage of variance, probability and correlation coefficient between physicochemical parameters and the first three axes of the Principal Component Analysis

| | Axis 1 | Axis 2 | Axis 3 |
|---|---|---|---|
| Eigenvalue | 6.6 | 2.1 | 1.1 |
| Percentage of variance | 51.06 | 16.49 | 8.91 |
| Probability | 0.001 | 0.001 | 1.00 |
| Physicochemical parameters | | | |
| Clay | -0.745 | -0.569 | -0.179 |
| Silt | -0.867 | 0.091 | 0.145 |
| Sand | 0.907 | 0.338 | 0.052 |
| Clay + fine silt | -0.851 | -0.457 | -0.096 |
| Organiccarbon | -0.827 | 0.249 | -0.274 |
| Total Nitrogen | -0.698 | 0.250 | -0.050 |
| Total Potassium | -0.488 | 0.576 | 0.508 |
| Total Phosphorus | -0.574 | -0.449 | 0.312 |
| AvailablePhosphorus | -0.643 | 0.203 | 0.540 |
| pH | 0.155 | 0.700 | -0.143 |
| Cation exchange capacity | -0.817 | 0.275 | -0.361 |
| Exchangeable bases | -0.676 | 0.461 | -0.401 |

**Table.2** Comparison of means (mean ± standard deviation) for the physical parameters of the soils according to the type of ecosystem

| Physical Parameters (%) | Agrosystem | | | | P | Silvopastoral system | | | P |
|---|---|---|---|---|---|---|---|---|---|
| | G1(n=7) | G5(n=13) | G6(n=5) | G7(n=24) | | G2(n=7) | G3(n=6) | G4(n=8) | |
| **Clay** | 10±2$^{a}$ | 22±2$^{b}$ | 9±2$^{a}$ | 9±2$^{a}$ | □0.001 | 15±3$^{a}$ | 23±2$^{b}$ | 27±4$^{b}$ | □0.001 |
| **Silt** | 9±4$^{c}$ | 4±2$^{b}$ | 5±2$^{b}$ | 3±1$^{a}$ | □0.001 | 12±5$^{a}$ | 13±3$^{a}$ | 14±5$^{a}$ | 0.724 |
| **Sand** | 82±5$^{b}$ | 74±3$^{a}$ | 86±3$^{b}$ | 89±2$^{b}$ | □0.001 | 73±5$^{a}$ | 64±4$^{b}$ | 59±8$^{b}$ | 0.003 |
| **Clay + fine silt** | 14±4$^{a}$ | 24±2$^{b}$ | 12±3$^{a}$ | 10±2$^{a}$ | □0.001 | 2 0±3$^{a}$ | 31±3$^{b}$ | 34±6$^{b}$ | 0.001 |

G1: fields + fallow, Tamou; G2: bare plateaus, Tamou; G3: bare plateaus, Simiri; G4: vegetated plateaus; G5: crusted glacis; G6: lowlands; G7: fields+fallow, Simiri; P: Probability; n: number of soil sample. On each line, values accompanied by different letters are significantly different at probability level α = 0.05

**Table.3** Comparison of mean (mean ± standard deviation) for chemical parameters of the soils according to the type of ecosystem

