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Biogas Production by Co-digestion: A Possible Alternative to the Threat of Climate Change

Alioune Senghor [a], Hawa Diatara Ndiath[a], André Ndecky [a], Christoph Müller [b], Issakha Youm[a]

[a]Laboratoire des Semi-conducteurs et d'Energie Solaire (LASES), Département de Physique, Faculté des Sciences et Techniques, Université Cheikh Anta Diop B.P. 5005 Dakar-Fann, Sénégal
[b]Institut fürPflanzenökologie, Heinrich-Buff-Ring 26, 35392 Gießen, Germany
Corresponding Author : alsenghor83@yahoo.fr

ABSTRACT

It is widely share that climate change could have conséquences on agricultural production systems worldwide. Sustained predictions are made on the rise in ppm of greenhouse gases and on the rise in temperature. Among these gases, CO_2 is particulary studied because it is on the essantiel elements involved in the photosynthesis of plants. A change in ppm could have consequences for food crops in general.

The same is true for an increase in temperature with a possible impact on the ability of crops to adapt to this increase. Alternatives are being tested to reduce the use of fossil fuels, the mains causes of climate change, by introducing anaerobic digestion (biogas) of organic compound. On the other hand, agriculture practiced n the nothern countries is timing more and more towards energy crops such as corn to serve as a substrate for anaerobic digestion. Previous studies have shown a negative effect of climate change on the future of biogas produced from energy crops.

To limit the damage caused by climate change, codigestion can be a reliable solution. In our study for about 52 g of organic matter (OM) and replacing water by sludge in each digester, we were able to obtain 37,8 NL of biogas with 62% of methan with corn silage and cow dung.

Key words: codigestion, biogas, energy crops, climate change

INTRODUCTION

Biogas production is a biochemical process that take place in the absence of many sensitives microorganisms essantially made up of bacteria. Dominant components are CH_4 and CO_2 with traces of other gases like H_2S, NH_3, CO, H_2, N_2 and water vapor. Several forms of biomass such as plants, municipal and animal waste are suitable substrates for biogas and biofuel production.

If there is a booming sector in developed countries, it is the use of energy crops for biogas production. Energy crops are being used exponentially and occupies a significant share as in Germany where they correspond to 41% of substrates with 78% for corn silage [1].

The plant used is exposed to the outside environment under the influence of parameters such as rise of temperature and CO_2 concentration. These parameters not only affect yield but also the quality of the plant. Thus the use of this sector for biogas production can be threatened or even slowed by the harmful effects of climate change.

Effect of elevated CO_2 on corn

Atmospheric CO_2 concentration increased at an average rate of 2±0.1 ppm/year and can reach 550 ppm by 2050 [2]. This rise can have positive impact on the growth of the plant and of corn in particular. Using simulation method and doubling CO_2 concentration we note an increase of 14% in yield. The OTC method at a concentration 550 ppm provides 53.7% more in yield. These results show the rise of CO_2 can be considered as fertilizer for corn [3].

On the other hand, there is negative effect of the rise in CO_2 on the quality of the corn with the drop in the protein content which can range from –4.6% to -11% [4].

For macro and micro-nutrients, except K which increases by 5%, a decrease is noted for everything else. Elements like S, Mg, P, N and P decrease respectively by -2.1%, -5.7%, -7.1%, -11% and -19% [5].
The main effect of elevated CO_2 is the lower protein and nutrient content, to key elements for a good methanisation. Several authors have argued that biogas production depends on protein content. Besides nutrient elements (C, H, O, N), metal elements including light metal ions (Na, K, Mg, Ca, Al) and heavy metal ions (Cr, Co, Cu, Zn, Ni, etc.), are also required by anaerobic bacteria because these cations play an important role in enzyme synthesis as well as maintaining enzyme activities. Basing on the theoretical equation of Buswell, methane concentration will decrease by -55% to -49% for maize [6].

Effect of elevated temperature on biogas production.

