

Experimental study of biogas production from water hyacinth

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Abstract. In the Littoral and East regions of Cameroon, the proliferation of the water hyacinth threatens the conservation of biodiversity. Indeed, its rapid multiplication asphyxiates fish and promotes malaria. Integrated pest management and many other methods have been used to eliminate this plant, but it persists, endangering the eco-systemic balance of marine environments. The efficient management of this plant remains a challenge. The aim of this study is to contribute to the implementation of a water hyacinth management protocol. The idea was to use this plant not only for natural fertilizer for soil improvement but also as energy production (biogas). The tests were carried out at the HIMA application farm in the Abong-Mbang area. Experiments were conducted using 60-Liters batch digesters. In all three sets of experiments, combinations of water hyacinth, cow dung and chicken droppings were used. For water hyacinth alone, an average production of 70 L of biogas was recorded. The best yield was obtained for the mixture of water hyacinth (5 kg), cow dung (1.5 kg) and chicken droppings (1 kg) at 1/4 dilution, *i.e.* 179 L/kg of substrate. The results obtained are encouraging and are being effectively used. This technology can therefore be applied in areas infested by *Eichhornia crassipes* for the production of energy, compost and control of water hyacinth proliferation.

Keywords: Water hyacinth, Biodigester, Biogas, Fertiliser, Cameroon.

1 Introduction

The water hyacinth, with its scientific name *Eichhornia crassipes*, is an invasive aquatic plant originating from the Amazon and spread by man through horticulture in tropical and subtropical regions. In Africa, it is thought to have been introduced in the Congo Basin in the early 20th century as an ornamental pond plant by Belgian settlers (ADEME, 2011), but it is only in the last twenty years that its populations have exploded (Gopal, 1987). In recent years, many rivers in Cameroon such as the Wouri, Nkam, Mounjo, Nyong and their tributaries have been invaded by the water hyacinth (Viginie and Jules, 2016). These rivers are vital compartments containing many natural resources (fauna, flora, microorganisms, and mineral elements). One of the inconveniences generally mentioned when discussing the proliferation of *Eichhornia crassipes* is its propensity to completely cover the surface of the water it colonizes, hence its negative impact on navigation, irrigation, fisheries, electricity production and on the conservation of biological diversity as it causes the disappearance of many species of flora and fauna (Holm *et al.*, 1977; Bote *et al.*, 2020). It is

in a context of preservation and protection of aquatic ecosystems that the presence of *E. crassipes* appears as a danger to be curbed (Téllez *et al.*, 2006). One way of using this plant is the production of biogas (Tize *et al.*, 2015), which can be used as a cooking fuel or for electricity production and Also, the waste produced by the biogas plant was used to build the briquette-making equipment. (Almoustapha *et al.*, 2008).

The objective of this study is to contribute to the establishment of a management protocol for water hyacinth in Cameroon through the use of this plant as a substrate for biogas production. The aim of this work is to evaluate the biogas potential of different associations between water hyacinth (FAO, 1997; Rathod *et al.*, 2018) and livestock residues. The conduct of field experiments on biogas and fertiliser production will enable applications to be envisaged within the framework of a full-scale project, for the satisfaction of collective domestic energy needs.

2 Materials and methods

2.1 Study site

This study was carried out on the HIMA application farm. The farm is located on the outskirts of Abong-Mbang,

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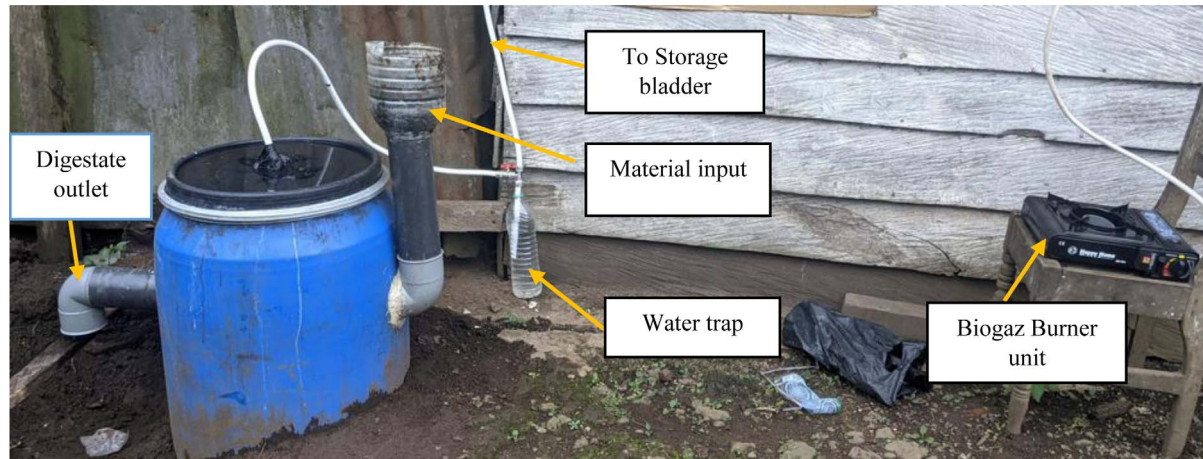