| Chemical parameters | Agrosystem | | | | P | Silvopastoral system | | | P |
|---|---|---|---|---|---|---|---|---|---|
| | G1(n=7) | G5(n=13) | G6(n=5) | G7(n=24) | | G2(n=7) | G3(n=6) | G4(n=8) | |
| **C (g kg$^{-1}$)** | 1.9±0.3$^{b}$ | 1.2±0.6$^{a}$ | 2.0±0.2$^{b}$ | 1.2±0.6$^{a}$ | 0.001 | 3.7±0.6$^{b}$ | 2.5±0.5$^{a}$ | 5.3±0.8$^{c}$ | 0.001 |
| **N (g kg$^{-1}$)** | 0.2±0.04$^{a}$ | 0.1±0.06$^{a}$ | 0.3±0.07$^{b}$ | 0.1±0.05$^{a}$ | 0.010 | 0.2±0.06$^{a}$ | 0.3±0.03$^{a}$ | 0.3±0.04$^{a}$ | 0.084 |
| **C N$^{-1}$** | 12±3$^{a}$ | 14±11$^{a}$ | 9±3$^{a}$ | 9±5$^{a}$ | 0.079 | 17±5$^{b}$ | 9±3$^{a}$ | 17±4$^{b}$ | 0.004 |
| **K (mg kg$^{-1}$)** | 139±45$^{d}$ | 33±6$^{a}$ | 96±28$^{bc}$ | 74±36$^{c}$ | 0.001 | 128±50$^{a}$ | 117±25$^{a}$ | 121±27$^{a}$ | 0.943 |
| **P_tot (mg kg$^{-1}$)** | 60±12$^{a}$ | 90±15$^{b}$ | 78±21$^{ab}$ | 67±18$^{a}$ | 0.001 | 96±15$^{a}$ | 165±29$^{b}$ | 92±15$^{a}$ | 0.001 |
| **P_avail (mg kg$^{-1}$)** | 8.1 ±1.7$^{a}$ | 5.3±1.2$^{a}$ | 7.5±4.7$^{a}$ | 6.0±1.8$^{a}$ | 0.066 | 8.7±2$^{a}$ | 12.3±1$^{c}$ | 9.0±1. 3$^{a}$ | 0.002 |
| **CEC (cmol$_c$ kg$^{-1}$)** | 2.9±0.6$^{c}$ | 2.1±0.6$^{b}$ | 2.7±0.9$^{c}$ | 1.6±0.5$^{a}$ | 0.001 | 3.7±1.4$^{a}$ | 2.8±0.7$^{a}$ | 5.0±0,8$^{b}$ | 0.002 |
| **S (cmol$_c$ kg$^{-1}$)** | 2.3±0.3$^{b}$ | 1.2±0.4$^{a}$ | 2.1±0.7$^{b}$ | 1.0±0.5$^{a}$ | 0.001 | 1.9±1.3$^{a}$ | 1.1±0.4$^{a}$ | 3.5±1$^{b}$ | 0.002 |
| **pH** | 4.3±0.2$^{b}$ | 4.0±0.1$^{a}$ | 5.8±0.2$^{d}$ | 4.6±0.4$^{c}$ | 0.001 | 4.3±0.3$^{b}$ | 4.1±0.3$^{a}$ | 4.8±0.5$^{b}$ | 0.017 |

C: Organic carbon; N: Total Nitrogen; C N$^{-1}$: Carbon/Nitrogen; K: Total Potassium; P_tot: Total Phosphorus;P_avail: Available Phosphorus; S: exchangeable bases; CEC: cation exchange capacity; pH: soil pH;G1: fields+fallow, Tamou; G2: bare plateaus, Tamou; G3: bare plateaus, Simiri; G4: vegetated plateaus; G5: crusted glacis; G6: lowlands; G7: fields+fallow, Simiri; P: Probability; n: number of soil sample. On each line, values accompanied by different letters are significantly different at probability level α = 0.05.

