Scientific Research Publishing

Open Journal of Applied Sciences, 2025, 15(1), 187-201
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Gas Chromatographic Analysis of the Methanogenic Potential of Lignocellulosic Biomass Consisting of Banana Residues in Tambacounda, Senegal

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How to cite this paper: Haroun, A.A., Hamza, A.O. and Ndiaye, M.L. (2025) Gas Chromatographic Analysis of the Methanogenic Potential of Lignocellulosic Biomass Consisting of Banana Residues in Tambacounda, Senegal. *Open Journal of Applied Sciences*, **15**, 187-201.
https://doi.org/10.4236/ojapps.2025.151013

Received: December 17, 2024
Accepted: January 23, 2025
Published: January 26, 2025

Abstract

The residual biomass composed of pseudo trunks and banana leaves is very important and poorly valued. There is very little quantified data on the deposits of residual biomass from banana plantations in Senegal and in particular in the Tambacounda region. In this work, we seek to evaluate the methanogenic potential and to valorize this biomass in biogas and biofertilizer. The laboratory experiment lasted approximately 35 days. During this time, the methanogenic microorganisms degrade the organic residue provided, which results in the production of biogas. At the end of the reactions, the rate of biogas production drops, indicating the end of the biodegradation of organic matter. Biogas production is measured over time and the composition of the biogas produced is analyzed by gas chromatography (GC) or by an infrared analyzer. The methane potential of each sample is determined from the cumulative quantity of methane produced in each flask representing a digestion system. The measurement can be expressed in m^3 of CH_4 per tonne of dry matter or per tonne of raw material. The first challenge of this study therefore lies in the acquisition of reliable and usable data to quantify the methanizable biomass. This study will allow us not only to evaluate the quantities of pseudo trunks and banana leaves available in a plot after harvest but also to test the biogas and methane production potential (BMP test) of this substrate and therefore determine the expected biogas production of this biomass.

Keywords

Residual Biomass, Banana, Tambacounda, Laboratory, Organic Matter,

Infrared Analyzer

1. Introduction

The assessment of the biogas potential of one type of waste compared to another is one of the best techniques for valorizing a biomass with high methanizable potential [1]. In the current global context, the management and valorization of organic waste, particularly biomass, constitutes a considerable economic, environmental and energy challenge. The use of the latter is both a necessity and an economic opportunity opening new avenues for sustainable development [2] [3]. This valorization of waste into biogas inevitably takes place in hermetically sealed enclosures called bio-digesters [4]. The anaerobic bioreactor makes it possible to transform volatile organic matter into energy, while preserving its fertilizing potential, both in terms of organic matter and mineral elements. It therefore constitutes a means of energy recovery for products such as livestock manure and crop residues whose return to the soil is essential [5]. It is therefore consistent with agricultural practices [6] [7] and the environment as well as the adaptation to climate change of different cultures that can not only feed an entire population but contribute considerably to the production of a biomass very favorable to biogas [8] [9]. The gas mixture obtained mainly includes methane (50% to 75% by volume) and carbon dioxide (25% to 50% by volume) [10]-[13]. The environmental benefits of implementing digesters for the production of biogas and digestate at low cost in small or large farms would considerably reduce (up to 80%) the potential environmental impacts associated with the handling of stored and unused manure, the use of diesel fuel used in generators and also synthetic fertilizer used in crops [14]. Among the biomasses with high methanizable potential, the banana tree provides a very good alternative for methanization solution.

Brief description of the banana tree

Originally from Southeast Asia, the banana tree is a giant herb belonging to the Musaceae family, order Zingiberales (Scitaminales). A large monocot without a vegetative stem and with zygomorphic flowers, it is composed of several morphological organs of variable size and chemical composition:

- The underground stem, improperly called bulb, is the vital center of the banana tree. It is the place where the roots, leaves and inflorescence form. It is at this level that the shoots ensuring the natural sustainability of the species are differentiated;
- The pseudo-trunk or false trunk results from the imbrication of the leaf sheaths within each other;
- In some cases, its leaf blade is 5 m long and 1.1 m wide [15]. The leaf system is highly developed and its structure presents particularities linked to the constraints of water supply [16]. The review showed that throughout the world, several researchers have worked on the valorization of banana plantation

biomass into biogas. Thus, there are convincing examples of valorization of biomass from banana plantations both in Africa (Cameroon) and in the Pacific (Guadeloupe) [15]-[20]. The aim of our study is to provide region-specific experience data on the composition of RRB and the biogas potential that could be derived from banana in the Tambacounda region of Senegal. Thus, our motivation is to explore the potential of an underutilized agricultural waste (RRB) for the production of renewable energy, namely biogas.