Fig. 1. Experimental batch digesters.

a town with an area of 11,250 km² (Longitude, 3°58'60" N; Latitude, 13°10'60" E.; Alt. 708 m). It is a large integrated farm of 5 ha, combining livestock (poultry and cattle), crop production and agro-processing activities. For the study, excreta were collected from the cow pens and chicken houses. Water hyacinth samples were taken along the of the Nyong River, in a swampy area with a series of pools and ponds with abundant aquatic vegetation including *E. crassipes*. The river Nyong is a freshwater river, which originates 40 km east of the town of Abong-Mbang in the great equatorial rainforest. It runs parallel to the lower reaches of the Sanaga River, following an East–West direction like the latter. It is crossed by an erosion valley, which receives household waste, sewage and rainwater draining into the beds of various rivers in the area, which in turn flow into the Nyong River (Rtabagaya, 2017).

3 Biogas production tests

3.1 Experimental set-up

The experiments were conducted in a batch digester consisting of a 200-L plastic drum sealed with a clamp. The lid is fitted with a valve that controls the outlet of the biogas to the water trap. The sides are fitted with two pipes. One is connected to a loading chamber and the other, mounted at the base of the drum, allows liquid and/or solid effluent to be taken for various measurements during fermentation without having to open the digester (Fig. 1).

3.2 The experimental protocol

Once collected, the fresh hyacinth is cut with a machete to a particle size of 5–8 cm (Fig. 2). For biogas production, this material is either tested separately or mixed with cow purse and/or chicken droppings.

Experiment 1: Water hyacinth + cow dung

Three digesters with a cow dung and water hyacinth substrate were tested. The first is labelled B1, the second

B2 and the third B3. After collection, pre-treatment and quantification of the cattle dung samples, they were diluted in three different doses (1/1, 1/2 and 1/3). Table 1 shows the dilution rate and the amount of waste contained in each digester. In all experiments, the digesters shown in Figure 3 were used.

Experiment 2: Water hyacinth + chicken droppings

Three digesters with chicken droppings and water hyacinth were tested. The first is labelled F1, the second F2 and the third F3. The droppings collected from the poultry houses were treated to remove large elements such as feathers and shavings, then mixed with the hyacinth and diluted at different proportions (1/3, 1/4 and 1/5). Table 1 shows the dilution rate and the amount of waste in each digester.

Experiment 3: Water hyacinth + cow dung + chicken droppings

In order to improve the fermentation of water hyacinth, cow dung and chicken droppings were combined and mixed with the hyacinth. The first is labelled BF1, the second BF2 and the third BF3. Table 1 shows the dilution rate and the amount of waste in each digester.

Production was monitored regularly and quantified throughout the anaerobic digestion cycle. The auto flammability test of the gas produced was carried out at each quantification of the production.

3.3 Evaluation of the biogas produced

The different mixtures were introduced into the digester, closed with the gasometer. The device is 95% embedded in the ground. During the anaerobic digestion, the volume of biogas was measured daily. This gas was analysed with a gas analyzer.

3.4 Valorization of the anaerobic digestion residue

After biogas production, the remaining heavy fraction called digestate is recovered and dried to a water content