**Figure.1** Location of district of Simiri, Tamou and climatic zones in Niger

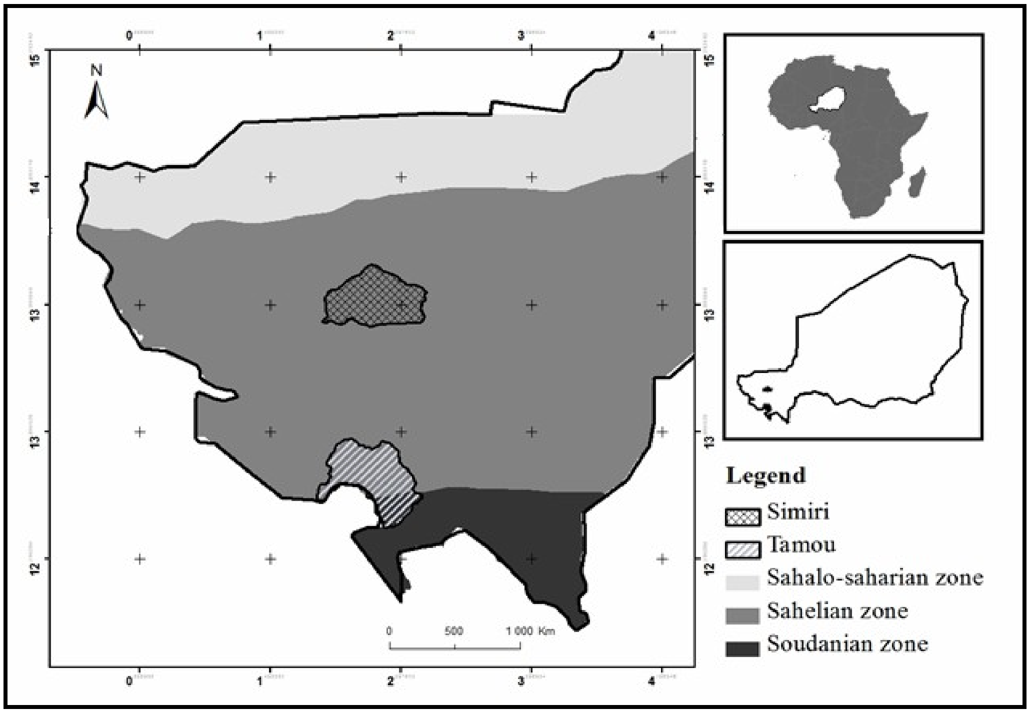
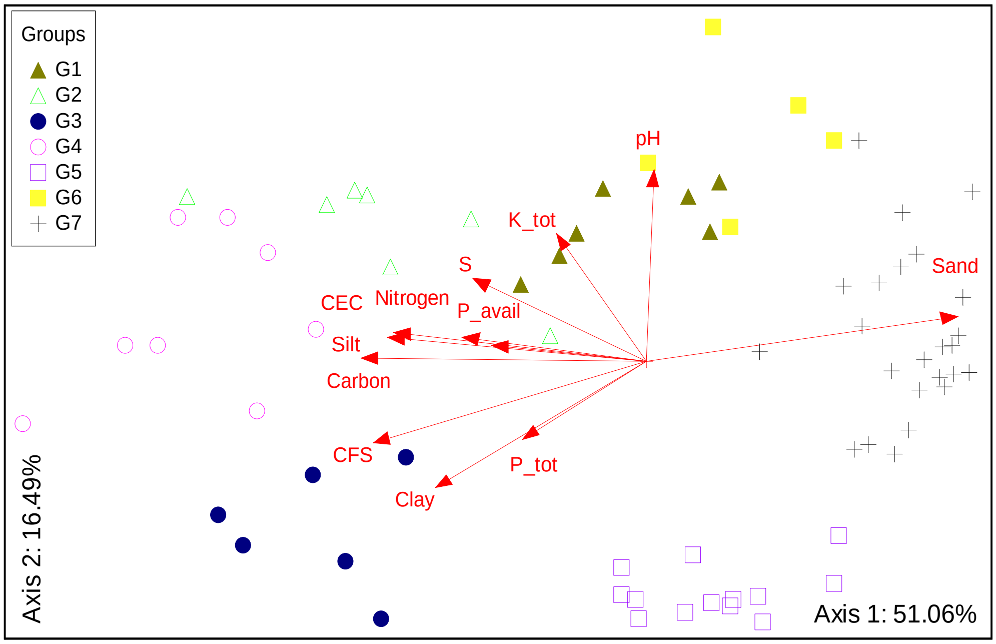



**Figure.2** Principal Component Analysis (PCA) based on 12 physicochemical parameters of soil groups (G1 to G7) based on a hierarchical classification are shown



**Acknowledgment**

We thank all those who have contributed to improve this document. We wish to thank also UNDESERT (EU FP7 243906), "Understanding and combating desertification to mitigate its impact on ecosystem services" funded by the European Commission, Directorate General for Research and Innovation, Environment Programme for financial support.

**References**

Ambouta, J.M.K., 1997. Définition et caractérisation des structures de végétation contractée au sahel: cas de la brousse tigrée de l'ouest nigérien. In : d'Herbès J.M., Ambouta J.M.K., Peltier R., éds. Fonctionnement et gestion des écosystèmes forestiers contractés sahéliens. John LibbeyEurotext, Paris, Pp. 41–57.

Ambouta, K., 1984. Contribution à l'édaphologie de la brousse tigrée de l'Ouest Nigérien. Thèse de Docteur Ingénieur, Université de Nancy, Pp. 115.

Barthes, B., Albrecht, A., Asseline, J., De Noni, G., Roose, E., Viennot, M. 1998. Pratiques culturales et érodibilité du sol dans les Rougiers de Camarès (Aveyron). *Etude et Gestion des Sols,* 5(3): 157–170.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B., Kimetu, J. 2007. Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricult. Syst.,* 94: 13–25.

Bationo, A., Buerkert, A. 2001. Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. *Nutr. Cycl. Agroecosyst.,* 61: 131–142.

Moussa, M.B., Inoussa, M.M., Ambouta, J-M.K., Mahamane, A., Jorgen, A.A., Harissou, Y., Habou, R., 2013. Caractérisation de la végétation ligneuse et des organisations pelliculaires de surface des agroécosystèmes à différents stades de dégradation de la Commune rurale de Simiri (Niger). *Int. J. Biol. Chem. Sci.,* 7(5): 1963–1975.

Brady, N.C., Weil, R.R. 2002. The nature and properties of soils, 13th edn. Pearson Education Inc., Upper Saddle River, NJ, USA.