As a result, global surface air temperature has increased about 0.74°C since 100 years ago from 1906 to 2005.
The expected changes in temperature over the next 30-50 years are predicted to be in the range of 2-3°C and will rise with about 1.1-6.4°C by the end of this century, influencing soil temperature in agricultural areas as well [1].
Mean while, flowering may also be partially triggered by high temperature, while low temperature may reduce energy use and increase sugar storage [7]. In temperate cereals, optimum mean temperature ranges for maximum grain yield were between 14 and 18°C. On the other hand, as maturation processes of cereals are related to specific temperature sums, moderate increases in average temperature by 1-2°C result in shorter grain filling periods are negatively affect yield components in some regions. Reduction in grain yield can be attributed to temperature induced metabolic changes to the shorter duration of crop growth and development. Earlier studies thus demonstrated that grain yield of cereal were decreased by 4% to 10% due to increase of the seasonal average temperature by 1°C [8]. Yield loss associated with global warming for C_3 may reach values up to 6% per °C and that for C_4 by up to 8%. Corn is projected to decline by about 30% by 2030 in southern Africa [9]. In the same way Knox et al, [10]. Through a simulation method show that by 2050, the yield in Africa could decline by up to 5% for corn.
The maximum growth period is expected to be 2 to 4 days for corn. The range of production changes are 5.7 to 19.1% for corn. Their result indicated that potential production declined by 2.5% to 12.5% across all studies due to elevated temperature [11].
Yield of maize increases until the temperature reaches 29°C and decreases continually with a higher temperature. Simulations by Li et al, [12] show that a 1°C warming at times when maximum temperatures occurred would reduce maize yields by 2-9% at different sites.
According to Lu [13], the optimum temperature for grain development in maize is between 27 and 32°C. Lu show that grain yield were most sensitive to heat stress applied at early day by a decrease of 35.8%, 15.8%, 37.5% and 27.7% for 4 different maize than heat stress at throughout grain filling respectively by 5.7%, 10%, 12.7% and 8.1%.
In sub-Saharan Africa and southeastern African, maize yields are negatively affected by elevated temperature which exceeds commonly 30°C. A yield loss of 10% per 1°C of warming is estimated [14]. Elevating temperature by respectively 1, 2 and 3°C reduce maize yield by -10%, -14% and -21% [15].
One the other hand, we noted a slight increase of protein and a decrease of lipids of 7%. Others authors have found no change due to the temperature. The C/N ratio is not affected but a considerable drop in some key elements such Se (-43.5%), Al (-15%) and Co (-22.5) [8].
In view of these results, we can predict a decrease of biogas production by corn in the future seeing that the drop in yield is considerable and keys elements except protein are negatively affected.
If codigestion is known to to provide excess methan by stabilizing the anaerobic digestion by mixing several substrates with water, few studies have been done on codigestion without water in favor of sludge. This study aims to provide a solution to the future of biogas production from energy crops in the face of the threat of climate change. to bring a solution to this threat we opted for the co-digestion of corn silage with cow dung and sludge without using water.
We will start by presenting the materials and method used during our experiments and pass finally to the results and discussions.

MATERIAL AND METHODS

This experimental part was carried out at the biomass laboratory of the University of Technical Application THM of Giessen in Germany.
The substrates used in our experimental part are corn silage, cow dung and sludge. Corn silage, which is the most widely used substrate in this country, so we can easily obtain it locally in its natural state or ensiled. The cow dung is taken from a farm in the Aachen region and the sludge from a sewage treatment plant in the same region.

The ovens

An oven whose temperature varies from 5 to 220 °C (Figure 1) is used in order to determine dry matter (DM).
Similarly, another oven (Figure 2) with ventilated convection and the temperature of which is raised to 505° C, is used to determine the content of organic matter (OM) and mineral matter (MM).

Fig. 1 Etuve Memmert UNB 500 (105 °C)

Fig. 2 Etuve Memmert UF 260 (505 °C)

Fig. 3 Corn silage after drying at 105°C

The ultra-centrifugal grinder

For the determination of the ash and organic matter content, the substrate after having been dried at 105°C is transformed into powder. Processing is done using a Retsch ZM 200 ultra-centrifugal grinder as shown in Figure 3. This device has the ability to transform dry corn silage into powder. Thanks to this transformation, the product obtained is more easily usable from the point of view of transformation into ash but also easier to analyze when taking samples. The powdered dry maize obtained is introduced into the oven and brought to a temperature of 505°C in order to determine its MM content.