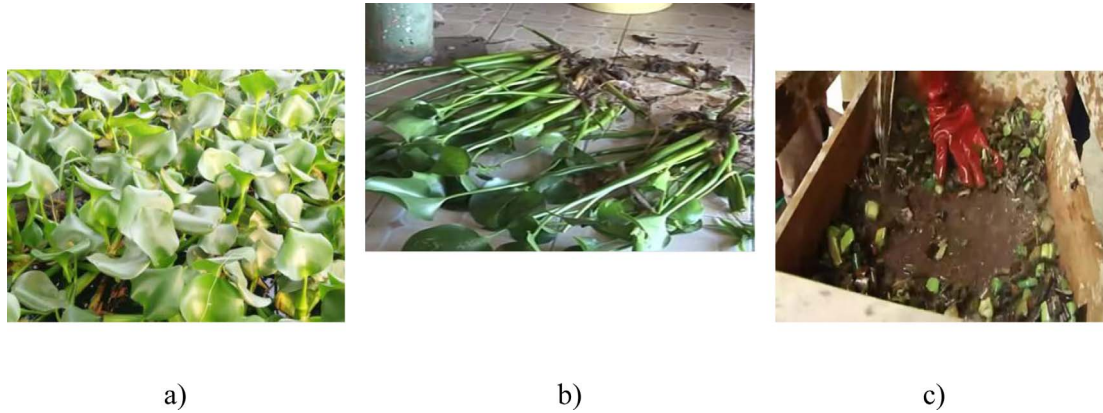


Fig. 2. Experimental protocol a) water hyacinth, b) picking and cleaning, c) cutting, adding cow dung and mixing.

Table 1. Dilution rates.

Dilution rates for cattle dung substrate digesters (Experiment 1)			
Digester	B ₁	B ₂	B ₃
Water hyacinth	11	7	5
Cow dung	4	3	2.5
Ratio	1/1	1/2	1/3
Dilution rates for poultry manure substrate digesters (Experiment 2)			
Digester	F ₁	F ₂	F ₃
water hyacinth	5	4	3.5
Poultry manure	2.5	2	1.5
Ratio	1/3	1/4	1/5
Dilution rates of the cow purse and poultry manure digesters (Experiment 3)			
Digester	BF ₁	BF ₂	BF ₃
Water hyacinth	15	5	3
Cow purse	0	1.5	1
Poultry manure	0	1	1
Ratio	1/1	1/3	1/5

of less than 15%. The objective is to recycle the digestate's constituent elements in order to have a transformed organic matter, rich in humic compounds, with maximum effects on soil fertility.

4 Results and discussions

The quantitative and qualitative production was recorded every day during the hydraulic residence of the substrate in the digesters. The results below show the quantity and quality of the biogas produced during the experiments.

4.1 Raw biogas analysis

At the end of the production cycles of the different water hyacinth treatments, the volumes of raw gas produced were

measured. [Table 2](#) summarises the quantities of raw biogas collected, taking into account all the gas produced, including the flammable fraction.

In general, the biogas potential and the digestion time vary according to the different substrates. According to [Table 2](#), the mixture of water hyacinth, cow dung and poultry manure has the best production potential ([Bhui et al., 2018](#)). The biogas potential of the different substrate combinations varies according to the dilution ratio. For water hyacinth + cow dung, the 1/3 ratio provides good potential with 175 l of biogas per kg of top substrate. Which is higher than those of the 1/1 and 1/2 ratios, which are respectively 92 and 171 L/kg of substrate. This similar result of the work of ([Aboubakar et al., 2016](#)) which shows that for the substrate made up of cow dung, the 1/3 ratio has the best yield. With regard to the mixture of water hyacinth and hen droppings, this potential also varies

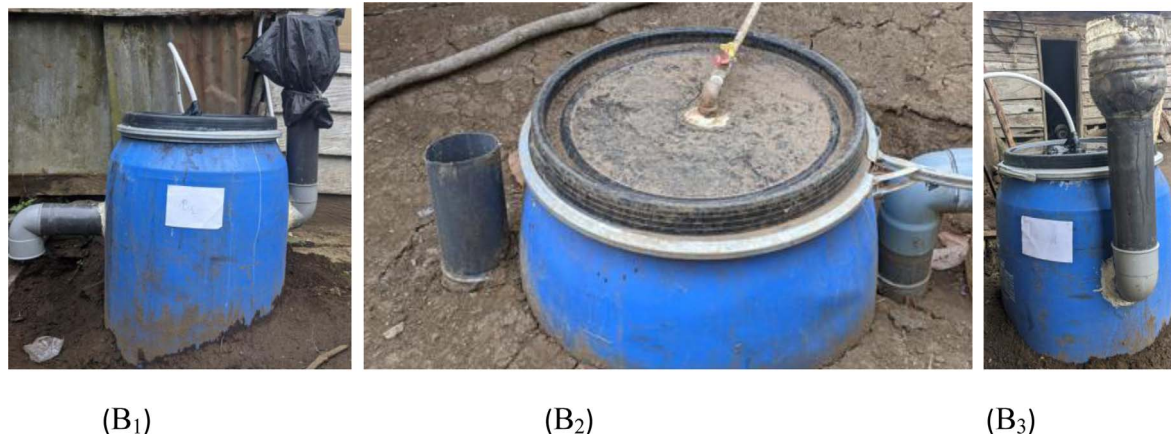


Fig. 3. Experimental batch digesters.

