

The cover features a close-up photograph of dark, rich soil. In the upper portion, there are vibrant green grass blades and other leafy plants. On the right side, a portion of a reddish-brown tuberous root, possibly a sweet potato, is visible. The text is overlaid on a semi-transparent dark grey band across the top half of the image.

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*Full Length Research Paper*

## Analysis of soils from cassava farms in floodplain terrain

Abah R. C.<sup>\*1,2</sup> and Petja B. M.<sup>1,3</sup>

<sup>1</sup>University of South Africa, Pretoria, South Africa.

<sup>2</sup>National Agency for the Control of AIDS, Central Area, Abuja, Nigeria.

<sup>3</sup>Water Research Commission (WRC), Rietfontein Pretoria, South Africa.

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The study was carried out to analyze soils from cassava farms in floodplain terrain of the River Benue. Cassava is the most extensively cultivated crop in Benue State. Soil samples were collected randomly from cassava farms owned by members of farming cooperative societies in Makurdi, Tarka, and Gboko Local Government Areas. These samples were analysed for physical and chemical properties. The pH was slightly acidic with a mean of 5.7 for surface soils and 5.7 for subsurface soils. The organic carbon content had a mean of 0.7% for surface soils and a mean of 0.72% for subsurface soils. The total percentage nitrogen had a mean of 0.05% for surface soils and 0.05% for subsurface soils. Available phosphorus had a mean of 8.48 mg kg<sup>-1</sup> for surface soils, while subsurface soils had a mean of 5.66 mg kg<sup>-1</sup>. The base saturation percentage was 86.58% for surface soils and a mean value of 86.55% for subsurface soils. The values of micro-nutrients were all below tolerable limits. The study recommends the effective application of inorganic fertilizers such as NPK to optimize crop production. Governments should support farmers with credit facilities, agricultural laboratory services, and effective extension services.

**Key words:** Soil assessment, soil nutrients, organic carbon, phosphorus, nitrogen, micro-nutrients, River Benue, Nigeria.

### INTRODUCTION

Cassava is an important source of calories for millions of people in Latin America, Asia, and Africa. Cassava has become very significant globally for agricultural income and food security. It is however associated mostly with peasant farmers, often women, ploughing marginal lands (FAO, 2008). According to the Food and Agriculture Organisation (2008), the Global Cassava Development Strategy launched in 2000 promoted cassava "as a raw

material base for an array of processed products that will effectively increase demand for cassava and contribute to agricultural transformation and economic growth in developing countries."

The earliest sites of cassava cultivation were in Northern Brazil and Central America. It was from these locations that cassava found its way to various tropical and subtropical areas in the world and became a major

\*Corresponding author. E-mail: [rolann04@yahoo.com](mailto:rolann04@yahoo.com).

**Table 1.** Major crops and area cultivated in Benue State (2009-2012) (Benue State Ministry of Agriculture, 2013).

Crop	Area cultivated ('000 Hectares)			
	2009	2010	2011	2012
Maize	108.99	114.98	104.15	123.65
Millet	43.03	42.68	42.60	46.80
Sorghum	112.26	113.44	110.17	130.47
Rice	144.42	155.48	137.49	182.90
Cassava	276.03	281.50	267.63	294.65
Yam	226.76	228.14	225.97	289.49
Ginger	1.24	1.30	0.63	0.75
Melon	37.63	89.10	29.16	31.60
Tomatoes	13.35	16.30	6.93	7.95
Sesame seed	46.55	45.38	41.28	41.28
Groundnut	206.38	207.46	199.04	201.04
Soybeans	90.84	93.62	86.13	100.13
Citrus	101.25	152.12	69.52	70.57
Mangoes	97.94	106.38	35.10	45.10

staple food (Eke-Okoro and Njoku, 2012). The global output of cassava produce surpassed 230 million metric tons in 2010. Most of the global cassava produce is in Africa with Nigeria being the largest producer. Nigeria produced 107 million metric tons of cassava in 2012 and 2013 (FAO, 2015). Portuguese traders were said to have introduced cassava to Warri in Western Nigeria in the late 18 Century. Since that time, cassava has become a daily food necessity of staple significance to over 70% of Nigerians (Eke-Okoro and Njoku, 2012).

Tropical conditions are suitable for cassava cultivation. Suitable parameters for cassava cultivation in savannah regions are documented in Titus et al. (2011) and Ande (2011). Cassava can grow on a wide variety of soils within a temperature of between 25 and 29°C, and with a rainfall range of 500 to 1500 mm. Cassava can grow on level to moderate slope and does not require much water for growth.

Benue State in Nigeria is known for the production of a varied number of agricultural produce such as grains crops, roots and tuber crops, legumes, fruits and livestock. The most extensively cultivated crop in Benue State between 2009 and 2012 was cassava (Benue State, 2013). According to an agricultural investment document on Benue State (Benue State, 2013), an expanse of 276, 030 hectares of cultivated cassava produced 3, 643, 660 metric tons in 2009 and 294, 650 hectares produced 3, 597, 280 metric tons in 2012. Other crops such as yams, groundnut, rice and maize were also extensively cultivated during the same period (Tables 1 and 2).

Most parts of Benue State are located either in the lowland or upland areas of the floodplain of the River Benue. The floodplain of the River Benue is about 181,000 hectares making it an important economic resource to Nigeria (Ita et al., 1985).

Floodplain soils are of immense interest to the global community because of the fragile ecosystem and high agricultural potential (Nsor and Akamigbo, 2009). Floodplains ecosystems are fragile; using them for crop cultivation has resulted in adverse environmental and ecological issues. Babalola et al. (2011) decried the gross misuse of floodplains in Nigeria stating that this has negatively influenced the natural hydrological cycles. According to Babalola et al. (2011), inefficient cultivation methods have resulted in low yields making many crop farmers to abandon floodplains due to depleted fertility and erosion.

The trend of cassava cultivation in Benue State is not surprising because the Federal Government of Nigeria in the last few years has called for increased cultivation of cassava. Cassava is also a staple food in North Central Nigeria. However, low yields of crops cultivated in Benue have been observed through the reduction in supply chain to some processing plants in Benue (Shabu et al., 2011). The preponderance of subsistence farmers in Benue State has resulted in the application of inefficient soil enhancement methods to increase productivity. Farm inputs such as inorganic fertilizer (NPK), herbicides and pesticides have been used over the years without proper feasibility and monitoring which could have adverse effects on floodplain ecosystems and human consumption (Uwah et al., 2007).

It is therefore necessary to analyse floodplain soils used for crop cultivation including cassava which has become a major cultivated crop in Benue State and Nigeria. This is because floodplain soils have become prone to physical and chemical degradation due to perennial crop cultivation and unwholesome farm practises. Studying the River Benue floodplain soils will reveal fertility status, appropriateness for crop cultivation

**Table 2.** Production output of major crops in Benue State (2009-2012) (Benue State Ministry of Agriculture, 2013).

Crop	Output ('000 Metric tons)			
	2009	2010	2011	2012
Maize	148.61	175.94	139.56	162.53
Millet	65.40	66.15	65.18	69.05
Sorghum	192.46	199.65	191.70	198.60
Rice	289.66	327.27	227.73	397.79
Cassava	3,643.66	3,721.62	3,559.48	3,597.28
Yam	2,902.80	2,954.41	2,874.34	2,994.30
Ginger	3.12	5.69	0.27	0.97
Melon	41.65	44.32	29.16	38.36
Tomatoes	52.29	66.36	18.85	19.86
Sesame seed	47.95	55.52	40.45	41.45
Groundnut	371.82	414.59	358.27	365.45
Soybeans	181.68	196.60	169.68	108.67
Citrus	32,187	31,953.4	1,067.13	1,102.35
Mangoes	11,135	12,678.4	986.35	832.30

including cassava, and physical and chemical deficiencies which require enhancement. Upon these premises, further analysis and appropriate soil management measures can be recommended.

## MATERIALS AND METHODS

### Study area

The study was carried out at Makurdi, Tarka, and Gboko Local Government Areas (LGAs) of Benue State Nigeria. The majority tribes are Tiv and Idoma. These Local Government Areas are located within the floodplains of the Lower River Benue Basin between Latitudes 7° 13'N and 8° 00'N and Longitudes 8°00'E and 9°00'E.

According to Ayoade (2004), the climate of the area is the tropical wet and dry type, Koppen's Aw classification, with double maxima. The rainy season usually lasts from April to October with an average annual rainfall of 1,332 mm. Precipitation is usually lowest in December. The mean annual temperature is about 27.2°C with an average annual humidity of 59.6%, and mean monthly sunshine of about 7 h. The areas have five months of dry season (November – March) and consists of guinea savannah vegetation type with scattered woodland, shrubs and grassland.

In terms of geology, it is a sedimentary basin that is made up of alluvium, shale, sandstones, siltstones and coastal sand plains, as well as ferruginous soils which can be subdivided on the basis of texture of the surface horizon into hydromorphics, lithosols and laterites. The land is generally low lying (averaging 100 to 250 m) and gently undulating (Kogbe, 1989). River Benue is the dominant geographical feature in the state. River Benue rises from the Adamawa Plateau of Central Cameroon, then flows west across Central Nigeria, and joins River Niger as the main drainage feature in the area. It is one of the few large rivers in Nigeria. The Katsina-Ala is the largest tributary of the River Benue. The floodplains of the River Benue are characterized by extensive swamps and ponds which have potential for dry season irrigated farming.

### Sample collection

A total of 12 soil samples were collected randomly from cassava

farms in Makurdi, Tarka, and Gboko Local Government Areas. These farms belonged to farmers who are members of farming cooperative societies within the study area. Soil samples were collected at a level of 0 to 30 cm since it was for agricultural purposes. Soil samples were collected at both the surface (0 to 15 cm depth) and subsurface (15 to 30 cm depth) at each sampling point. The soil samples were collected with the soil augur and preserved in foil papers and properly labelled black polythene bags and transported to the laboratory for analysis.

### Physical analysis

Soil samples were air-dried and ground with a wooden roller before sieving with a 2 mm mesh. The particle size distribution of the soils was determined using the Bouyoucos hydrometer method (Gee and Bauder, 1986). Sodium hexa-metaphosphate was used as a dispersant after which the textural classes was determined using the textural triangle chart developed by the United States Department of Agriculture (USDA, 1996).

### Chemical analysis

The pH of soil was measured using the soil/water ratio of 1:2 method of the International Institute of Tropical Agriculture (IITA, 1979). Soil organic carbon was determined using the method of Walkley and Black (1934). Total nitrogen was determined by the micro-Kjeldahl digestion method (Jackson, 1962) while available phosphorus was determined using the Bray and Kurtz (1945) No. 1 method. Exchangeable bases (Ca, Mg, K and Na) were extracted from ammonium acetate buffered at pH 7 (neutral IM NH<sub>4</sub>OAc, pH 7.0), flame photometry, and versenate EDTA titration method as prescribed in Jackson (1962) and IITA (1979). The effective cation exchange capacity (CEC) was determined through the summation of exchangeable bases.