2. Material and Method

To better determine the methanizable potential of banana residue, samples were taken from the 3 most common varieties on the farm: the most cultivated Sankagne variety (70%), followed by the vitro plant variety (20%) and finally the ordinary variety (10%). 5 plots were randomly selected. Depending on the varietal composition, there are plots with a single variety and plots with 2 or 3 varieties grown in association. We present in **Table 1** the average of the banana residue samples taken which were used for the different texts.

Table 1. Plots selected for sampling banana residues.

Plots	P1	P2	P3	P4	P5
Variety (s)	Ordinary + Vitro plant + Sankagne	Sankagne + Ordinary	Vitro plant + Ordinary	Vitro plant	Sankagne

In each plot, and for each variety, a banana plant that had already been harvested was taken. In total, we have: 3 plants of the Vitro plant variety, 3 plants of the Sankagne variety and 3 plants of the Ordinaire variety. **Figure 1** below gives us an overview of the different varieties used for this work.

Ordinary variety　Sankagne variety　Vitro plant variety

Figure 1. Photo of the varieties sampled: Ordinary, Sankagne and Vitro plant.

For each plant, the pseudo-trunks and leaves were weighed separately in order to have the proportion in terms of weight of each part. Then samples were taken from 4 different points of the banana plant: basal part of the trunk, the middle of the trunk, apical part of the trunk and the leaves. Then, for each variety, the sampling points were mixed together in order to have a composite sample. The main samples obtained are shown in Table 2:

Table 2. Samples taken according to the banana variety.

Variety	Sankagne	Vitro plant	Ordinary
Number of samples	4	4	4
Type of samples	- Basal part Trunk - Middle Trunk - Apical part Trunk - Leaves	- Basal part Trunk - Middle Trunk - Apical part Trunk - Leaves	- Basal part Trunk - Middle Trunk - Apical part Trunk - Leaves

The samples were placed in plastic bags and labeled to facilitate identification (sample manager, type of substrate, sampling point, sampling date, location, etc.). For this purpose, we present in Figure 2 below the photos of the composite mixtures and the banana leaves used in our experiment.

(a) pseudo trunk sampling (b) pseudo trunk composite mixture (c) leaf composite mixture

Figure 2. Photo Samples, composite mixtures of pseudo trunks (b) and banana leaves (c).

The bags were kept cool in a cooler from bagging in the field to the laboratory.

The BMP test and characterization trials were entrusted to the UPR recycling and risk LMI IE SOL laboratory of the ISRA/IRD center in Bel Air in Dakar. The aim was to determine from the samples respectively.

- the biogas and methane production potential of the substrates;
- and their physicochemical characteristics: PH, humidity rate (% DM), % ash, organic matter, % total carbon (C), % total nitrogen (N), C/N ratio, Kjeldahl N, Phosphorus, Potassium. This already predisposes the agronomic quality of the digestate and its use as organic fertilizer.

BHR (Banana Harvesting Residues) samples for estimation of methanogenic potential

The banana harvest residues were collected on 03/22/2019 in the Gouloumbou banana plantations (Tambacounda region) by the Thecogas team. A composite leaf sample, a composite pseudostem sample and a composite leaf + pseudostem sample, representative of the varietal composition of the banana plantations were constituted to estimate their methanogenic potential (Table 3).

Table 3. Composite BHR samples for estimation of methanogenic potential.

Sample sheet	Pseudotrunk sample	Leaf sample + Pseudostem
10% F.VO (SN 70543 + SN 70550) 70% F.VS (SN 70538 + SN 70544) 20% F.VV (70537 + SN 70542)	10% T.VO (SN 70527 + SN 70549 + SN 70545 + SN 70546 + SN 70532 + SN70539) 70M% T. VS (SN70530 + SN 70547 + SN 70528 + SN 70535 + SN 70529 + SN 70541)	12% Leaf sample 88% Pseudostem sample

According to the leaf and pseudostem biomass data measured by the Thecogas team in the Gouloumbou banana plantations, the leaf/pseudostem mass distribution is 12% and 88% respectively.