Table 2. Evolution of biogas production.

		Gross biogas production (L)	Biogas volume (L) per kg substrate	Digestion time or hydraulic residence time (day)
Cow purse	B ₁ (1/1)	1381	92	42
	B ₂ (1/2)	1719	171	42
	B ₃ (1/3)	1316	175	42
Poultry manure	F ₁ (1/3)	414	55.2	25
	F ₂ (1/4)	341	45	25
	F ₃ (1/5)	265	35	25
Mixed	BF ₁ (1/1)	1051	70	40
	BF ₂ (1/3)	1347	179	40
	BF ₃ (1/5)	1228	245	40

according to the water content and is quite low. This result can be explained by the fact that during the methanation reaction, ammonia is produced, which inhibits the process. This is corroborated by the work of [Tize *et al.* \(2011\)](#), when they argue that an increase in nitrogen supply can lead to increased ammonia production, which can harm microorganisms and inactivate methanation. Regarding the hydraulic retention time, it should be noted that the fermentation process was stopped as soon as the daily production was less than 1 L/day.

4.1.1 Daily production

In order to monitor the production of gas at the level of the digesters, a gasometer is installed. The evolution of the gross biogas production of the different tests has been illustrated. Thus, the gross daily productions of biogas recorded in experiment 1 (B₁, B₂ and B₃) are appreciated through [Figure 4](#).

[Figure 5](#) represents the evolution of the volume of biogas produced according to the hydraulic retention time for the substrate consisting of water hyacinth and cow dung. In general, the 3 curves have the same appearance. The methanization reaction of water hyacinth takes place in three phases. During the first eight days, gas production is low

at all the bioreactors. Subsequently, it increases to a peak around 92l/day for the 1/2 dilution, followed by the peak for the 1/3 and 1/1 dilutions.

In reactors with a substrate consisting of water hyacinth and chicken droppings, the best yield per kg of substrate was obtained for the 1/3 dilution. The daily gas production at the level of the pilot digesters with water hyacinth + manure substrate is shown in [Figure 6](#).

During the production of biogas from the substrate consisting of water hyacinth and poultry droppings, a very short retention time is observed. Indeed, the first peak of production (1/5) occurs on the 11th day, to fall very quickly because of the stoppage of the methanogenic fermentation.

For the substrates composed of water hyacinth, poultry manure, cow purse, the daily gross production of biogas recorded, and the results are recorded in [Figure 7](#). The average values recorded after indicate a production of 105 L of biogas for 15 kg of Water hyacinth, *i.e.* 70 L/kg/MH.

[Figure 5](#) shows the evolution of the volume of biogas produced as a function of time in digesters BF₁ (ratio 1/3), BF₂ (ratio 1/4) and BF₃ (ratio 1/5). The gas production starts to increase in a variable way after the tenth day, where a maximum daily production of 81 L of biogas is recorded for the BF₃ digester on the 23rd day, a maximum daily production of 79 L of biogas is recorded for the BF₂ digester on

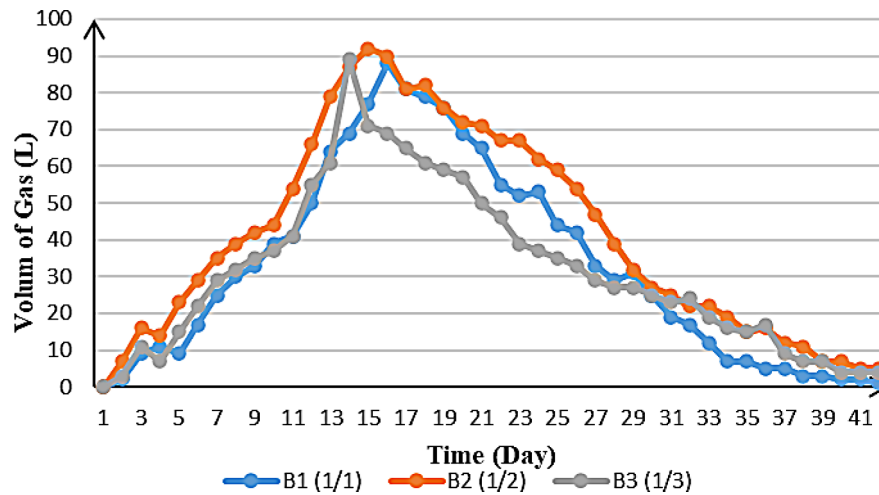


Fig. 4. Curves of daily production of biogas with water hyacinth substrate + cattle dung.