Micro-nutrients in the soils (Fe, Mn, Ni, V, Co, and Mo) were extracted by digesting the samples with a mixture of concentrated nitric acid (HNO<sub>3</sub>) and hydrogen chloride (HCl) and their concentrations determined by Atomic Absorption Spectrophotometry (AAS) method - Buck Scientific 200A flame atomization prescribed by Barnshiesel and Bertsch (1982). Quality assurance was



**Table 3.** Location and particle size characterisation of soils samples from cassava farm sites.

Farm site	Crop	Depth (cm)	GPS coordinates		Particle size distribution (%)			Textural class (USDA)	Silt/Clay ratio
			Northings	Eastings	Sand	Silt	Clay		
MKD C1	Cassava	0-15	7.835757	8.5862	87.00	8.00	5.00	Ls	1.60
		15-30			77.00	13.00	10.00	SI	1.30
MKD C2	Cassava	0-15	7.835332	8.5861	85.00	7.00	8.00	Ls	0.88
		15-30			74.00	15.00	11.00	SI	1.36
TRK C1	Cassava	0-15	7.66213	8.83203	68.00	29.00	3.00	SI	9.67
		15-30			68.00	28.00	4.00	SI	7.00
TRKC2	Cassava	0-15	7.66526	8.83358	68.00	22.00	10.00	SI	2.20
		15-30			62.00	24.00	14.00	SI	1.71
GBKC1	Cassava	0-15	7.31069	8.98387	76.00	22.00	2.00	Ls	11.00
		15-30			72.00	22.00	6.00	SI	3.67
GBKC2	Cassava	0-15	7.31024	8.98401	74.00	20.00	6.00	SI	3.33
		15-30			70.00	21.00	9.00	SI	2.33

MKD: Makurdi farm sites; Ls: Loamy sand; SI: Sandy loam; TRK: Tarka farm site; SI: Sandy loam; L: loam; GBK: Gboko farm site; Ls: Loamy sand; SI: Sandy loam.

**Table 4.** Texture of soils samples collected from cassava farm sites.

Parameter	Surface soil		Subsurface soil	
	Range	Mean	Range	Mean
Sand (%)	68.00-87.00	73.42	62.00-77.00	72.18
Silt (%)	8.00-29.00	19.25	13.00-28.00	20.27
Clay (%)	2.00-10.00	7.33	4.00-14.00	7.55

guaranteed by laboratory officers through double determinations and use of blanks for correction of background. The unit of measurement for exchangeable elements was centimoles of positive charge per kilogram ( $\text{cmol kg}^{-1}$ ) while other elements such as phosphorus and micro-nutrient were measured at milligrams per kilogram ( $\text{mg kg}^{-1}$ ). Measures of central tendency such as mean, averages, and range, were used for analyse and results were presented in tabular and graphic form.

## RESULTS AND DISCUSSION

### Physical properties

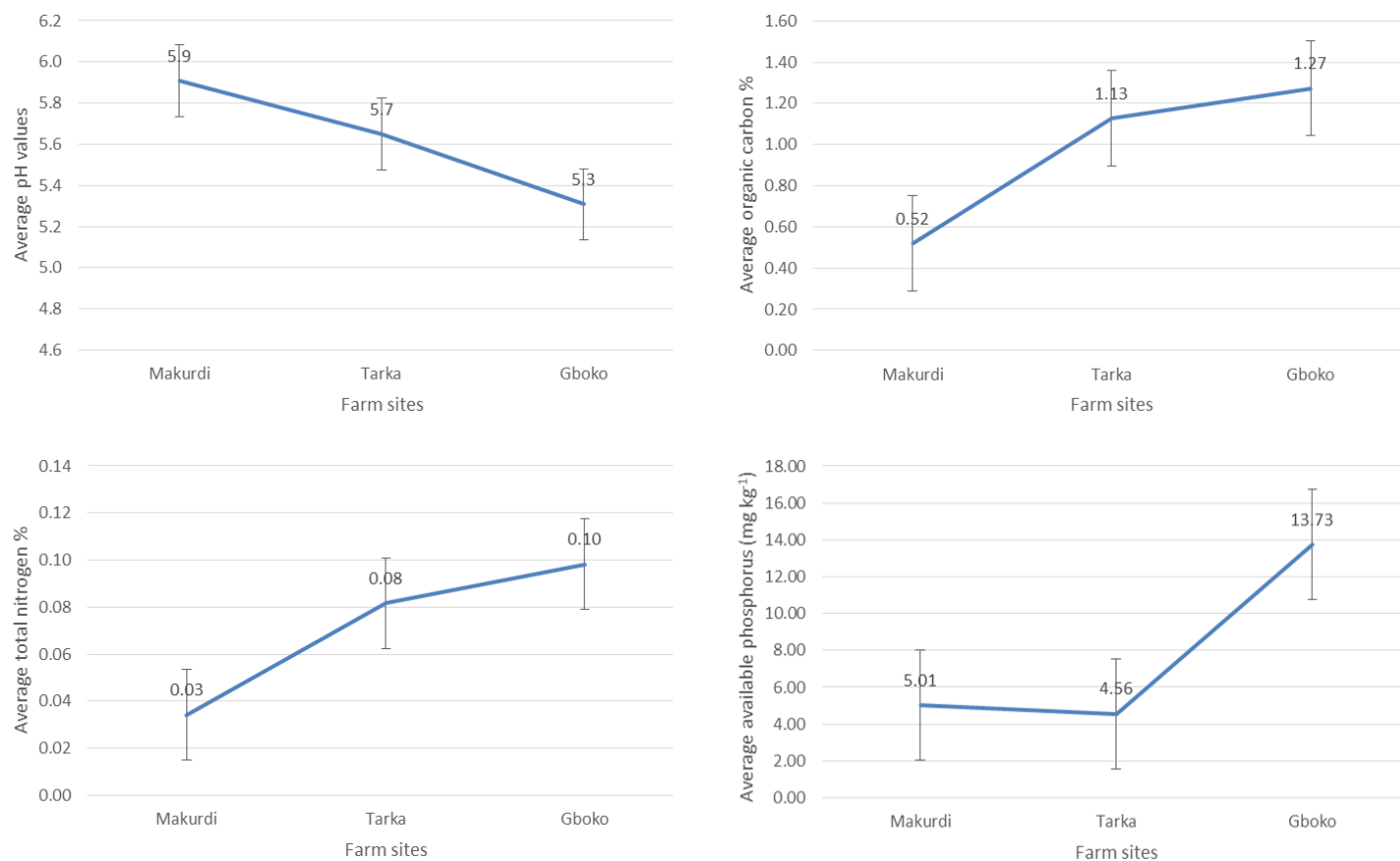
The soil texture of the soil samples from cassava farm sites in Makurdi, Tarka, and Gboko were mostly sandy loam and loamy sand (Table 3). The sand fraction of soils collected from cassava farm sites ranged from 68 to 87% with a mean of 73.42% for surface soils and 62 to 77% and a mean of 72.18% for subsurface soils (Table 4). These soils have low water holding capacity, good drainage and aeration. The soils textures observed have capacity to retain nutrients moderately. Sandy loam and loamy sand soils appear moderately suitable for irrigation, but may be drought prone (Utsev et al., 2014).

### Chemical properties

The occurrence of soil pH, total nitrogen, organic carbon, and available phosphorus in Makurdi, Tarka, and Gboko are presented in Figure 1. Soils from Gboko were more acidic but had the highest amount of nitrogen and organic carbon. Soils from Tarka had the least amount of available phosphorus and soils from Makurdi had the least amount of nitrogen and organic carbon.

### Soil pH

The chemical properties of soil samples collected from cassava farm sites were summarized with permissible limits and presented in Table 5. The pH of soils collected from cassava farms were slightly acidic and ranged from 5.1 to 6.1 with a mean of 5.7 for surface soils and a range of 5.2 to 6.1 with a mean of 5.7 for subsurface soils. The pH of soils collected from cassava farms were slightly acidic as a result of leaching of appreciable quantities of exchangeable base forming cations such as calcium, magnesium, potassium and sodium from the surface layers of the soils and high buffering capacity. This was



**Figure 1.** Graph showing soil nutrient values in Makurdi, Tarka and Gboko.

observed elsewhere in the Lower River Benue Basin (Akpan-Idiok et al., 2013; Utsev et al., 2014). Literature reported that cassava tolerates soils within a wide pH range (4.0 to 8.0) but the best pH range for growing cassava is 5.5 to 6.5 (Titus et al., 2011). The pH of these soils is therefore suitable for cassava cultivation.

### Organic carbon and total nitrogen

The organic carbon content of samples from cassava farms ranged from 0.44 to 1.04% with a mean of 0.7% for surface soils, and a range of 0.46 to 0.93% with a mean of 0.72% for subsurface soils. The percentage of organic carbon was moderate, but did not meet the acceptable limit of 2% as referenced in Table 5. The total percentage of nitrogen ranged from 0.03 to 0.09% with a mean of 0.05% for surface soils, and a range of 0.03 to 0.08% with a mean of 0.05% for subsurface soils. The organic carbon content and total nitrogen were quite low. This has been attributed elsewhere (Akpan-Idiok et al., 2013) to poor vegetative growth, fast rate of decomposition, and the high temperature of the ecological zone. However, the low content of nitrogen in

the study area could be attributed to burning of bush and plant residue during the farming season, leaching and the high rate of organic matter decomposition by micro-organisms, as well as, rapid mineralisation and absorption of nitrogen due to continuous farming. The low levels of organic carbon and total nitrogen cannot sustain intensive cropping, and the application of inorganic fertilizer such as NPK is necessary (Abua and Edet, 2013).

### Available phosphorus

Available phosphorus in the soil samples from cassava farms ranged from 1.62 to 42.37 mg kg<sup>-1</sup> with a mean of 8.48 mg kg<sup>-1</sup> for surface soils, while subsurface soils had a range of 1.00 to 13.50 mg kg<sup>-1</sup> with a mean of 5.66 mg kg<sup>-1</sup>. Available phosphorus levels below 20 mg kg<sup>-1</sup> (Holland et al., 1989) are a limitation to successful crop production and therefore such soils should be enhanced with fertilizers. The low content of available phosphorus can be explained by the high phosphorus absorption capacity of the soils, and the slight acidity of the soils prevalent in floodplain soils.

**Table 5.** Chemical properties of soils from cassava farm sites in Makurdi, Tarka, and Gboko.

Parameter	Surface soil		Subsurface soil		Maximum permissible limits
	Range	Mean	Range	Mean	
pH	5.1-6.1	5.7	5.2-6.1	5.7	5.1-6.5
Organic Carbon (C) (%)	0.44-1.04	0.7	0.46-0.93	0.72	2.0 (%) ++
Total Nitrogen (N) (%)	0.03-0.09	0.05	0.03-0.08	0.05	0.2 (%) ++
Available Phosphorus (P) (mg kg <sup>-1</sup> )	1.62-42.37	8.48	1.00-13.50	5.66	20 (mg kg <sup>-1</sup> ) +++
Calcium (Ca) (cmol kg <sup>-1</sup> )	2.11-3.80	3.3	2.80-4.60	3.28	10-20 (cmol kg <sup>-1</sup> ) +++
Magnesium (Mg) (cmol kg <sup>-1</sup> )	1.36-2.40	2	1.80-2.26	1.96	3-8 (cmol kg <sup>-1</sup> )
Potassium (K) (cmol kg <sup>-1</sup> )	0.06-0.10	0.09	0.05-0.14	0.09	0.6-1.2 (cmol kg <sup>-1</sup> ) +++
Sodium (Na) (cmol kg <sup>-1</sup> )	0.05-0.07	0.06	0.04-0.09	0.06	0.7-1.2 (cmol kg <sup>-1</sup> ) +++
Exchange Acidity (cmol kg <sup>-1</sup> )	0.6-0.96	0.77	0.86-1.06	0.92	4.1 (cmol kg <sup>-1</sup> ) +++
ECEC (cmol kg <sup>-1</sup> )	4.78-7.13	6.3	5.83-7.96	6.23	10.00 (cmol kg <sup>-1</sup> ) +++
Base Saturation (%)	86.00-88.00	86.58	85.00-88.00	86.55	60-80 (%) +++
<b>Fertility indices</b>					
Calcium/Magnesium ratio	0.94-2.43	1.69	1.32-2.09	1.7	3:1-5:1
Magnesium/Potassium ratio	17.50-37.50	24.22	16.14-37.20	23.73	1:2
Carbon/Nitrogen ratio	11.0-16.0	14.33	12.0-17.0	14	25

++ FPDD (1990), +++ Holland et al. (1989).