An aliquot of each of these 3 composite samples, accompanied by an aliquot of cow dung methanization digestate serving as inoculum, was sent to the IRD Laboratory of Analytical Means (LAMA) in Dakar for characterization.

Twenty-four elementary samples of frozen BHR were deposited at the LMI IE SOL by the Thecogas actuel team www.sb2-4all.com. These samples were recorded and stored in the freezer pending analysis. They are mentioned in **Table 4** Next.

Reference of terms:

F = Leaf;

VO = Variety Ordinary = 10% of the plantation = border plantation in windbreak;

VS = Variety; #1 = bag number 1 of the same sample;

#2 = bag number 2 of the same sample;

Sancagne = 70% of the plantation;

VV = Variety Vitroplant = 20% of the plantation;

T = Trunk;

Api = Apical part;

Mil = Middle part;

Bas = Basal part.

Table 4. BHR samples recorded for estimation of methanogenic potential.

Ref LEMSAT IRD (Carnet 362)	Sample name	Weight (g)
SN70543	F.VO.#1	100.5
SN70550	F.VO.#2	93.5
SN70538	F.VS.#1	119
SN70544	F.VS.#2	90
SN70537	F.VV.#1	140.5
SN70542	F.VV.#2	156.5
SN70527	T.Api.VO.#1	563.5
SN70549	T.Api.VO.#2	483.5

Continued

SN70530	T.Api.VS.#1	366.5
SN70547	T.Api.VS.#2	383.5
SN70536	T.Api.VV.#1	332.5
SN70540	T.Api.VV.#2	295.5
SN70545	T.Mil.VO.#1	416
SN70546	T.Mil.VO.#2	499
SN70528	T.Mil.VS.#1	428
SN70535	T.Mil.VS.#2	532.5
SN70531	T.Mil.VV.#1	441
SN70548	T.Mil.VV.#2	502
SN70532	T.Bas.VO.#1	1023
SN70539	T.Bas.VO.#2	678.5
SN70529	T.Bas.VS.#1	632
SN70541	T.Bas.VS.#2	561
SN70533	T.Bas.VV.#1	626
SN70534	T.Bas.VV.#2	755

The equipment is composed of:

1) A thermostatically controlled incubation unit (up to 95˚C) for the 15 anaerobic digestion reactors with a volume of 650 mL each;

2) A carbon dioxide (CO_2) capture unit composed of 15 trapping bottles;

3) A 15-channel biogas flow measurement unit;

4) A user interface software allowing the hardware to be configured, an experiment to be launched and results to be accessed.

A photograph of the experiments conducted in the laboratory is given in **Figure 3** below.

Figure 3. Photo of the AMPTS II (Automatic Methane Potential Test System II) methane potential analyzer device from Bioprocess Control deployed at LMI IESOL at the ISRA/IRD Bel Air center in Dakar, Senegal © J.-M. Médoc, April 2019.

For the same organic residue, one to two repetitions can be implemented. A flask containing only the inoculum, not fed throughout the experiment, serves as a control for each test.

The following configuration was implemented (**Table 5**):

- Nine digesters (*i.e.* reactors) containing 3 different inoculum/BHR mixtures. 3 measurements of methanogenic potential for the same sample in order to have repeatable/reproducible results;
- Three digesters containing a mixture of inoculum/other sample so as not to run the system empty;
- Three digesters containing only the inoculum in order to know its methane productivity and to be able to isolate the production of methane from the substrates.

Table 5. Experimental device.

Samples	Reactors	Inoculum quantity (g)	BHR quantity (g)
B. feuil. #1	1	384.86	15.14
B. feuil. #2	2	384.86	15.14
B. feuil. #3	3	384.86	15.14
B. tronc. #1	4	349.54	50.46
B. tronc. #2	5	349.54	50.46
B. tronc. #3	6	349.54	50.46
B. f+t. #1	7	357.53	42.47
B. f+t. #2	8	357.53	42.47
B. f+t. #3	9	357.53	42.47
Inoc. #1	13	400	0
Inoc. #2	14	400	0
Inoc. #3	15	400	0

The BHRs were crushed frozen to a diameter of approximately 2 mm using a blender before weighing and inserting into the reactors.