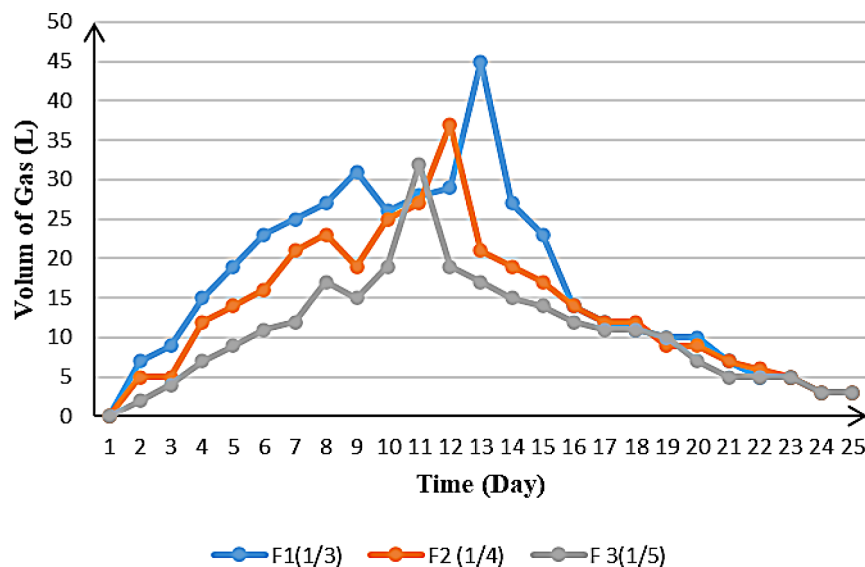


Fig. 5. Daily production of biogas with water hyacinth substrate + poultry manure.

the 24th day, and a maximum daily production of 69 L of biogas is recorded for the BF1 digester on the 21st day.

For all the different substrates, a general trend can be observed: the average biogas production values recorded during the experiment show that the decomposition reaction takes place in three phases. The first phase takes place between the 1st and the 9th day after the start of the experiment. The gas that is produced during this phase is non-combustible. The second phase lasts 22 days, with gas production gradually increasing until day 29. Finally, the last phase where the methane production decreases to the lower limit of 5 l/day.

4.2 Cumulative biogas production

The cumulative biogas production profiles are illustrated by the curves in Figures 8–10.

The cumulative productions of biogas from the three types of experiments are all characterized by a low production of biogas during the first week of digestion (latency phases), then an acceleration of production was observed from the 8th to the 26th day (exponential phase), then a slowing down/stopping of production during the last week of digestion (bearing phase). The duration of these different phases depends on the nature of the substrate. The largest biogas production is revealed for experiment 1 [B1(1/1), B2(1/2) and B3(1/3)] profile in Figure 8, ranging up to 1700 L of biogas production. Biogas during the 42 days of digestion of the substrates.

The cumulative production of biogas from cow dung substrates in a dilution ratio (11 kg of hyacinth, 4 kg of cow dung and a 1/1 ratio of water dilution), (7 kg of hyacinth, 3 kg of cow dung and a 1/2 water dilution ratio), and (5 kg of hyacinth, 2.5 kg of cow dung and a 1/3 water

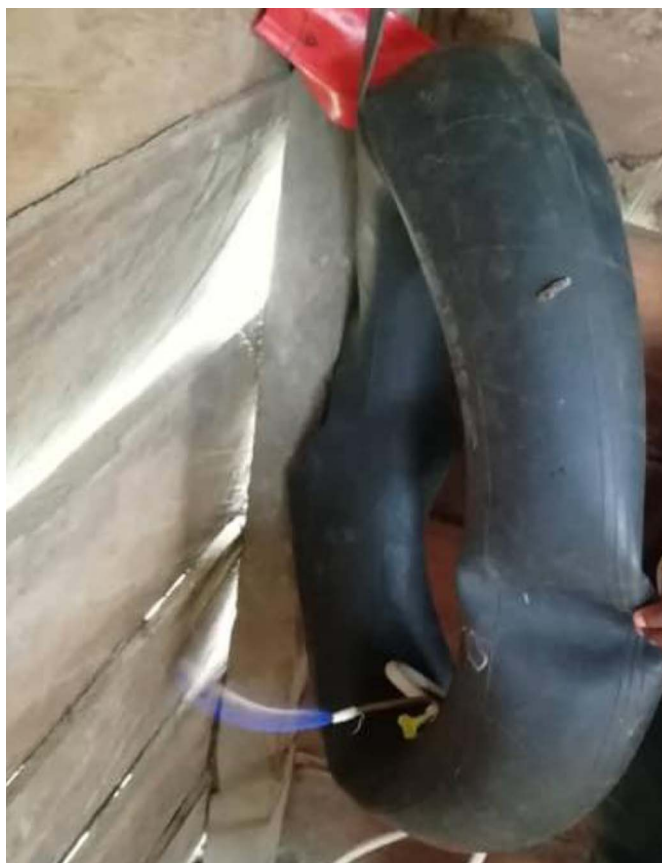


Fig. 6. Combustion tests of the produced gas.