### Exchangeable bases and exchange capacity

The level of exchangeable bases (Ca, Mg, K, and Na) were moderate with mean values of 3.3, 2, 0.09, and 0.06 cmol kg<sup>-1</sup> for surface soils and 3.28, 1.96, 0.09, and 0.06 cmol kg<sup>-1</sup> for subsurface soils, respectively. Calcium and magnesium were the dominant cations, while potassium and sodium had low concentrations (Table 5). This was also reflected in the moderate levels of the effective cation exchange capacity (ECEC) which ranged from 4.78 to 7.13 cmol kg<sup>-1</sup> with a mean value of 6.3 cmol kg<sup>-1</sup> for surface soils and a range of 5.83 to 7.96 cmol kg<sup>-1</sup> with a mean value of 6.23 cmol kg<sup>-1</sup> for subsurface soils. Exchangeable acidity (Al<sup>3+</sup> and H<sup>+</sup>) of soils from cassava farms were well below the permissible limit of 4.1 cmol kg<sup>-1</sup>. Exchangeable acidity ranged from 0.6 to 0.96 cmol kg<sup>-1</sup> with a mean of 0.77 cmol kg<sup>-1</sup> for surface soils and a range of 0.86 to 1.06 cmol kg<sup>-1</sup> with a mean of 0.92 cmol kg<sup>-1</sup> for subsurface soils.

### Base saturation

The base saturation percentage of the soils were high and ranged from 86 to 88% with a mean of 86.58% for surface soils and a range of 85 to 88% with a mean value of 86.55% for subsurface soils. These base saturation results are above the recommendations in Holland et al. (1989) and indicate the presence of good amounts of soluble forms of basic cations in soil solution. This kind of situation enhances the availability fertilizers in soil for crop uptake. It is generally accepted in literature that soils with base saturation percentages over 50% are fertile

soils. The fertility indices of soils from cassava farm sites as presented in Table 5 also support this assertion. These soils however require fertility enhancement with organic/inorganic fertilizers for optimal crop production.

### Micro-nutrients

Micro-nutrients in this study are metals that are required by the body in trace quantities and are essential for maintaining various body functions and metabolic activities. The micro-nutrients analysed in this study were iron (Fe), manganese (Mn), nickel (Ni), vanadium (V), cobalt (Co), and molybdenum (Mo) as stated in the methodology section. According to the National Academy of Science/Institute of Medicine (NAS/IOM, 2003), the biological functions of micro-nutrients in plants, animals and humans are still under research. However, Lokeshappa et al. (2012) stated that toxicity of micro-nutrients in farm produce depend largely on crop exposure to soils that have been contaminated, hence the need for periodic monitoring. The ranking of micro-nutrients in order of concentration was Fe>Ni>Mn>Mo>Co>V. The values of micro-nutrients (Fe, Mn, Ni, V, Co, Mo) analysed for soils from cassava farm sites were all below tolerable limits as referenced in Table 6. The comparative graphs for micro-nutrient occurrence in Makurdi, Tarka, and Gboko are presented in Figure 2. Tarka Local Government Area had higher occurrence of most of the micro-nutrients analysed.

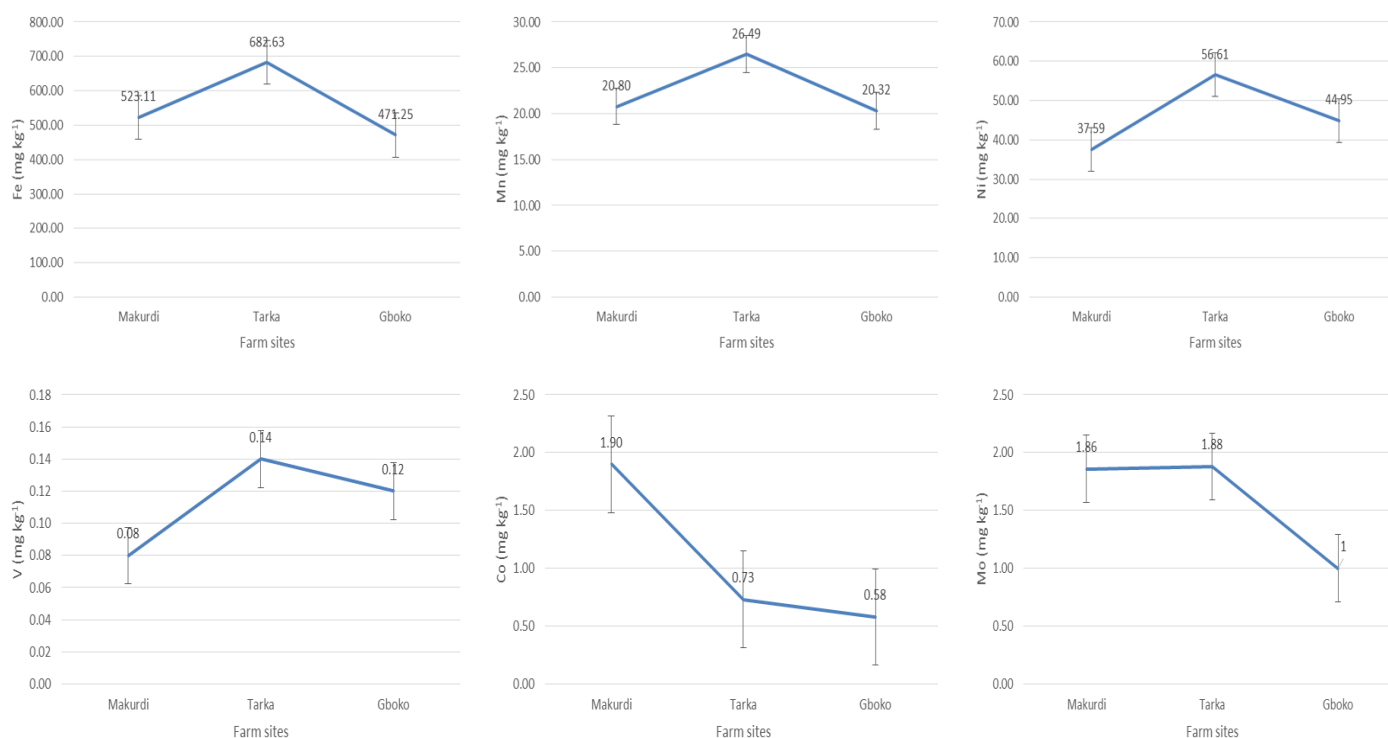
### The need for effective soil management

Cassava extracts enormous amounts of nutrients from

**Table 6.** Micronutrients of soils from cassava farm sites in Makurdi, Tarka, and Gboko.

Parameter	Surface range	Mean	Subsurface range	Mean	Maximum tolerable limits
Iron (Fe)	201.06-900.48	589.09	429.23-900.49	560.78	10,000-100,000 mg kg <sup>-1*</sup>
Manganese (Mn)	10.10-26.13	21.13	13.24-40.10	21.8	200-2000 mg kg <sup>-1**</sup>
Nickel (Ni)	29.21-56.20	40.32	20.06-54.60	39.91	10-1000 mg kg <sup>-1**</sup>
Vanadium (V)	0.09-0.16	0.12	0.05-0.22	0.12	20-500 mg kg <sup>-1**</sup>
Cobalt (Co)	0.38-0.73	0.61	0.43-0.78	0.6	1-70 mg kg <sup>-1**</sup>
Molybdenum (Mo)	1.09-2.29	1.4	0.20-1.89	1.32	4 mg kg <sup>-1</sup>

\*Brady and Weil (1996), \*\* Bohn et al. (1985).

**Figure 2.** Graph showing values of micro-nutrients in Makurdi, Tarka, and Gboko.

the soil notwithstanding that it can grow on soils with low nutrient levels. Therefore, effective application of fertilizer assures healthy plant growth capable of resisting pests and diseases (Rio, 2012). According to Rio (2012), nutrient deficiency affects the cassava plant in several ways (Table 7).

The result of the study demonstrates that these soils are suitable for crop cultivation including cassava. However, the values of parameters measures reveal deficiencies in nutrient availability for optimal crop yield. The River Benue floodplain is an area of perennial crop cultivation and the use of inorganic fertilizer is already an annual occurrence. The cultivation of cassava crops in

ecosystems with the reported level of deficiencies may witness low crop yields. The aggressive utilization of nutrients by root crops such as cassava could exacerbate the degradation of soil physical and chemical composition. Without effective application of inorganic fertilizer in fragile ecosystems such as floodplains, the risk of attendant pollution such as buildup of soil chemicals and water pollution is imminent. A similar study by Abah et al. (2013) assessed amounts of micro-nutrients in soils and roots and cassava grown in farms where agrochemicals have been used in parts of Benue State. The study by Abah et al. (2013) revealed widespread inefficient application of inorganic fertilizer

**Table 7.** Attributes of cassava plant faced with nutrient deficiency (Rio, 2012).

Parameter	Deficiency attributes
Soil pH	Reduced growth and yield in soils with pH outside 5.5-6.5
Nitrogen	General yellowing of plants; reduced plant and root growth; and stunting of plant
Phosphorus	Leaf tips look burnt; reduced plant growth and yields; and thin stems narrow leaves and fewer lobes
Potassium	Wilted and scorched leaves; crooked upper stems with grooves and interveinal from leaves; and reduced plant height and vigour
Calcium	New leaves at the top of the plant are distorted or irregularly shaped; and poor root formation
Magnesium	Interveinal chlorosis from tip or edges and advancement towards the centre; and leaf margins may become necrotic
Iron	Uniform chlorosis of leaves; and reduced plant and leaf size
Manganese	Interveinal chlorosis of young fully expanded leaves; reduction in size of plant leaves, shoots, and tubers; and dead spots or parches appear

and herbicides which had caused a buildup of micro-nutrients in soils and cassava roots. Abah et al. (2013) called for the education of farmers on efficient use of agrochemicals.