The principle of determining methanogenic activity in AMPTS II involves inoculating a small amount of substrate with a large amount of inoculum and incubating the whole at a controlled temperature under anaerobic conditions.

The inoculum and the BHRs are contained in the water bath reactors filled with enough demineralized water to cover the digesters. The bath temperature is maintained at 37˚C.

The trapping solution is a 3 M sodium hydroxide solution and a colored pH indicator bromo-thymolphthalein. 80 mL of this solution is placed in each bottle of the CO_2 trapping system.

The flasks and reactors are closed with rubber stoppers equipped with two metal pipes as an outlet to connect all 15 reactors to the 15 trapping flasks and the trapping flasks to the methane counting unit by Tygon® tubes. Before starting the incubation, we "flushed" (*i.e.* expelled the ambient air) each of the 15 reactor/trapping flask/bubble counter circuits with a low-pressure helium flow in order to put the assembly in anaerobic condition.

The motors allowing the agitation of the 15 reactors were programmed to agitate the mixtures for 30 seconds every 3 minutes for the entire duration of the incubation planned for 35 days.

3. Result and Discussion

The methanogenic activity of an organic residue and its potential methane production are measured from a known quantity of organic residue and a known quantity of inoculum (*i.e.* methanizer reactor bottom, landfill leachate, sewage sludge, etc. recovered) inserted in a 500 ml glass flask placed in an incubation unit thermostated at 37˚C generally. In order to determine these quantities of organic residue and inoculum to be inserted in the flask, it is necessary to measure their dry matter (DM) and organic matter (OM, *i.e.* volatile matter—MV) content for a solid sample, the chemical oxygen demand (COD) for a liquid sample. In the laboratory, the instrument we used allows the online analysis of low methane flows (which corresponds to a biogas measurement that follows CO_2 trapping) from the anaerobic digestion of waste and any fermentable material. It is equipped with 15 parallel reactors and the same number of gas flow meters connected to the data acquisition system allowing the automatic analysis of 15 organic residues (or repetitions of a few organic residues) at the same time.

Principle of estimating the methanogenic potential of our organic residue

Measuring the methanogenic potential or Biochemical Methane Potential (BMP) makes it possible to determine the potential of an organic residue to produce methane by anaerobic digestion (*i.e.* indicator of the maximum quantity of methane produced per unit mass of residue).

This measurement can be carried out for any type of organic residue, liquid or solid, of agricultural origin (slurry, droppings, manure, crop residues), of agro-industrial origin (food processing waste, food waste and wastewater, oils and fats, uncontaminated slaughterhouse waste), of municipal origin (biowaste, sewage treatment plant sludge, sewage sludge, etc.).

BHR characteristics (input)

Launching an incubation to estimate the methanogenic potential of an organic substrate requires prior knowledge of the MS and MO or MV contents.

In our case, we added an analysis request for the carbon, total nitrogen, kjedhal nitrogen, phosphorus and potassium contents at the experiment input and output. The biochemical characteristics of the incubation are given in Table 6 below.

Presentation of raw results

The incubation of BHRs to estimate their methanogenic potential started on Wednesday April 17 at 4:30 p.m. and stopped on Wednesday May 22 morning, *i.e.* 35 days. Figure 4 gives us the cumulative CH_4 volumes from a mixture of banana leaves and pseudostems and inoculum.

Table 6. Biochemical characteristics of BHR and inoculum.