Fig. 4 Centrifugal grinder

Fig. 5 Ground corn silage

The digesters

The digesters are small prototypes of about 1000 cm^3 equiped with a thermometer to control the temperature and also a stirrer to homogenize the mixture. Digestion is of the mesophilic type because the temperature varies between 25 and 27°C. Figure 4 shows the digester fitted with a thermometer. The biogas obtained is collected in insulated bags.

Fig. 6 Stirrer and thermometer

Fig. 7 Biogas recovery

The volumeter and the gas analyzer.

The ADOS multi-channel gas and biogas analyzer is the device used for the determination of the percentage composition of all the gases present in the biogas. Figure 5 illustrates the device giving the percentages of CH_4, CO_2, H_2, O_2 and H_2S. Similarly, the device supplies the volume of biogas contained in the tank.

Fig. 8 Determination of volume and biogas composition

RESULTS AND DISCUSSION

Results

Determination of dry matter and organic matter

The dry matter content and the percentage of organic matter of the different substrates were determined. As a precaution, a double measurement was carried out for each substrate using two test tubes. Table 1 presents the results obtained before and after drying of all the substrates.

Let m_a be the mass of the vacuum tube, m_b that of the tube containing the substrate, m_c that of the assembly after drying at 105°C and m_d that of the assembly after calcination at 505°C.

Table -1 Mass of differents substrates

Substrat	m_a	m_b	m_c	m_d
Corn	63.71	94.99	74.99	64.23
Corn	61.07	94.54	72.97	61.63
Sludge	68.17	83.34	73.27	68.74
Sludge	63.81	80.43	69.11	64.41
Dung	60.95	149.81	65.25	62.20
Dung	58.26	125.80	62.56	59.33

The percentage of dry matter (% DM) is given by the following formula:

$$\% \text{ DM}=(mc-ma)/(mb-ma)x100$$

The percentage of ash or mineral matter (% MM) is calculated as follows:

$$\% \text{ MM}=(mc-md)/(mc-ma)x100$$

The percentage of dry organic matter (% DOM) is deduced from the other percentages by the formula below:

$$\% \text{ DOM}= \% \text{ DM}*\% \text{ MM}*0,01$$

Table 2 gives us the results in MS, MM and MOS obtained at the end of the drying and by application of their formulas of determination.

Table -2 Percentage of dry, mineral and organic matter of the substrates

Substrat	% DM	Average	% MM	Average	% DOM	Average
Corn	36.06	35.8	95.39	95.3	34.40	34.1
	35.55		95.29		33.86	
Sludge	33.62	32.8	88.82	88.7	29.86	29.1
	31.89		88.68		28.28	
Dung	4.84	5.6	70.93	73	3.43	4.1
	6.37		75.12		4.79	

Determination of the amount of biogas and methan

Into the digester 10.8 L of sludge were introduced with 129 g of maize and 166 g of dung, ie 44 g of MOS in maize and 6.8 g of dung. Readings are constantly taken in order to have an idea of the quantity of biogas produced and the variation in composition over time. The volumes in liters of biogas and methan are shown in figure 7. Table 3 gives the variation of the different biogas compounds as a function of time.