Another study by Babalola et al. (2011) assessed the soils of two wetlands in Nigeria for rice production. Babalola et al. (2011) stated that site specific soil assessments were more beneficial to crop production and revealed that soil infertility, especially regarding soil pH, potassium, and nitrogen, as the limiting factor for rice production. It therefore means that optimizing the level of chemicals such as nitrogen, potassium, and phosphorus would add to the fertility quality of these soils. The most utilised method for this approach is the application of inorganic fertilizer such as NPK. The efficient use of inorganic fertilizer has been emphasized in literature. Babalola et al. (2011) recommended fertility evaluation studies and the efficient use of appropriate fertilizers.

A study by Chukwu (2007) assessed soils in wetlands in Southeastern Nigeria and recommended increased use of bio-fertilizers such as Azolla as a supplement to inorganic fertilizers. A change in farming method as reported elsewhere (Nwite et al., 2013) reduces the overdependence on inorganic fertilizer and depletion of nutrients. Nwite et al. (2013) observed that rice farmers in inland valleys of Southeastern Nigeria alternated between various methods to prevent leaching and dependence on inorganic fertilizer. Shifting cultivation as a way of preserving soil fertility on floodplains was reported by Zarin et al. (2006). Zarin et al. (2006) concluded that flooding and fluvial erosion had more significant effects on soil fertility in floodplains than continuous cultivation.

The efficient application of inorganic fertilizers to optimize soils fertility has drawn the attention of scholars for some time now. According to Finke and Stein (1994), optimizing soil fertility could result in leaching and

contamination of soils as it is quite difficult to strike a balance between actual nutrient requirements and plant uptake. Finke and Stein (1994) proposed site specific assessment of nutrient requirements and efficient application of fertilizers.

Given the result of this paper, the use of inorganic fertilizers is inevitable. This is because, even though the soils were found to be suitable for crop cultivation including cassava, total nitrogen, organic carbon, and available phosphorus were found to be inadequate and varied in Makurdi, Tarka, and Gboko. This study therefore strongly recommends that all farmers should identify the nutrient requirements of farm soils before embarking on the use inorganic fertilizers. Governments should establish or collaborate with relevant laboratories to make periodic soil analysis available to farmers at subsidized rates depending on local economic realities. Agricultural extension services should be active in areas of intensive crop farming to provide guidance on efficient application of agrochemicals and evaluation of compliance. Subsistence farmers require adequate support from both the public and private sector to improve cultivation methods and practices. This will engender a culture of efficiency and productivity with long term benefits for sustainable agriculture.

### Conflict of Interests

The authors have not declared any conflict of interests.

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## Full Length Research Paper

# The effect of *Jatropha curcas* L. leaf litter decomposition on soil carbon and nitrogen status and bacterial community structure (Senegal)

Tidiane Dieye<sup>1,2</sup>, Komi Assigbetse<sup>1\*</sup>, Ibrahima Diedhiou<sup>3</sup>, Mbacké Sembene<sup>2</sup>, Amadou Lamine Dieng<sup>1</sup>, Mariama Gueye<sup>1</sup> and Dominique Masse<sup>1</sup>

<sup>1</sup>Centre de Recherche IRD-ISRA de Bel-Air, UMR 210 Eco&Sols LMI IESOL, Laboratoire d'Ecologie Microbienne des Sols et Agrosystèmes Tropicaux, B.P. 1386 CP 18524 Dakar, Sénégal.

<sup>2</sup>Département de Biologie Animale, Université Cheikh Anta Diop Dakar, Senegal.

<sup>3</sup>Ecole Nationale Supérieure d'Agriculture, Thiès, Senegal.

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The cultivation of *Jatropha curcas* L. as a biodiesel feedstock has been encouraged in Senegal to reduce dependence on fossil fuels and mitigate the effects of climate change. *J. curcas* is a poisonous plant which sheds its leaves during the dry season. Although the leaves are toxic for animals, they can help to recycle soil organic matter. This study set out to determine the effect of the decomposition dynamics of green and senescent *J. curcas* leaves on the soil C and N contents and on the structure of the bacterial community. Leaf litter decomposition was studied for 4 months by laboratory incubation and samples were taken at the start of incubation and at 3, 28, 56, 90 and 120 days. Green leaves had a higher N content, higher concentrations of water soluble compounds and hemicelluloses, but a lower C:N ratio and lignin content than senescent leaves regardless of the cultivar. The cultivar, the type of litter and the interaction between them, all had a significant effect on the soil N content ( $p < 0.0001$ ,  $R^2 = 0.995$ ) and C:N ratio ( $p < 0.0001$ ,  $R^2 = 0.998$ ). However, the cultivar was the only factor that affected the leaf C content ( $p < 0.05$ ,  $R^2 = 0.624$ ). The initial N content explained the  $N-NH_4^+$  mineralization at the start of decomposition and the initial lignin content explained the  $N-NH_4^+$  mineralization at later stages of decomposition. The recalcitrant C content in the green leaves was estimated as being between 70.01 and 73.33% of the total C content and between 72 and 77.33% in senescent leaves. This suggests that *Jatropha* litter may contribute significantly to soil C sequestration. The results indicate that the soil had higher bacterial diversity in the later stages of litter decomposition, for both types of litter and all cultivars.

**Key words:** *Jatropha curcas* L., leaf litter, nitrogen mineralization, carbon mineralization, bacterial community, polymerase chain reaction denaturing gradient gel electrophoresis (PCR-DGGE), Senegal.

## INTRODUCTION

Soils in the arid and semi-arid Sudano Sahelian region of West Africa have an intrinsic low level of fertility (Bationo

and Buerkert, 2001) and increasing pressure from livestock grazing is causing a significant loss of organic

matter and depletion of nutrient reserves in soils (Dossa et al., 2009). Organic matter input has been shown to be critical for improving soil quality and optimizing nutrient and water efficiency and ultimately crop productivity in these degraded agro ecosystems (Sinaj et al., 2001; Tschakert, 2004). The preservation of soil functions requires sustainable management of soil organic matter (SOM). Of the practices aiming to maintain and increase SOM, mulching with plant residues is beneficial as it improves soil fertility, increases carbon sequestration and provides sustainable recycling of organic residues.

In Senegal, the gradual depletion of world fossil fuel reserves and the inability to provide adequate energy services have led to the adoption of renewable energy sources. *Jatropha curcas* L., an oil-yielding tropical plant, was considered to be a promising alternative to fossil fuels with high economic potential. Given this increased interest in *J. curcas* as a biodiesel feedstock, it was introduced in Senegal in 2007 and has since been cultivated intensely throughout the country, especially in rural areas. *J. curcas* is a perennial plant belonging to the Euphorbiaceae family with poisonous seeds and leaves. Wani et al. (2012) estimated that the accumulated leaf fall from a 3 to 5 year old *J. curcas* plantation added 1450 kg ha<sup>-1</sup> of carbon to the soil, 800 kg of this from the leaves, suggesting that leaves can recycle soil organic matter and nutrients (Patrício et al., 2012).

However, little research has been carried out into *J. curcas* leaf litter decomposition processes and their role in the maintenance of soil and environmental functions. It has been established that litter decomposition and nutrient release is controlled by the chemical composition of the litter (Arriaga and Maya, 2007) as well as by abiotic factors and microbial activities (Li et al., 2011). Although the C:N ratio or N related indices of residues are often found to be the main factors governing decomposition processes (Kemp et al., 2003; Bray et al., 2012), other factors such as the lignin, cellulose, polyphenolic and tannin contents of the litter also affect nutrient release dynamics during decomposition (Zhang et al., 2008; Talbot and Treseder, 2012). Changes in the chemical composition of the litter have been found to affect the decomposition rates of different types of litter (Milcu et al., 2011) and to have a noticeable effect on the microbial decomposer community during the decomposition process (Bray et al., 2012; Knelman et al., 2012; Esperschütz et al., 2013; Pfeiffer et al., 2013). Microbial decomposer communities can change during litter decomposition owing to biotic interactions and shifting substrate availability (Chapman et al., 2013).

Recent studies have found out that changes in litter

composition owing to decomposition can have a significant effect on microbial community composition and on ecosystem processes (Chapman et al., 2013). The cultivation of *J. curcas* modifies the fungal community structure, but does not have a specific, systematic effect on the structure of the soil bacterial community (Dieng et al., 2014). However, *J. curcas* may affect the structure of the soil bacterial community indirectly through litter decomposition. Further research is required into the mechanism of the decomposition of senescent or green *J. curcas* leaf litter and its potential or releasing nutrients and thus providing agronomic and environmental services.

This study investigated the effect of *J. curcas* leaves on the dynamics of soil C and N cycling and the structure of the bacterial community after the soil had been mulched with senescent and green leaves in laboratory conditions.

## MATERIALS AND METHODS

### Soil sampling

The site from which soil samples were taken was located in Goudiry, South East Senegal (14°11'15.27"N 12°42'44.79"W). The soil is hydromorphic ferruginous containing 6 to 9% clay, 0.90% total C, 0.08% total N and 7.9 mg g<sup>-1</sup> total P and the pH is estimated at 6.17. Soil samples were collected in February 2010 from the 0 to 20 cm horizon. The samples were air dried in the laboratory and sieved through a 2 mm mesh prior to treatment and analysis.

### Mozambic

Fresh green and senescent leaves were collected from the branches of two native and two introduced cultivars of *J. curcas* planted at the Higher National School of Agriculture, Thiès University (14°42'52"N, 16°28'64"W). This plantation was a completely randomized design with 4 cultivars. The spacing between plants was 2 m. No fertilizer was used for this experiment. The native cultivars selected were Banfadjiré (Ban) and MadiopBoye (MB) from Senegal and the introduced cultivars were from Mozambique (MOZ) and Tanzania (TZ) (Table 1). For each cultivar, leaves were taken from 4 plants (4 replicates) and mixed, air-dried at ambient temperature in the laboratory for 3 weeks and then sieved through a 2 mm mesh. The green leaf litter is indicated by a 1 (Ban1, MB1, MOZ1 and TZ1) and the senescent leaf litter is indicated by a 2 (Ban2, MB2, MOZ2 and TZ2) (Table 1).

### Soil and litter incubation

Two sets of soil samples, 20 g for C mineralization and 40 g for N mineralization and bacterial dynamics, were used. The samples were pre-incubated at 28°C for one week to reactivate the microorganisms. The soil humidity was adjusted to 60% of water holding capacity during the pre-incubation phase and 80%

\*Corresponding author. E-mail: Komi.Assigbetse@ird.fr.



thereafter. The litter was applied as a mulch on the soil surface at a rate of 508 kg ha<sup>-1</sup> (Abugre et al., 2011). This was equivalent to the highest litter fall of *J. curcas* at a planting distance of 1 × 1 m during the dry season. Three replicates were taken for each type of litter. For C mineralization, samples were transferred to a 150 ml glass flask sealed with a septum and incubated at 28°C for 120 days. For N mineralization, each sample was incubated at 28°C in 500 ml glass flasks with 15 ml of 1 M NaOH as a CO<sub>2</sub> trap. Three flasks with soil and no litter were used as controls. Samples were taken at the start of incubation and at 3, 28, 56, 90, and 120 days for determination of the total soil C and N contents and an aliquot of each sample was stored at -20°C for DNA extraction later.