				LAMA analysis results expressed relative to MS							Result expressed in relation to the PB			
		Humidity %	MS%	Cendre %	C total %	N total %	C/N	N	Pmg/Kg	Kmg/Kg	MO %	MO (g/Kg PB	Ct %PB	Nt %PB
Sample sheet	10% F.VO (SN 70543 + SN 70550) 70% F.VS (SN 70538 + SN 70544) 20% F.VV (70537 + SN 70542)	76.94	23.06	13.701	43.26	2.18	20		29819	1553	19.90	199.01	9.98	0.50
Pseudotrunk sample	10% T.VO (SN 70527 + SN 70549 + SN 70545 + SN 70546 + SN 70532 + SN70539) 70M% T.VS (SN70530 + SN 70547 + SN 70528 + SN 70535 + SN 70529 + SN 70541)	93.98	6.02	9938	39.58	0.87	45		19189	716	5. 42	54.22	2.38	0.05
Leaf sample + Pseudostem	12% Leaf Sample 88% Pseudostem Sample	92.59	7.41	11.068	40.91	1.31	31		22681	902	6.59	65.90	3.03	0.10
Inoculum		97.36	2.64	40.705	31.86	1.77	18		80022	6193	1.57	15.65	0.84	0.05
	MS = Dry matter													
	Ct = Total Carbon													
	Nt = Azote Total = (N_{org} + NH_4 + NNO_3 + Nu)													
	Nk = Azote Kjeldahl = (Norg + NH_4)													
	P = Total phosphorus													
	K = Total potassium													
	MO = Organic Matter													
	PB = Gross product													

Figure 5 gives us the cumulative volume of CH_4 from a mixture of banana leaves (3 varieties) + cow dung digest inoculum.

Figure 6 gives us the volume of CH_4 accumulated from banana pseudostems (3 varieties) + cow dung digest inoculum.

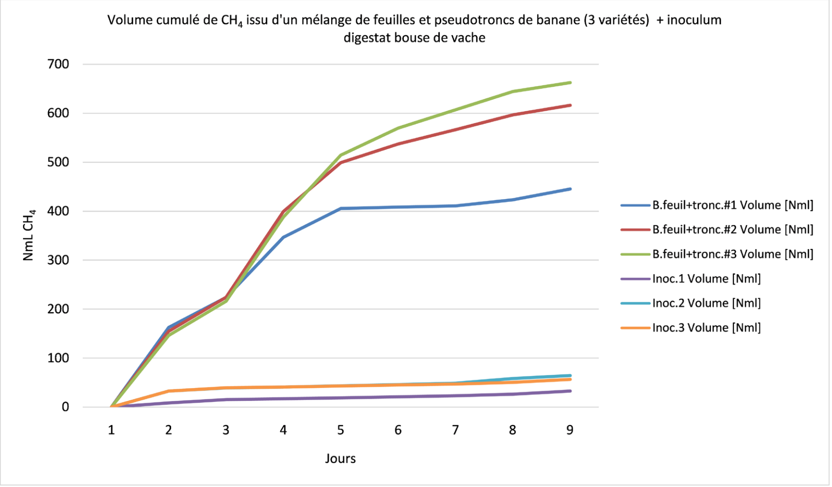

Figure 4. Cumulative volume of CH_4 from a mixture of banana leaves and pseudostems (3 varieties) + cow dung digest inoculum.

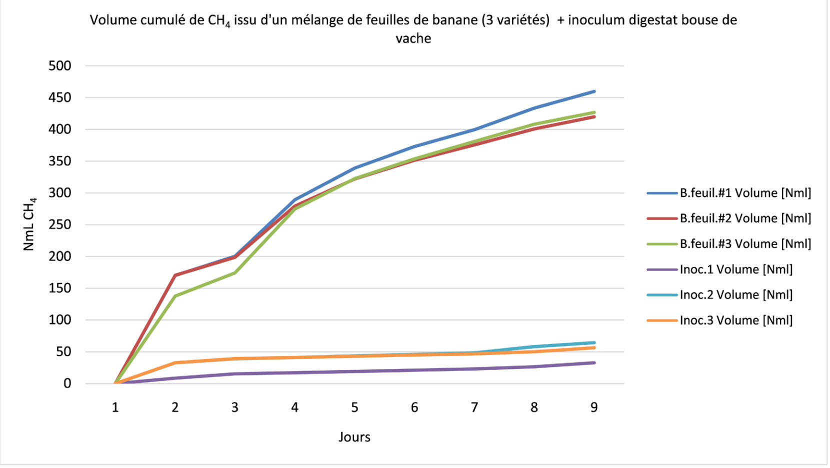

Figure 5. Cumulative volume of CH_4 from a mixture of banana leaves (3 varieties) + cow dung digestate inoculum.