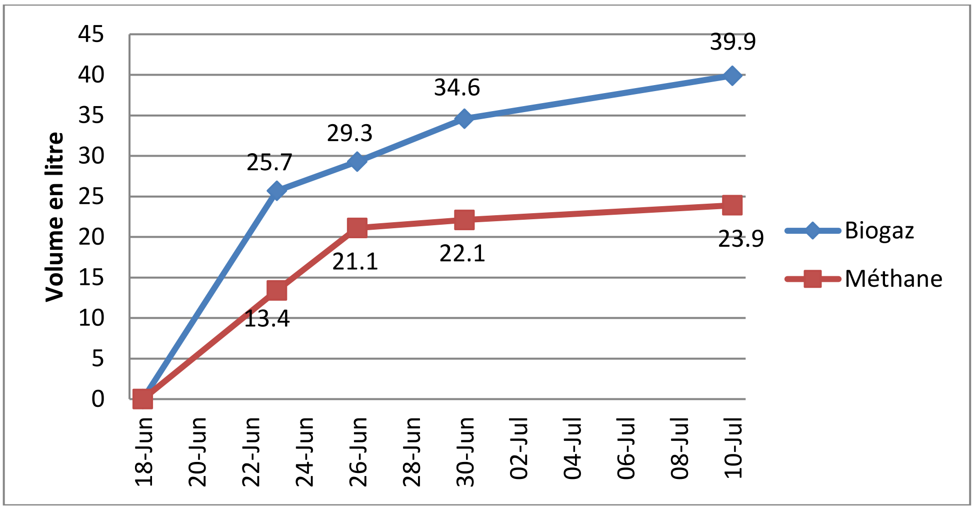

Fig. 9 Volum of biogas and methan in liter

Table-3 Variation of the composition of biogas

Date	% CH_4	% CO_2	% O_2	% H_2	% H_2S
18/06	0	0	0	0	0
23/06	52	20	1.4	0.06	0.05
26/06	72	18	0	0	0
30/06	64	22	2.6	0	0
10/07	60	26	0.5	0	0

In international standards, the volume of biogas is expressed in normal liters or normal liters, which is the volume reduced to normal conditions of temperature and CNTP pressure as shown in figure 8.

Biogas is made up of several gases, the main ones being methan and carbon dioxide. Some gases are present there in trace form, such as dihydrogen and hydrogen sulphide which is responsible for its smell, others not being considered as sewer gases are present there by default, such as nitrogen and oxygen. These gases should not in principle appear in the final composition, they must therefore be removed from the final percentage. Figure 9 gives us the corrected volumes of methan and biogas.