### Chemical composition of soil and leaf litter

The water soluble compound, hemicellulose, cellulose and lignin contents were determined as described by Goering and Van Soest (1970). The total N and C contents were determined by dry combustion using a LECO FP 428 CHN autoanalyzer (LECO Corp, St. Joseph, Mich). The total P content was determined by colorimetry (Murphy and Riley, 1962). All C, N and P analyses were performed at the IRD LAMA laboratory (Laboratoire des Moyens Analytiques, certified ISO 9001 2008), Dakar, Senegal.

### Carbon and nitrogen mineralization

Carbon mineralization was analyzed by measuring the CO<sub>2</sub> released during incubation. The air in the flasks was analyzed by injecting the gas directly from the flask into an MTI Analytical Instruments P200 gas chromatograph (Microsensor Technology, Fremont, Calif.) equipped with a TCD detector using helium as the carrier gas. The gas analyzer was used in combination with the Windows-based EZChrom 200 chromatography data system.

The mineral N was determined using KCl soil extracts (1 M KCl) by colorimetric flow injection analysis as described by Bremner (1965). Net N, N-NH<sub>4</sub><sup>+</sup> and N-NO<sub>3</sub><sup>-</sup> content were determined relatively to soil control.

### Soil DNA extraction and polymerase chain reaction denaturing gradient gel electrophoresis (PCR-DGGE)

#### Soil DNA extraction

The soils used for DNA extraction were aliquots of the same soil samples used for mineralization analysis which had been stored at -20°C from each sampling day. DNA was extracted from 0.25 g aliquots of soil using Fast DNA Spin Kit for Soil (MP-Biomedicals, NY, USA) according to the manufacturer's instructions. The purified DNA was re-suspended in 100 µl of DNase-free water (MP-Biomedicals) and the DNA concentrations were quantified using a NanoDrop ND-1000 UV-Vis Spectrophotometer (NanoDrop Technologies, USA) according to the manufacturer's instructions. Three replicate DNA extractions from each sample were pooled prior to PCR amplification.

#### PCR-DGGE

The V3 region of the 16S rRNA gene was amplified for DGGE analysis using primers UNIV518r (Ovreås et al., 1997) and EUB338f with a 40-bp GC clamp at the 5' end (Muyzer et al., 1993). The reaction mixture of 25 µl contained 5 ng of DNA, Taq Polymerase Ready-To-Go (Amersham-Biosciences, France) and 1

µM of each primer. The PCR was performed using the following program: initial denaturation for 5 min at 94°C, followed by 20 cycles of 30 s at 94°C (denaturation), 1 min at 65°C (annealing) with a 0.5°C touch down every second cycle, and 1 min at 72°C (elongation), followed by 10 cycles with an annealing temperature of 55°C and a final cycle of 10 min at 72°C. The PCR products were separated by electrophoresis in 1.5% (w/v) agarose gels and stained for 30 min with ethidium bromide (1 mg L<sup>-1</sup>). 20 µl of the PCR products were separated using the Ingeny U-Phor system (Ingeny, Goes, The Netherlands) in 8% polyacrylamide (acrylamide–bisacrylamide [37.5:1]) gel with a linear 45 to 70% denaturant gradient (100% denaturant containing 7 M urea and 40% formamide). Electrophoresis was carried out using a 1X Tris-acetate-EDTA buffer at 100 V and 60°C for 17 h. The gels were stained for 30 min with ethidium bromide (1 mg L<sup>-1</sup>) and de-stained in distilled water for 10 min. The bands were then photographed using a Vilber Lourmat imaging system (EtsVilberLourmat, France). Band detection and intensity quantification were performed using Total Lab gel imaging software (Nonlinear Dynamics Ltd., Newcastle UK), with manual checking and adjustment of each band position. The band intensity was used as an indication of relative abundance.

### Statistical analysis

The N and C contents and C:N ratio were analyzed by two way analysis of variance (ANOVA) and the means were assessed using Fisher's Least Square Difference (LSD) test at 95%. A one way ANOVA was performed to assess the difference between the mineral N for each treatment. A Pearson test at 95% was used for all correlation tests. All analyses were performed using XLSTAT-Pro (AddinSoft, v10, France).

The net CO<sub>2</sub> emitted by the mulched samples was obtained by subtracting the CO<sub>2</sub> emitted by the controls and C loss was calculated as the net CO<sub>2</sub> divided by the initial litter carbon content. The carbon loss data were also fitted to the double exponential decomposition model of Wider and Lang (1982) used in previous studies (Beyaert and Voroney, 2011; Staelens et al., 2011; Patrício et al., 2012).

$$C_t = C_1 e^{-k_1 t} + C$$

where C<sub>t</sub> is the % of carbon remaining at time t, C<sub>1</sub> is the initial % of component 1 (labile C) at the start; k<sub>1</sub> is the decomposition rate for labile C; C<sub>2</sub> is the initial % of component 2 (recalcitrant C) at the start, and k<sub>2</sub> is the decomposition rate for recalcitrant C.

The 16S rDNA-DGGE banding patterns were scored by the presence/absence of bands using the Dice index. Phoretix 1D (TotalLab Ltd) was used to cluster the patterns using the unweighted pair group method with mathematical average (UPGMA). The structural diversity of the bacterial community was estimated using the Shannon index of general diversity based on the number of bands and the relative intensity of the bands in each lane. The intensity of the bands was estimated from the peak heights. The Shannon H index was calculated using the following equation:

$$H = -\sum (P_i \times \log P_i)$$

where P<sub>i</sub> is n<sub>i</sub>/N, n<sub>i</sub> is the peak height and N is the sum of all peak heights.

To show the overall differences, Principal Component Analysis (PCA) was performed on a data matrix of various variables (mineral N, soil C/N ratio, cumulative CO<sub>2</sub> and Shannon diversity) using the

**Table 1.** Litter origin and chemical characteristics.

Origin	Litter type	Treatment	Total N (%)	Total C (%)	C/N	WSC	HEM	CEL	LIG
Banfadjiré (Senegal)	Green	Ban1	3.09 (0.09)	44.66 (0.68)	14.44 (0.24)	46.6	10.7	18.8	12.3
	Senescent	Ban2	1.69 (0.02)	45.34 (0.50)	26.75 (0.51)	38.6	4.1	21.3	24.8
MadiopBoye (Senegal)	Green	MB1	2.85 (0.09)	43.27 (0.37)	15.19 (0.54)	47.0	10.9	17.5	11.7
	Senescent	MB2	1.46 (0.05)	44.81 (0.94)	30.75 (0.48)	38.1	6.9	17.1	22.7
Mozambic	Green	MOZ1	3.11 (0.02)	44.22 (0.46)	14.24 (0.11)	44.3	6.1	11.9	25.9
	Senescent	MOZ2	1.33 (0.02)	43.60 (0.15)	32.78 (0.63)	29.0	3.8	26.5	27.8
Tanzania	Green	TZ1	2.95 (0.07)	44.87 (1.01)	15.19 (0.07)	48.8	10.9	15.7	12.3
	Senescent	TZ2	1.70 (0.05)	45.16 (0.63)	26.52 (0.54)	40.0	7.5	18.9	23.0

**Table 2.** Two ways ANOVA (origin and litter type) on C, N and C/N ratio litter contents.

Variation sources	Statistical parameters	N total	C total	C/N
Model	R <sup>2</sup>	0.995	0.624	0.998
	F	478.920	3.794	965.156
	Pr > F	<0.0001	0.013	<0.0001
Origin	F	17.883	4.983	65.693
	Pr > F	<0.0001	0.013	<0.0001
Litter type	F	3.240.771	3.144	6.314.537
	Pr > F	<0.0001	0.095	<0.0001
Originxlitter type	F	19.341	2.822	81.492
	Pr > F	<0.0001	0.072	<0.0001

XLSTAT, PCA option (XLSTAT version 10, Addinsoft, France).

## RESULTS

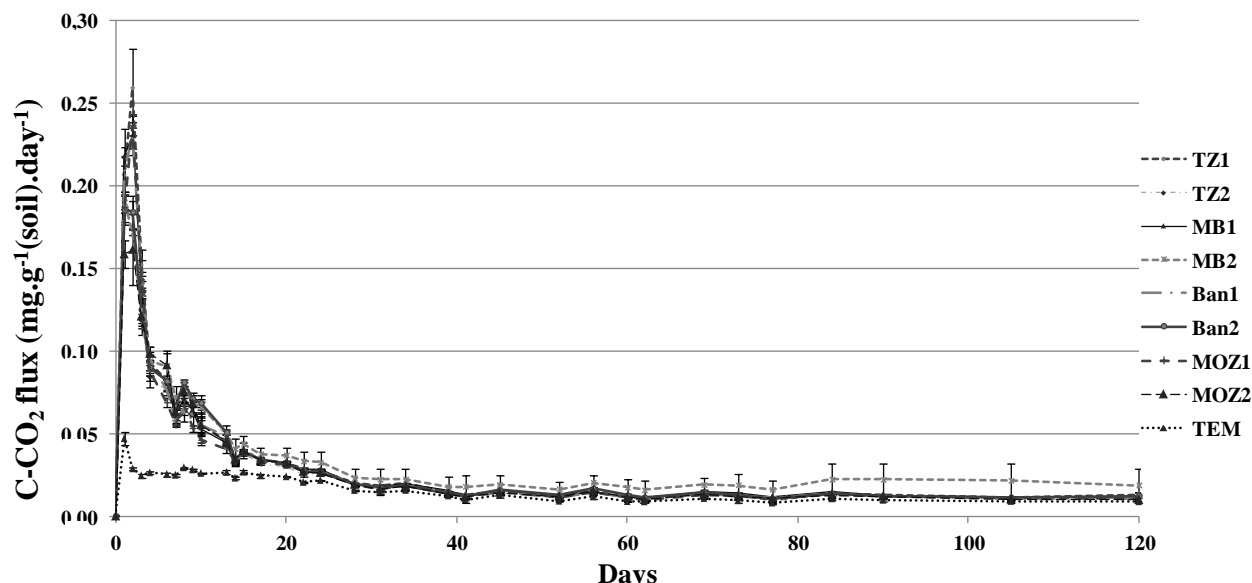
### Chemical composition of the litter

The chemical characteristics of the leaf litter are shown in Table 1. For green leaves, Ban1 and MOZ1 had a significantly higher N content ( $p < 0.0001$ ) than TZ1 and MB1. For senescent leaves, MOZ2 had the lowest N content ( $p < 0.0001$ ). The C content of Ban and TZ was significantly higher ( $p < 0.05$ ) than MB and MOZ indicating that the cultivar had a significant effect ( $p < 0.05$ ) on the leaf C content (Table 2). For all cultivars, the C:N ratio was significantly higher ( $p < 0.0001$ ) in senescent leaves (1.7 to 2.2 times higher) than in green leaves. Senescent leaves from MOZ had the highest C:N ratio (32.78) followed by those from MB (30.75). Water soluble compounds and hemicellulose content were higher in the green leaves than in the

senescent leaves while the senescent leaves had a higher lignin content. Senescent leaves had the highest cellulose content. MOZ1 leaves had high lignin and low cellulose and hemicelluloses contents. Two way ANOVA showed that the type of leaf litter, the cultivar and interaction between them, all had a significant effect ( $p < 0.0001$ ) on the soil N content and C:N ratio (Table 2). Green leaves had a higher N content than senescent leaves ( $p < 0.0001$ ) for all cultivars.