dilution ratio), in the different digesters (B1, B2 and B3), are respectively: B1 (1381 L), B2 (1719 L) and B3 (1316 L). For a total cumulative production of 4416 L. It appears from these results that the substrates with a dilution ratio close to 1/2 remain the most favorable in anaerobic digestion for the optimal production of biogas.

4.3 Fertilizer production

Once fermentation is complete, a material called digestate is recovered and subjected to controlled dehydration. For the anaerobic digestion of the water hyacinth + cow dung (B1) substrate, the digested matter represents only 6.5 kg of organic matter. According to (Oumarou *et al.*, 2008), this material contains nitrogen, phosphate and organic carbon compounds.

Oumarou Almoustapha gives us the content of nitrogenous and phosphorus compounds (mg/kg/DM) of water hyacinth composts by anaerobic fermentation on a sample of 49 kg of fresh digestate, samples of which, analyzed in the laboratory, have shown that the compost obtained contains approximately 0.75 kg of nitrogen compounds, 10.6 kg of phosphate compounds and 1.1 kg of organic carbon (Table 3).

These results support our choice of using digestate as an agricultural fertilizer.

Nevertheless, we must analyze the different digestate in order to know if it is necessary to do a post-treatment to

Table 3. The below results support our choice of using digestate as an agricultural fertilizer.

Parameters	Water hyacinth
Nitrogen kjeldahl	627
Ammonia nitrogen	128
Total phosphorus	9930
Ortho phosphates	690
Total organic carbon	1099

improve its fertilizing qualities. Here is a general methodology that can be used:

- Sample preparation: Take representative samples of digestate at different depths and mix them to obtain a homogeneous sample.
- Physico-chemical measurements: measure physico-chemical properties such as pH, conductivity, humidity, density, organic matter content, nutrient content (nitrogen, phosphorus, potassium), element content traces (heavy metals, *etc.*) and the content of microorganisms.
- Gas analysis: measure the gas content of the digestate, *i.e.* the composition of methane, carbon dioxide, hydrogen sulphide and other gases.
- Biomass analysis: analyze the composition of residual biomass such as fibres, particles and fines.
- Microbiological analysis: study the microbial communities present in the digestate to understand their role in the fermentation process and their interactions.
- Digestibility analysis: measure the ability of the digestate to produce biogas, *i.e.* measure the residual biodegradability of organic matter.
- Economic analysis: assess the costs associated with the production and management of digestate, as well as the economic value of the digestate and its applications.

4.4 Economic evaluation and material balance

The experimental results obtained are encouraging and in the process of being put to effective use. The mixture of water hyacinth, cow purse and poultry droppings offer the best yield.

The material balance for the production of biogas from 7 kg of water hyacinth mixed with 3 kg of cow purse is as follows:

- Initial biomass: 7 kg of hyacinth + 3 kg of cow purse = 10 kg

with the dilution ratio $\frac{1}{2}$ 15 kg of initial biomass

- Cumulative biogas production: 1719 L
- Biogas yield: 1719 L/15 kg = 114.6 L/kg

using data from B2 (1/2) digester results

Cost of production of 1719 L of biogas

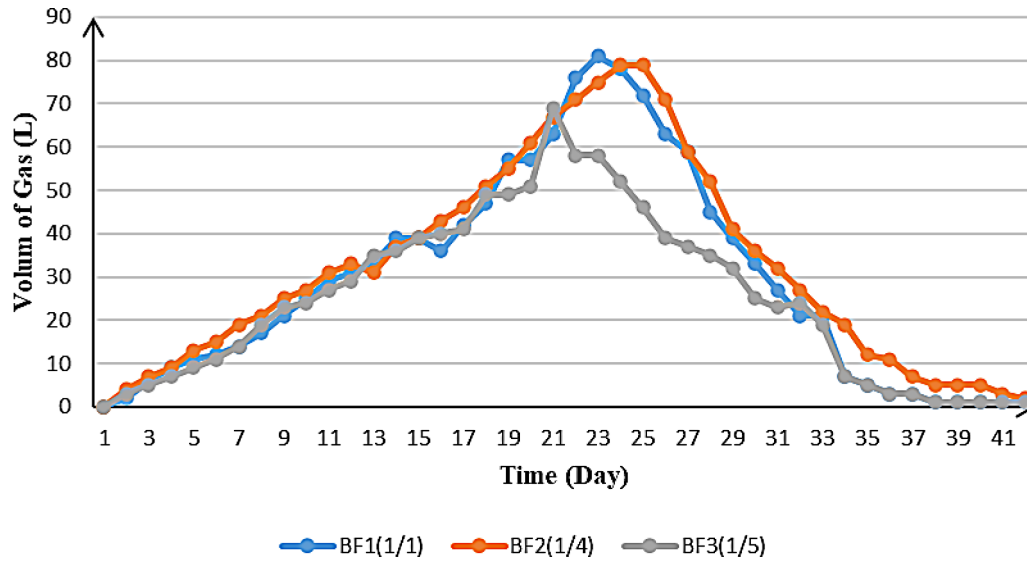


Fig. 7. Daily biogas production with water hyacinth + cow dung + poultry manure substrate.

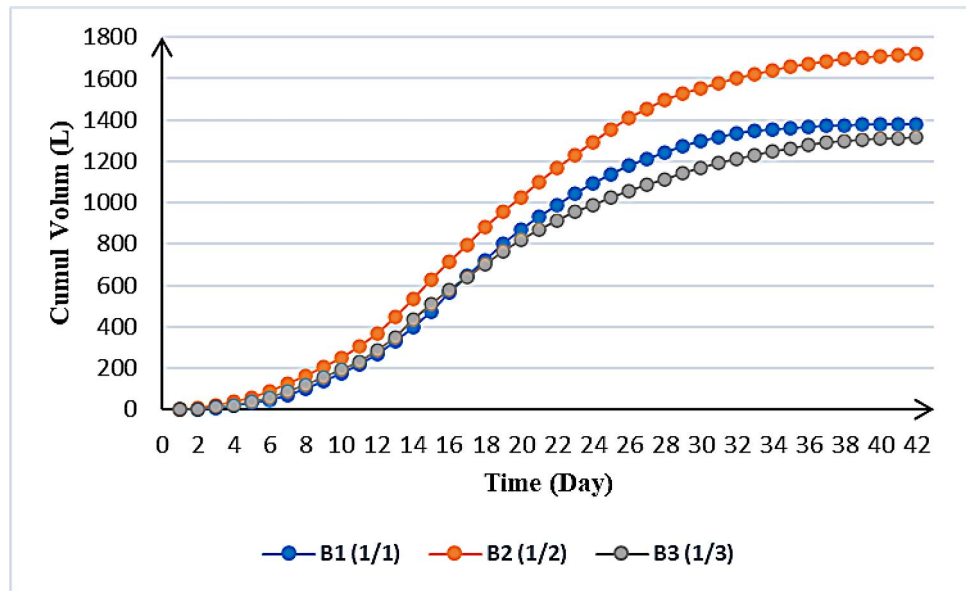


Fig. 8. Cumulative biogas production with water hyacinth + cow dung + poultry manure substrate.

- Cost of hyacinth: $0.16 \text{ USD/kg} \times 7 \text{ kg} = 1.16 \text{ USD}$
- Cost of the cow purse: $0.33 \text{ USD/10 kg} \times 3 \text{ kg} = 0.09 \text{ USD}$
- Cost of water: $0.04 \text{ USD/10 L} = 0.41 \text{ USD/L}$
- Total cost of the biomass: $1.16 \text{ USD} + 0.33 \text{ USD} + 0.0041 \text{ USD} = 1.52 \text{ USD}$
- Potential revenue from 1719 L of biogas: $1 \text{ USD} \times 1719 \text{ L} = 1719 \text{ francs}$
- Potential profit: $1719 \text{ USD} - 1.52 \text{ USD} = 1717.48 \text{ USD}$

That is $1717.48/15 \text{ kg of biomass} = 114.49 \text{ USD/kg}$ of biomass for a cycle of 42 days.

It should be noted that this economic study is based on simplifying assumptions, such as the cost of raw

materials and the selling price of biogas, which may vary depending on various factors such as market demand, government subsidies and production costs. Further cost and revenue analysis is needed to determine the economic viability of a biogas project from water hyacinth and cow's purse.