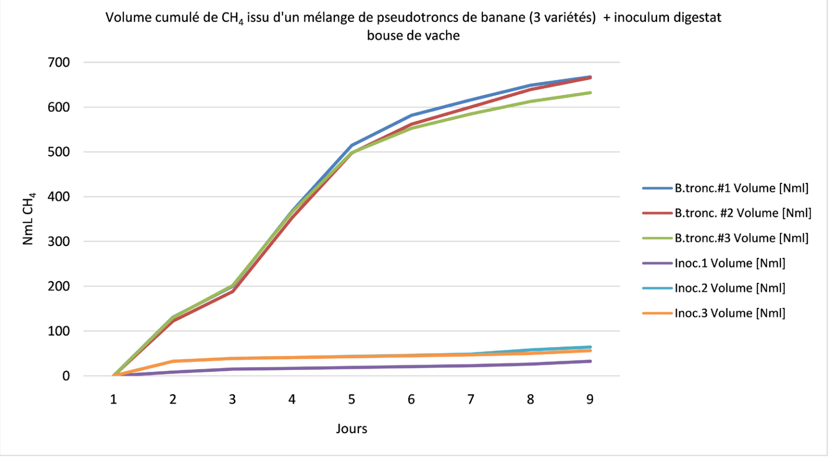

Figure 6. Cumulative volume of CH_4 from a mixture of banana pseudostems (3 varieties) + cow dung digestate inoculum.

Methanogenic potential

The methanogenic potential in quantity of methane produced can be expressed in Nm^3 per tonne of OM, DM and raw product (RP). In order to calculate the CH_4 productivity, the calculations implemented only take into account inoculum #2 and #3. Inoculation #1 was excluded due to its lower productivity which led to an overestimation of the productivity of the BHR. A good repeatability of the 3 repetitions of the 3 samples tested is observed. If we wish to maximize the methanogenic potential of the BHR Leaves + trunk, it is possible not to include the repetition "B.leaf + trunk #1" in the calculation of the average. The average methane potentials found are shown in Table 7 and Figure 7.

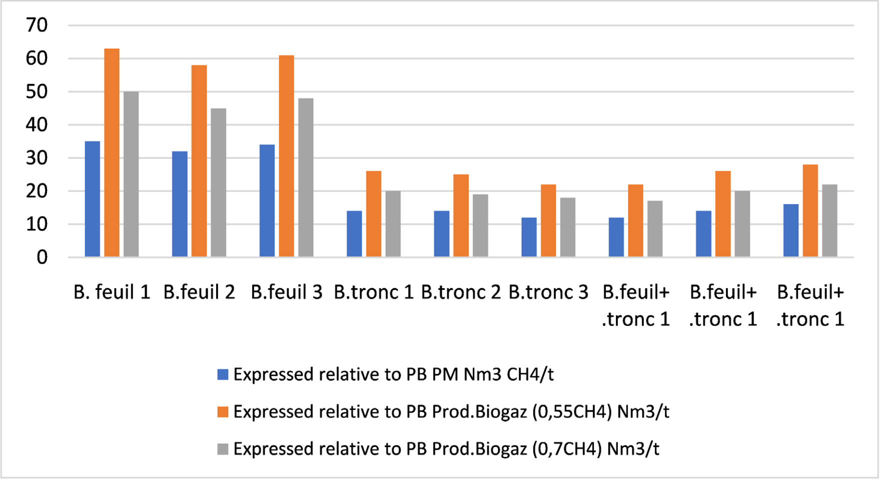

Figure 7. Methanogenic potential and biogas production (based on a low 55% and a high 70% CH_4 content) of banana crop residues from the Gouloumbou production site (Tambacounda region, Senegal).

Table 7. Methanogenic potentials (MP) and biogas production of BHR.