### C-CO<sub>2</sub> flux and carbon loss during decomposition

The C-CO<sub>2</sub> flux was higher in the early stages of incubation and was significantly higher ( $p < 0.0001$ ) for all mulched soils than for the control (Figure 1). The CO<sub>2</sub> flux in soils mulched with green leaves (0.14 to 0.15 mg g<sup>-1</sup> day<sup>-1</sup>) was higher than in soils mulched with senescent leaves (between 0.11 and 0.12 mg g<sup>-1</sup> day<sup>-1</sup>) after 3 days for all cultivars. However, there was no significant difference thereafter. The CO<sub>2</sub> flux after 3 days was positively correlated with the initial N ( $p < 0.0001$ ,



**Figure 1.** C-CO<sub>2</sub> flux (mg.g<sup>-1</sup>.day<sup>-1</sup>) of soil under litter supply by TZ1 and TZ2 (Tanzania), MOZ1, and MOZ2 (Mozambique), Ban1 and Ban2 (Banfadjiré) and MB1 and MB2 (Madiop Boye).

$R^2=0.946$ ) and negatively correlated with the C:N ratio ( $p=0.0003$ ,  $R^2=0.90$ ). At the end of experiment (120 days), there was no difference in the CO<sub>2</sub> flux ( $p<0.0001$ ) between mulched soils and the control. The C loss data for the mulched soils was a good fit with the double exponential decomposition model (Figure 2) with  $R^2$  varying between 99 and 99.9% (Table 3). In this model, carbon is separated into 2 compartments with different decomposition dynamics: labile and recalcitrant compounds. Labile C was decomposed rapidly (Table 3). The labile C decomposition rate  $k_1$  was not significantly different between leaves from different cultivars but was significantly higher ( $p<0.05$ ) for green leaves than for senescent leaves. Recalcitrant C was decomposed very slowly with a decomposition rate  $k_2$  which was similar for all except MB1 and MB2. MB1 and MB2 were significantly different from TZ ( $p=0.044$ ) and MOZ ( $p=0.04$ ). The decomposition rate  $k_1$  was negatively correlated with the initial cellulose content ( $p<0.05$ ,  $R^2=0.707$ ), whereas  $k_2$  was not correlated with the initial content of any chemical compounds.

### Nitrogen mineralization

The N-NO<sub>3</sub><sup>-</sup> release rate from the soil differed significantly during the incubation period (Figure 3). In TZ1, TZ2 and MB2, N-NO<sub>3</sub><sup>-</sup> was immobilized in the early stages of incubation, at 3 days. After 28 days, N-NO<sub>3</sub><sup>-</sup> was being immobilized in TZ1, TZ2, MB1 and MB2, the highest rate being in TZ2 (-21.8 µg g<sup>-1</sup> soil). From 56 to 120 days, N-

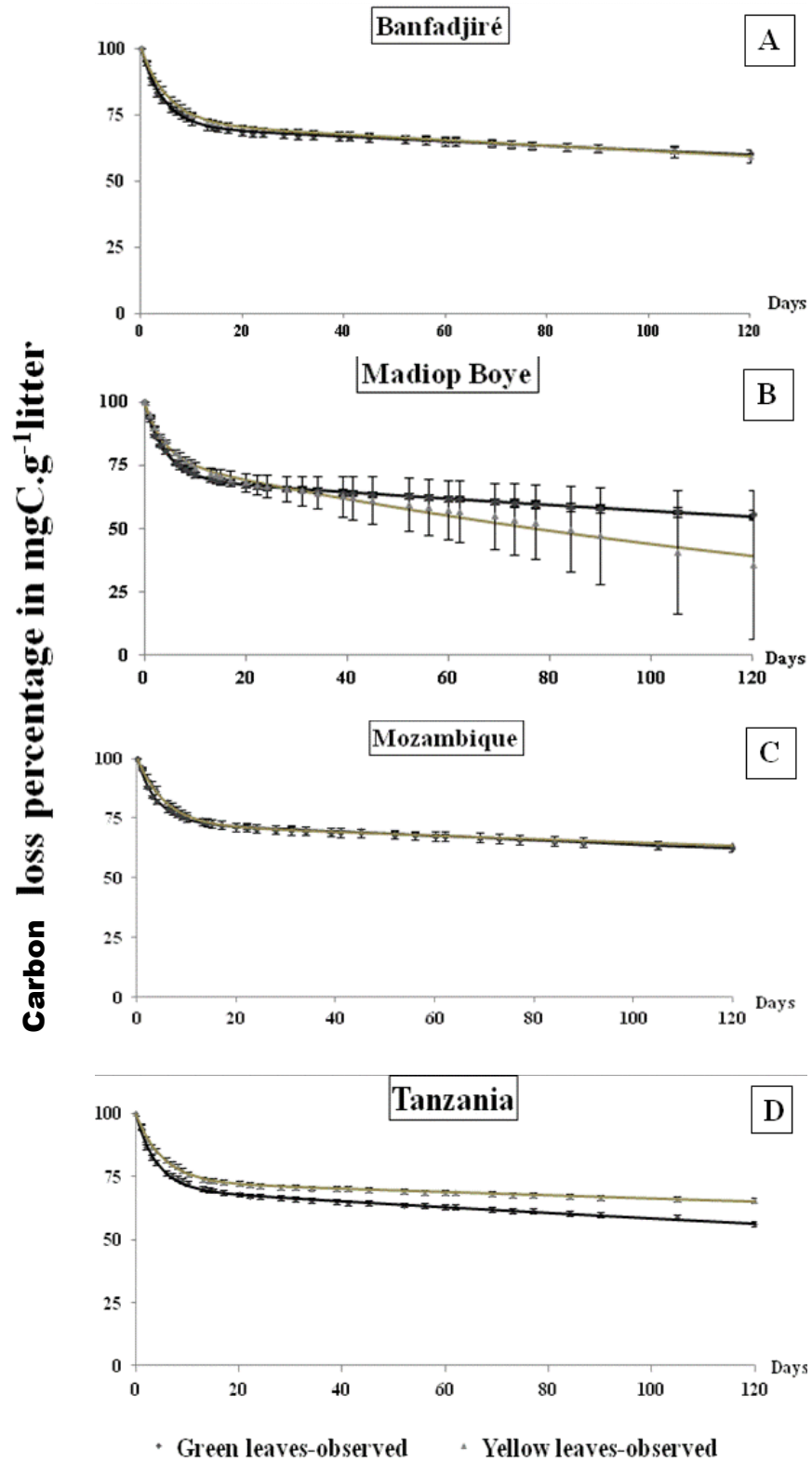
NO<sub>3</sub><sup>-</sup> was mineralized in all mulched soils except TZ2, where N-NO<sub>3</sub><sup>-</sup> was still being immobilized. The highest nitrification rate was in Ban1 during the incubation period except at 90 days when it was declining for both types of litter and all cultivars.

There were significant differences in the dynamics of N-NH<sub>4</sub><sup>+</sup> release during the incubation period (Figure 4). From day 3 to day 28, N-NH<sub>4</sub><sup>+</sup> was immobilized in TZ2, MB2, Ban2 and MOZ1. From day 56 to day 120, there was net ammonification in TZ1 and Ban1, while there was net N-NH<sub>4</sub><sup>+</sup> immobilization in all other mulched soils with the highest rate in MOZ1 (Figure 4). Finally, from day 28 to the end of the incubation, the highest net N mineralization was in Ban1, and the highest N immobilization was in TZ2 (Figure 5).

The N mineralization rates were correlated with the chemical composition. The N-NH<sub>4</sub><sup>+</sup> mineralization rate at day 3 was positively correlated ( $R^2=0.53$ ,  $p<0.05$ ) with the total N content of the litter and negatively correlated with the lignin content at day 28 ( $R^2=0.62$ ,  $p<0.05$ ), day 56 ( $R^2=0.53$ ,  $p<0.05$ ) and day 90 ( $R^2=0.62$ ,  $p<0.05$ ). The lignin content of the litter explained the change in net N mineralization at day 90 ( $R^2=0.54$ ,  $p<0.05$ ). PCA showed that during decomposition the net mineral N (N-NH<sub>4</sub><sup>+</sup> + N-NO<sub>3</sub><sup>-</sup>), content of the soil was negatively correlated with the C:N ratio of the soil (Figure 6).

### Bacterial DGGE banding patterns

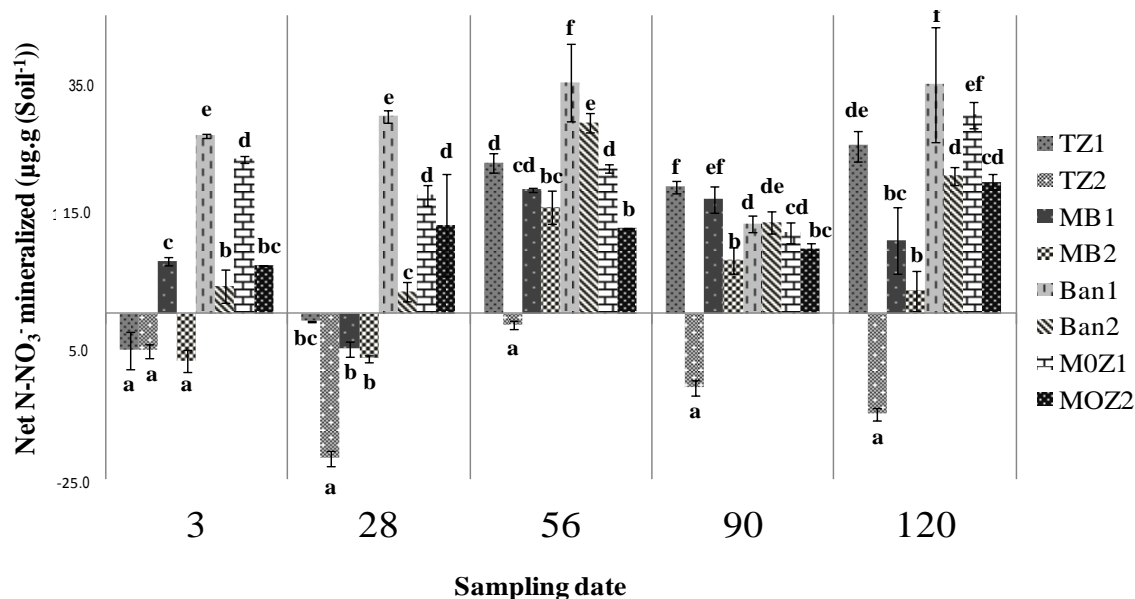
Cluster analysis of DGGE banding fingerprints gave a



**Figure 2.** Percentage of Carbon remaining mass (mgC.g<sup>-1</sup> litter) of treatment Banfadjiré (A), Madiop Boye (B), MOZ (C) and TZ (D) during green and senescent (yellow) leaves decomposition; dots are observed values (bars=standards deviation) and lines are expected values.