The HIMA farm intends to develop this technique by building a 20 m^3 biogas plant. This will allow the recovery of about 475 kg of water hyacinth per cycle with a production of 120 m^3 of biogas. This biogas will be used to heat the chicks and to cook their meals. In addition, this gas can be used to produce electricity (ADEME, 2010). This transformation will not only reduce the energy costs of the farm but will also prevent the invasion of the Nyong River by water

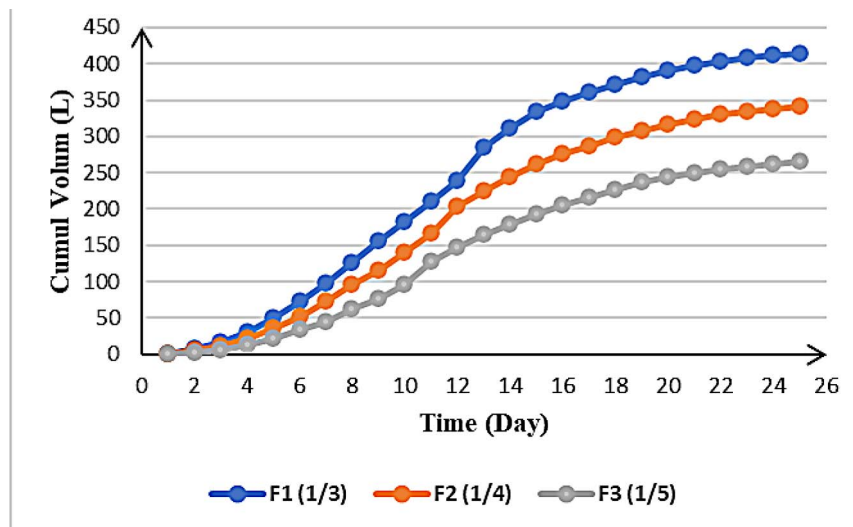


Fig. 9. Cumulative biogas production with water hyacinth + cow dung + poultry manure substrate.

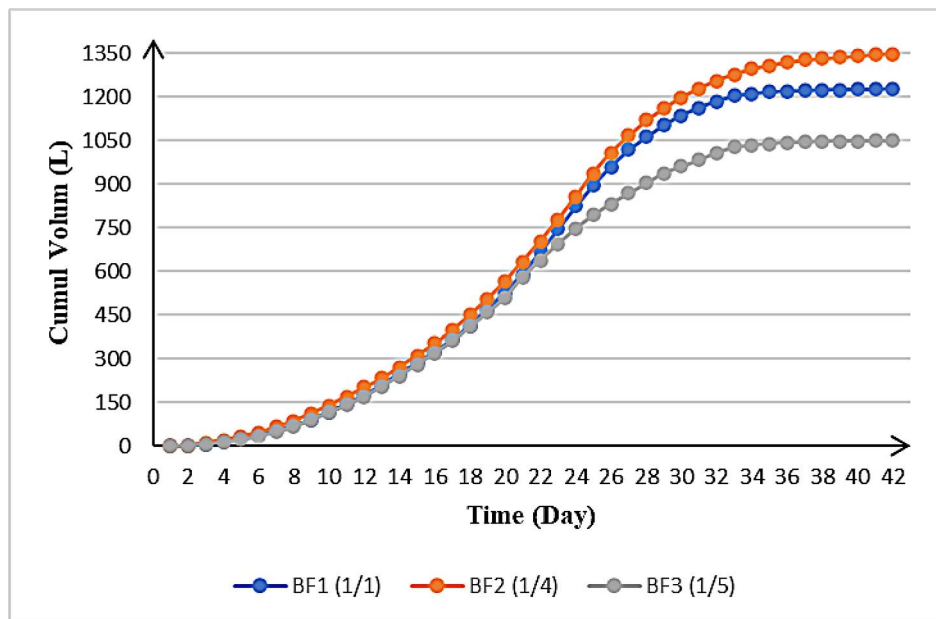


Fig. 10. Cumulative biogas production with water hyacinth + cow dung + poultry manure substrate.

hyacinth. In addition, the assessment of the growth rate of this plant in the region shows that it is possible to generate more than one million people's cooking gas (Moletta-Denat *et al.*, 2010). This will cover the needs of 160,000 six-person households.

5 Conclusion

In the Nyong River area, *E. crassipes* invasion is important and the rate of renewal is very fast, so it is a source of raw material for biogas production. Indeed, the study shows that a continuous type digester of 20 m³ volume using water hyacinth, cow dung and chicken droppings produces an average of 120 m³ of biogas. About 1.2 tons of compost

can be recovered from this process. In Cameroon, as in most countries colonized by the water hyacinth, the application of this technology offers several solutions, including the production of energy and fertiliser in a decentralized manner, and above all the control of the proliferation of the water hyacinth, which, in addition to threatening biodiversity conservation, has harmful effects on certain economic activities.

Conflicts of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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