Busman, L., Lamb, J., Randall, G., Rehm, G., Schmitt, M. 2002. The nature of phosphorus in soils. In: Phosphorus in the Agricultural Environment. Regents of the University of Minnesota, Minnesota, FO-06 795-GO., Pp. 1–7.

Courault, D., D'Herbes, J.M., Valentin, C. 1990. Le bassin versant de Sama Dey : premières observations pédologiques et phyto-écologiques. ORSTOM, Paris. Danin,

Craswell, E.T., Lefroy, R.D.B., 2001. The role and function of organic matter in tropical soils. *Nutr. Cycl. Agroecosyst.,* 61: 7–18.

De Rouw, A., Rajot, J.L. 2004. Soil organic matter, surface crusting and erosion in Sahelian farming systems based on manuring or fallowing. *Agricult. Ecosyst. Environ.,* 104: 263–276.

Diouf, A., Barbier, N., Mahamane, A., Lejoly, J., Saadou, M., Bogaert, J. 2010. Caractérisation de la structure spatiale des individus ligneux dans une "Brousse tachetée" au Sud-ouest du Niger. *Can. J. Forest Res.,* 40: 827–835.

Esteban, G.J., Robert, B.J. 2000. The vertical distribution of soil organic carbon and its ecological applications. 10(2): 423–436.

Feller, C., Beare, M.H. 1997. Physical control of soil organic matter dynamics in the tropics. *Geoderma,* 79: 69–116.

Greigert, J. 1966. Description des formations crétacées et tertiaires du basin des Iullemeden (*Afrique occidentale*). BRGM, 208 Pp.

Guillaume, K., Abbadie, L., Mariotti, A., Nacro, H. 1999. Soil organic matter dynamics in tiger bush (Niamey, Niger). Preliminary results. *Acta Oecologica,* 20(3): 185–195.

Hiernaux, P. & Gérard, B., 1999. The influence of vegetation pattern on the productivity, diversity and stability of vegetation: The case of "brousse tigrée" in the Sahel. *Acta Oecologica,* 20(3): 147–158.

Houba, V.J.G., van der Lee, J.J., Novozamsky, L., Walinga, I. 1988. Soil and plant analysis, Part 5: Soil analysis procedures. Department of soil science plant nutrient, Wageningen Agricultural Univrsity, The Netherlands.

Kemmitt, S.J., Wright, D., Goulding, K.W.T., Jones, D.L. 2006. pH regulation of carbon and nitrogen dynamics in two agricultural soils. *Soil Biol. Biochem.,* 38: 898–911.

Kouassi, B. 2009. Innovation technologiques et productions agricoles en Afrique de l'Ouest : exemple du Burkina Faso, du Ghana et du Togo. Karthala, Economie et Développement, France, 432 Pp.

Martius, C., Tiessen, H., Vlek, P.L.G. 2001. The management of organic matter in tropical soils : what are the priorities ? *Nutr. Cycl. Agroecosyst.,* 61: 1–6.

Masto, R.E., Chhonkar, P.K., Purakayastha, T.J., Patra, A.K., Singh, D. 2008. Soil quality indices for evaluation of long-term land use and soil management practices in semi-arid. *Land degrad. Dev.,* 19: 516–529.

Mathieu, C., Pieltain, F. 2003. Analyse chimique des sols : méthodes choisies Tec. et Do., Paris, France, Lavoisier, Pp. 388.

Pieri, C. 1989. Fertilité des terres de savane. Bilan de trente ans de recherche et de développement agricoles au sud du Sahara. Ministère de la Coopération/Cirad, Paris, France.

Olsen, S.R., Sommers, L.E. 1982. Phosphorus. In: Methods of soil analysis, Part 2, Agronomy monographs 9, 403–430, A.L. Page, R.H. Miller and D.R. Keeney (Eds). American Society of Agronomy and Soil Science Society of America, Madison.

R Development Core Team, 2010. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL: http://www.R-project.org.

Sanchez, P.A., Shepherd, K.D., Soule, M.J., Place, F.M., Buresh, R.J., Izac, A-M.N., Mokwunye, A.U., Kwesiga, F.R., Ndiritu, D.G., Woomer, P.L. 1997. Soil fertility replenishment in Africa: An investment in natural resource capital. In: Replenishing soil fertility in Africa, Buresh, R.J., Sanchez, P.A., Calhoun, F. (Eds). Soil Science Society of America, Madison, Pp. 1–46.

Troeh F.R., Thompson, L.M. 2005. Soils and soil fertility, 6th edn. Blackwell Publishing Oxford, UK.

Walkley, A., Black, I. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.,* 37: 29–38.