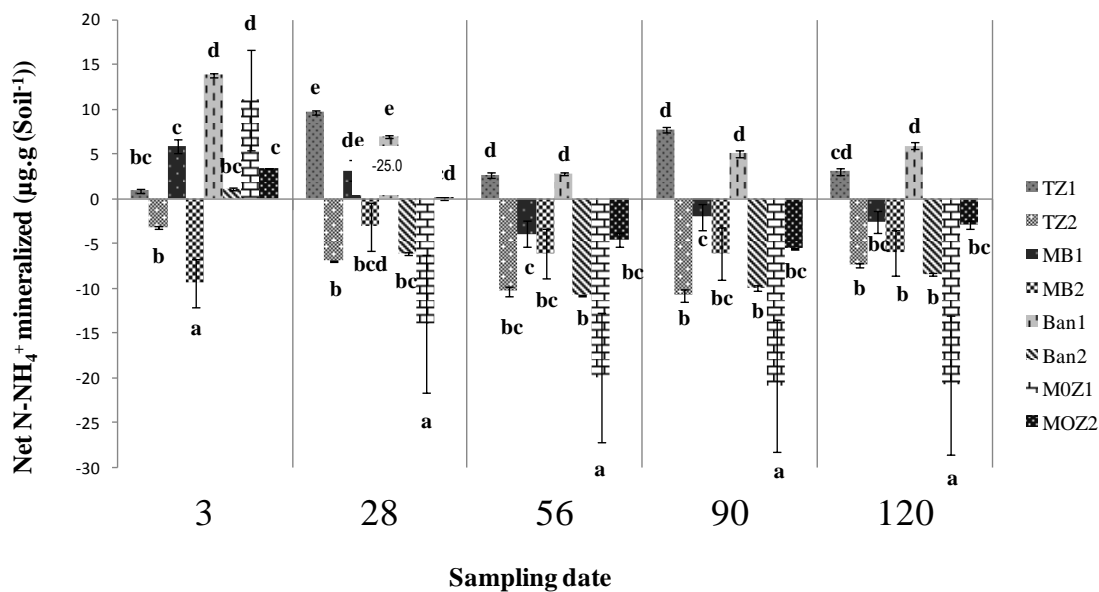
**Table 3.** Carbon loss model parameters with  $k_1$  the decay constant rate of labile carbon and  $k_2$  decay constant rate of recalcitrant C with standard deviation of green and senescent leaves.

Litter type	Origins	$k_1$ (day <sup>-1</sup> )	$k_2$ (day <sup>-1</sup> )	Labile carbon (%)	Equations	R <sup>2</sup>
Green leaves	Banfadjiré	0.23 -0.019	0.001 (0.0002)	29.39 -1.7	$Ct = 29.39e^{-0.23t} + 70.61e^{-0.001t}$	0.995
	Madiopboye	0.24 -0.001	0.002 -0.0002	29.99 -1.09	$Ct = 29.99e^{-0.24t} + 70.01e^{-0.002t}$	0.998
	Mozambica	0.25 -0.009	0.001 -0.0002	26.67 -1.92	$Ct = 26.67e^{-0.25t} + 73.33e^{-0.001t}$	0.99
	Tanzania	0.25 -0.012	0.002 -0.0001	29.77 -1.65	$Ct = 29.77e^{-0.25t} + 70.23e^{-0.002t}$	0.997
	Banfadjiré	0.19 -0.015	0.002 -0.0003	28 0.43	$Ct = 28e^{-0.19t} + 72e^{-0.002t}$	0.999
Senescent leaves	MadiopBoye	0.26 -0.073	0.006 -0.005	22.67 -4.58	$Ct = 22.67e^{-0.26t} + 77.33e^{-0.006t}$	0.991
	Mozambica	0.18 -0.008	0.001 -0.0002	27.8 -1.14	$Ct = 27.8e^{-0.18t} + 72.2e^{-0.001t}$	0.99
	Tanzania	0.19 -0.006	0.001 -0.0002	27.26 -0.47	$Ct = 27.26e^{-0.19t} + 72.74e^{-0.001t}$	0.998

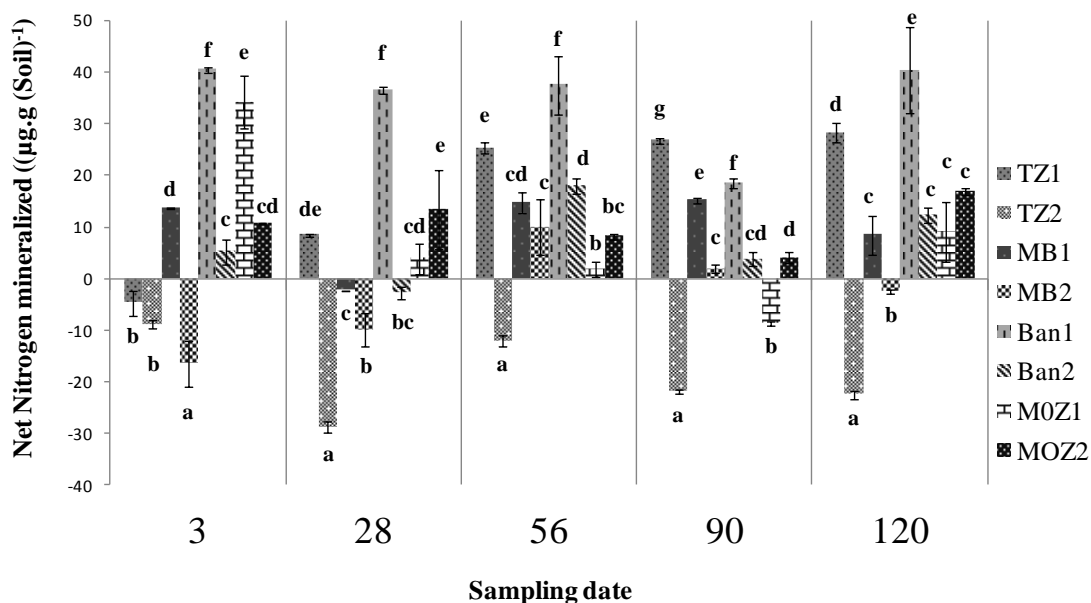


**Figure 3.** Net N-NO<sub>3</sub><sup>-</sup> mineralized under soil incubated with TZ1 and TZ2 (Tanzania), MOZ1 and MOZ2 (Mozambic), Ban1 and Ban2 (Banfadjiré), MB1 and MB2 (Madiop Boye).

dendrogram with 2 separate clusters with 72% similarity (Figure 7). The DGGE banding patterns at 0, 3, 28 and



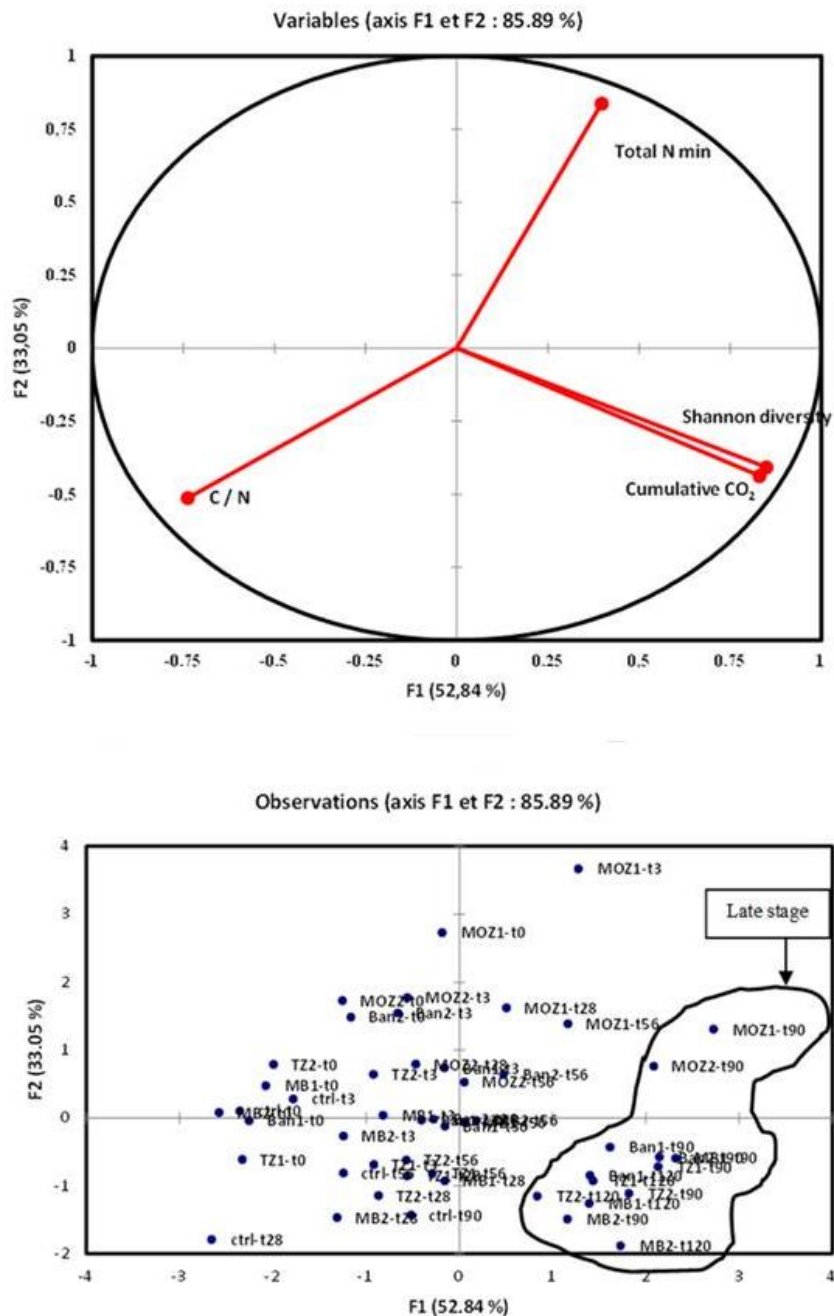
**Figure 4.** Net N-NH<sub>4</sub><sup>+</sup> mineralized soil incubated with TZ1 and TZ2 (Tanzania), MOZ1 and MOZ2 (Mozambic), Ban1 and Ban2 (Banfadjiré), MB1 and MB2 (Madiop Boye).



**Figure 5.** Net soil N mineralized under soil incubated with *Jatropha* green and senescent from Tanzania (TZ1, TZ2), Mozambic (MOZ1, MOZ2), Banfadjiré (Ban1, Ban2) and Madiop Boye (MB1, MB2).