		Expressed relative to the MO			Expressed relative to PB		
	MS (%)	MO (%)	PM15j (NmL CH_4/gMO)	PM35j (NmL CH_4/gMO)	PM Nm^3 CH_4/t	Prod.Biogaz (0.55 CH_4) Nm^3/t	Prod.Biogaz (0.7 CH_4) Nm^3/t
B. feuil 1	23.06	19.90	168	175	35	63	50
B.feuil 2	23.06	19.90	150	160	32	58	45
B.feuil 3	23.06	19.90	152	170	34	61	48
B.tronc 1	6.02	5.42	253	261	14	26	20
B.tronc 2	6.02	5.42	252	251	14	25	19
B.tronc 3	6.02	5.42	225	227	12	22	18
B.feuil + .tronc 1	7.41	6.59	170	182	12	22	17
B.feuil + .tronc 1	7.41	6.59	222	217	14	26	20
B.feuil + .tronc 1	7.41	6.59	141	236	16	28	22

Table 7 presents the methanogenic potentials of each sample repeated 3 times after 35 days of incubation. These results present an estimate of the ultimate methanogenic potential of BHR as well as an extrapolation of the potential biogas production.

Figure 7 presents in parallel the methanogenic potential and the biogas potential, according to a low content (55%) and a high content (70%) in CH_4, of banana harvest residues from the Gouloumbou production site (Tambacounda region).

The methanogenic potential of a mixture of banana leaves and pseudostems is equivalent to the methanogenic potential of local horse dung and twice that of local cow dung. Lacour *et al.* (2011) [21] [22] estimated the methanogenic potential of a mixture of banana and plantain leaves and pseudostems in Haiti at 123 m^3 CH_4/t OM. 3.2 Biogas potential on the perimeter.

Laboratory results

Calculated on a tonne of raw product, Table 8 below gives the quantities of biogas in Nm^3 produced according to the density of methane.

With a density of 55% methane, the analyses of the methanogenic potential give 61 m^3 of biogas/t of fresh matter for the leaves, 24 m^3 for the pseudo-stems and 25 m^3/tonne for the mixture of leaves and pseudo-stem of banana trees.

With a density of 70%, the leaves remain more productive than the other parts of the plant.

Table 8. Biogas production for 1 tonne of PB according to methane density.

	PM Nm^3 CH_4/t	Biogas production (0.55 CH_4) Nm^3/T	Biogas production (0.7 CH_4) Nm^3/T
BHR SHEETS	33	61	48
BHR PSEUDO Trunk	13	24	19
BHR-F + T	14	25	20

In short, both for the C/N ratio and for the biogas production potential and whatever the density of methane in a m^3 of biogas, the leaves remain more interesting for setting up a methanization project as their potential is great.

Quantity of biogas produced (Nm^3) at the perimeter level

Table 9 below gives us the results at the level of the perimeter studied.

Table 9. Final analysis result of the samples studied on the chosen plot.

	PM Nm^3 CH_4/t	Biogas production (0.55 CH_4) Nm^3/t	Biogas production (0.7 CH_4) Nm^3/t	Biogas depot in tons	Biogas quantity at 55%	Biogas quantity at 70% CH_4
BHR SHEETS	33	61	48	3837	233,700	183,621
BHR PSEUDO Trunk	13	24	19	26,675	646,630	508,067
				30,512	880,330	691,688

4. Conclusion

It is risky to judge the agronomic value of banana harvest residues with this characterization alone. In practice, many banana farms in West Africa produce compost from these residues and return it to the soil. The doses of compost(s) to be provided each year, as part of a reasoned fertilization, will have to be adapted according to the expected yield, soil and leaf analyses. The contributions of organic matter will also have to take into account their state of evolution (C/N, temperature stability and constant composition). The C/N ratio of the leaves is ideal for their anaerobic digestion. On the other hand, that of the trunks is too high and that of the mixture of leaves + trunks is at the limit of the optimum. Based on a controllable biomass deposit of 30,512 tonnes for the entire perimeter, the expected biogas yield at a density of 55% methane is 880,330 Nm^3 while it is only 691,688 Nm^3 when the biogas is titrated at 70% methane. Due to the much higher weight of the pseudo-trunks, biogas production is mainly supported by this part of the plant. Thus at 73% whatever the density considered, biogas production is ensured by the pseudo-trunks. This situation will lead us towards the use of pseudo-trunks to feed our digesters. There will be less biomass to handle and the density of the biogas is still interesting overall (55% methane).

Acknowledgements

At the end of this work, we would like to warmly thank www.sb2-4all.com (Formerly Thecogas), ERA for the trust and availability to support the mission and the GIE NGUENE 3 for its patience and collaboration. As well as the African Laboratory for Sustainable Development Research for writing this document.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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