56 days were clustered in Cluster I, whereas Cluster II comprised patterns at 90 and 120 days. Cluster I was divided into 2 sub-clusters (A and B) with 76% similarity comprising DGGE patterns at 0 and 3 days (sub-cluster A) and at 28 and 56 days (sub-cluster B). In sub-cluster

A, day 0 had 88% similarity with day 3 (Figure 7). UPGMA analysis showed that for both types of litter and all cultivars, the bacterial community patterns for the various soils were clustered according to the litter decomposition stage. The Shannon diversity index (H)



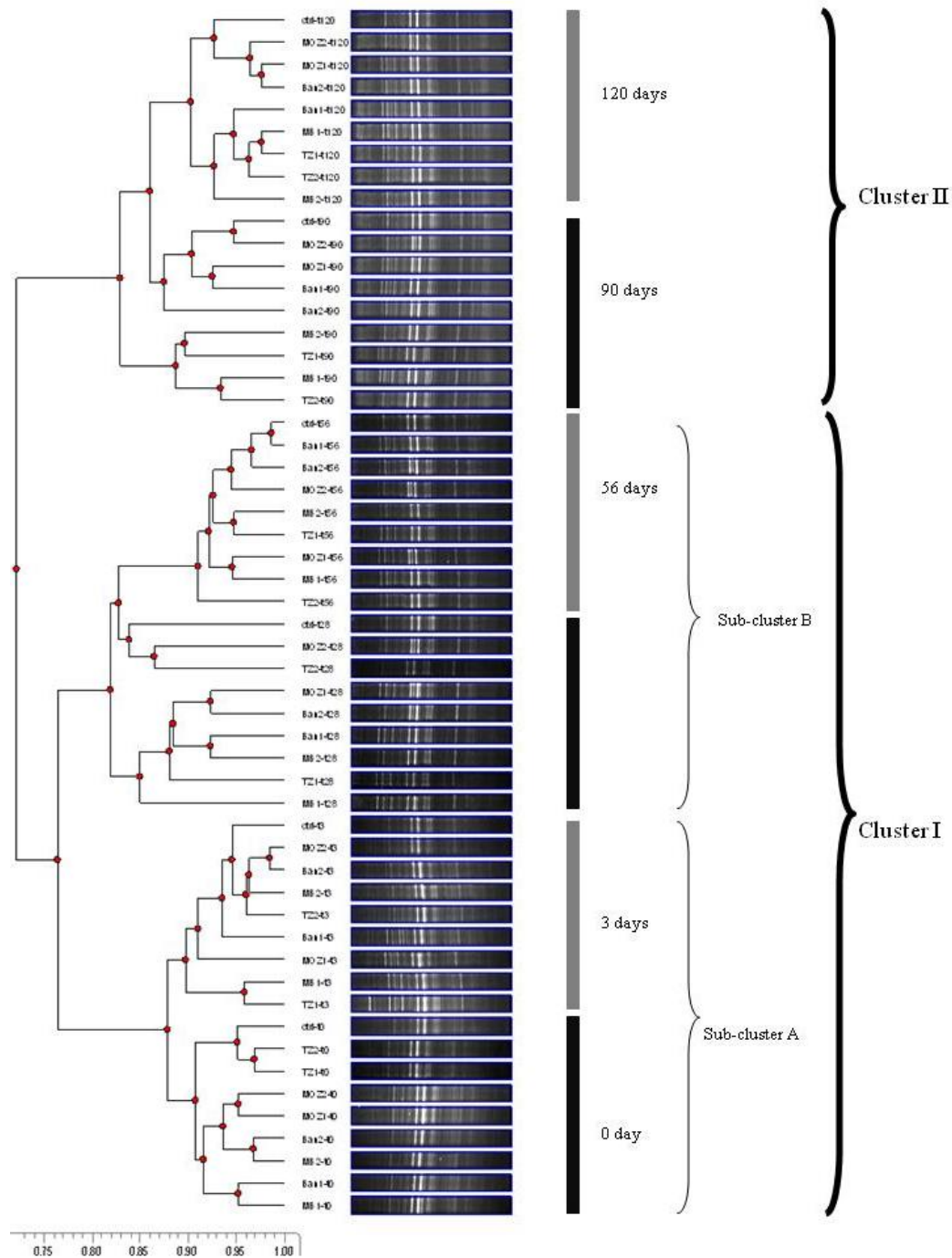
**Figure 6.** Principal Component Analysis of Shannon diversity, mineral nitrogen, C/N ratio and cumulative CO<sub>2</sub> on factorial plan F1-F2 (Ban=Banfadjiré; MB=Madiop Boye; TZ=Tanzania; MOZ=Mozambic; 1 = green leave; 2= senescent leave).

showed that the bacterial diversity increased significantly towards the end of incubation (Figure 6) and was correlated with the cumulative CO<sub>2</sub> indicating that the mulch had affected the bacterial diversity (Figure 6). However, the bacterial diversity and cumulative CO<sub>2</sub> were negatively correlated with the soil C:N ratio (Figure 6).

## DISCUSSION

### Chemical composition of *J. curcas* litter

This study showed that the chemical composition of *J. curcas* leaves depended on the cultivar. The



**Figure 7.** UPGMA clustering of soil DGGE fingerprints at 0, 3, 28, 56, 90 and 120 days after incubation. Ban = Banfadjiré; MB = Madiop Boye; MOZ=Mozambic; TZ=Tanzanian; Ctrl=control; 1 = green and 2 = senescent leaves.

geographical diversification of *J. curcas* has been found to affect the intraspecific variation of the plants and the leaf traits (Lecerf and Chauvet, 2008; Tanya et al., 2011) which confirmed that the phenotypic plasticity of *J. curcas*

allows the expression of different phenotypes in response to changing environments (Heil, 2010). The lignin, C and N contents in the leaves has been shown to depend on the cultivar (Hättenschwiler et al., 2008). The lignin



content of green leaves was similar to that reported by Abugre et al. (2011) but was higher than that reported by Chaudhary et al. (2014). These biochemical differences could be explained by the intraspecific diversity of *J. curcas*. These findings agree with the findings of several authors (Lecerf and Chauvet, 2008; Petrakis et al., 2011; Zimmer et al., 2015) indicating that the intraspecific variation of leaf litter characteristics depends on environment rather than genetic background.

The lower N content in senescent leaves than in green leaves appeared to be the result of N resorption. As a drought-resistant perennial tree, *J. curcas*, resorbs the leaf macronutrients before shedding its leaves in the dry season. Nutrient resorption is a process in which nutrients, especially macronutrients, are transferred from leaves to other plant compartments before shedding (Wright and Westoby, 2003). The lower N nutrient content of senescent leaves for MOZ2 compared to those for Ban2 and MB2, indicated variation in N nutrient resorption. This result suggests intraspecific variation in the resorption process confirming the results obtained by Ramírez-Valiente et al. (2010). This finding is important for understanding the contribution of *J. curcas* leaves to soil nutrient inputs, because the different concentrations of nutrients in senesced leaves will affect litter quality and thus litter decomposition rates (Kitayama et al., 2004; Wardle et al., 2009; Hayes et al., 2014).

### Modeling C decomposition rate and C sequestration

The double exponential decomposition model was a good fit with C mineralization data. It showed that C was divided into 28% labile C and 72% recalcitrant C. The decomposition rate for the labile component ( $k_1$ ) was higher than that for the recalcitrant component ( $k_2$ ) which agrees with the litter decomposition dynamics reported by Patrício et al. (2012). The rate of decomposition of recalcitrant compounds plays a key role in organic matter sequestration. In comparison to other published dynamics, *J. curcas* L. litter may, therefore, be considered as a slow decomposing litter, confirming its potential for sequestering C and improving soil fertility (Vauramo and Setälä, 2011).

The results showed that the labile C fraction and decomposition rate  $k_1$  depended on the type of litter. Although the decomposition rates  $k_1$  and  $k_2$  were not correlated with the lignin content,  $k_1$  was negatively correlated with the cellulose content ( $p < 0.05$ ,  $R^2 = 0.707$ ), which implies that an increase of cellulose content in *J. curcas* leaf litter leads to a decrease in the decomposition rate of labile C. Different leaf litters decompose at different rates and it has been established that the initial chemical composition of the litter plays an important role in the decomposition rates. In this study, green leaf litter decomposed faster than senescent leaf litter which

agrees with Li et al. (2011) who reported that increased nutrient availability, in particular N, stimulated litter decomposition. Therefore, it was not surprising that the decomposition rate was significantly higher in green leaves than senescent leaves ( $p < 0.05$ ).

It has been proposed that the composition of the soluble fraction, hemicellulose, cellulose and lignin compound are good indicators of the decomposition dynamics of organic residues (Lecerf and Chauvet, 2008; Pascault et al., 2010; Beyaert and Paul Voroney, 2011; Bray et al., 2012). Senescent leaves had a higher lignin content than the green leaves. The lignin content may, therefore, explain the difference in decomposition rate between the 2 types of litter. These results confirmed the general findings that the lignin content in *J. curcas* leaves reduced their decomposition rate (Trinsoutrot et al., 2000; Amougou et al., 2011). Arriaga and Maya (2007) and Allison (2012) reported that the chemical contents of mature residues and C:N ratio were negatively correlated with the decomposition rate as they reduced the degradation rates by decomposer microorganisms (Wardle et al., 2006; Esperschütz et al., 2013).

### Nitrogen mineralization

It was found that the litter N content explained the changes in  $\text{NH}_4^+$  mineralization during the early stage of incubation. The ammonification rate was higher for soils mulched with litter with a high N content. Previous studies on litter have reported a positive correlation between N mineralization rates and N content (Banning et al., 2008; Abbasi et al., 2014; Chaudhary et al., 2014). The initial lignin content in the litter explains the ammonification rates in the later stage of incubation. In this study, the net N mineralization pattern was similar to the nitrification pattern, as reported in other studies (Azeez and Van Averbeke, 2010). The similarity between the net N mineralization and nitrification rates suggested that ammonification was not only transitory in N transformation, but that the net ammonification rate is very low and ammonium is rapidly transformed into nitrate (Azeez and Van Averbeke, 2010).

### Bacterial activity and community structure

Plant species differ considerably in the quality of litter that they produce and the species is often a major determinant of the decomposer community structure (Parmelee et al., 1989; Badejo et al., 1999). Our results confirmed the general findings of previous studies that the  $\text{CO}_2$  flux is high during the early stage of incubation of plant residues (Sall et al., 2003; Dossa et al., 2009; Cleveland et al., 2013). This high  $\text{CO}_2$  flux suggests an increase in microbial activity during this period and

corresponds to the use, by *r* strategists, of directly available, easily degradable compounds released from litter material (Esperschütz et al., 2013). Thereafter, *k* strategists colonize the litter during the later stages of decomposition (De Angelis et al., 2013). The end of the incubation period was marked by a decrease in microbial activity and an increase in bacterial diversity (Shannon diversity) confirming the findings of Dilly et al. (2004). The slow decomposition rate during the later stages was due to the decomposition of recalcitrant compounds (lignin and cellulose) by the decomposer communities mainly present in these stages (Esperschütz et al., 2013). The positive correlation between C mineralization and changes in bacterial community structure agrees with the findings of Basiliko et al. (2013). Our study also showed that bacterial diversity was negatively correlated with the litter C:N ratio, as also reported by Ge et al. (2010). The changes in the bacterial community with time may be explained by the chemical changes in the litter during the decomposition process (Wardle et al., 2006; Bray et al., 2012). According to Pfeiffer et al. (2013), litter with a low C:N ratio and low lignin content has only a minor impact on the soil bacterial community. Therefore, in rapid decomposing litter, *r* strategists will take up available nutrients rapidly leading to a reduction in bacterial diversity. However, *k* strategists colonized slowly decomposing litter such as *J. curcas* litter leading to an increase in diversity.

## Conclusion

The chemical composition of the *J. curcas* litter depended on the geographical origin of the cultivars. There were correlations between the chemical composition of the litter, the decomposition rates and the bacterial community structures. The results showed that the double exponential decomposition model accurately predicted the changes in C content in *J. curcas* mulch. This mulch modifies C and N cycling and appears to have an effect on soil C sequestration.

## Conflict of Interests

The authors declare that there is no conflict of interests.

## ACKNOWLEDGEMENTS

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