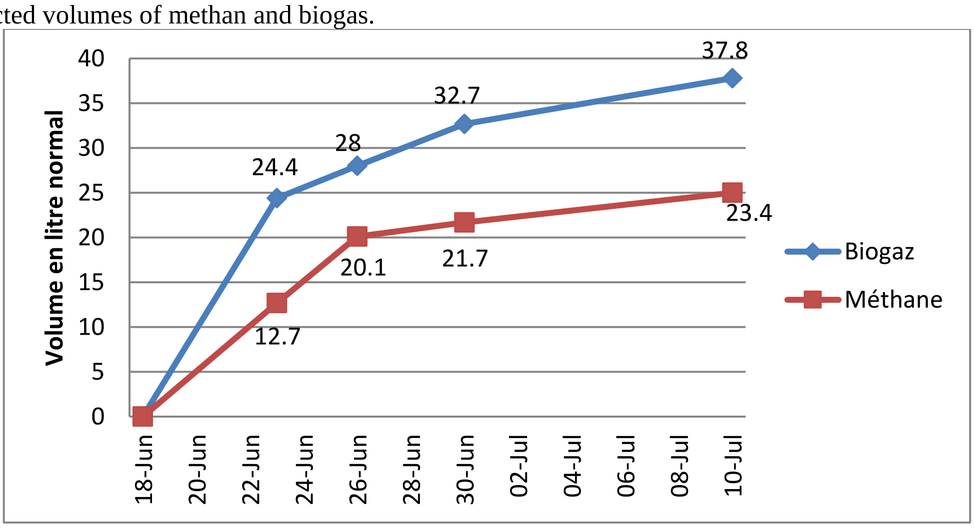

Fig. 10 Volume in normal liter

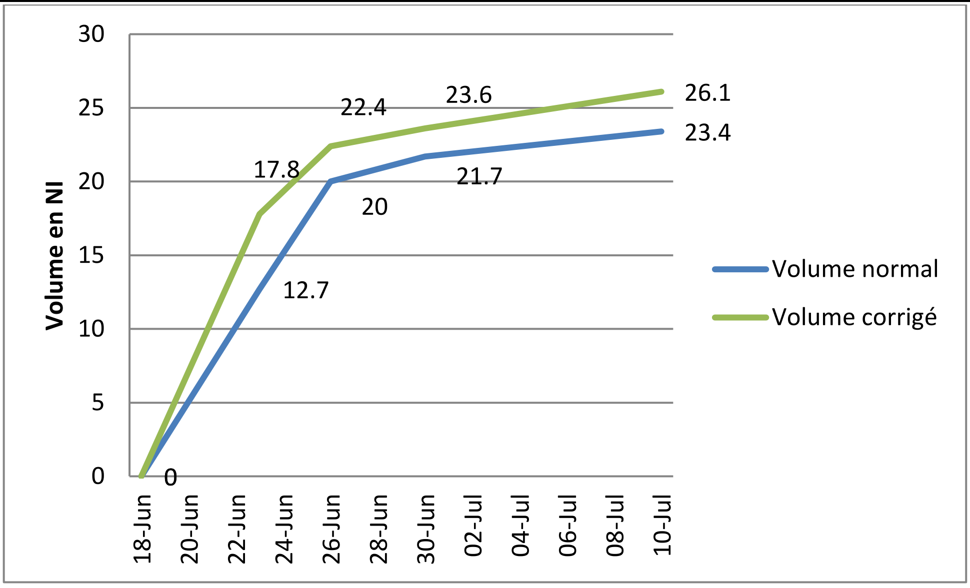

Fig. 11 Corrected volum

DISCUSSIONS

The volumes of biogas and methane obtained are governed by figures 9, 10 and 11 where we find respectively the volumes in liters (39.9 and 23.9), in normal liters (37.8 and 23.4) and corrected (37.6 and 26.1).

The methane percentage reached 52% then rose to 72% in 3 days before stabilizing at 60%, giving an average value of 62%.

Maize has a DM content of 36%, 34% MOS. The high MOS content of a lignin-free plant substrate results in high methane production. The results on the characteristics explain the good yield in biogas and methane on the one hand. For its use, corn is often ensiled before being introduced into the digester because it increases the yield. According to Chandra [16], the maize plant has a potential of 338 I/kg MOS, i.e. a volume of 17.2 I of gas. This quantity can be improved through silage before methanization. Silage has a positive effect on maize production as it can improve yield by up to 11% [17]. According to Herrmann, the methane production by maize is between 342 and 378 NI/kg MOS.

The cow dung used in our experiments has a content of 4.1% MOS and 5.6% DM. Several studies have shown that co-digestion allows a better yield by stabilizing the medium. An advantage of co-digestion can be the possibility of obtaining a better C/N ratio, a better balance of nutrients, a rapid degradation of the substrates thus allowing a significant increase in the biogas produced.

Anaerobic co-digestion of waste with cow manure could improve the biodegradation process resulting in a higher methane yield due to the accumulation of long fatty acid chains in lipids.

The nutrient imbalance of AD is overcome by co-digestion with other biomass wastes (cow dung, municipal wastewater) to obtain a more appropriate C/N ratio and an appropriate concentration of metals [18]. Cow dung under mesophilic conditions (38°C) provided 166.3 NI of methane/kg MOS according to Amon [19]. Braun found the methane range to be between 140 and 266 NI/kg MOS for dung. Materials with a high C/N ratio can be mixed with those with a low C/N ratio to bring the mix ratio down to a desirable C/N ratio. In the same way by varying the proportion of each substrate, we find a higher level of gas with the manure + maize / maize ratios 40/60, 50/50 and 60/40 respectively (221, 234 and 259 I/kg MOS) and (48, 52, and 51% methane) i.e. a maximum quantity of 13 L for 50 g MOS [20]. Eva found a quantity of methane of 318 Ncm3/g MOS by combining the mud with the algae against 310 Ncm3/g for the mud used alone as a substrate, i.e. an increase of 8% in methane. Our results obtained in the field of co-digestion which are 39.9 I of biogas and 23.9 I of methane are also superior to those found in the literature. The quantity of maize introduced is 44 g of MOS against 6.8 g for dung, i.e. an 80/20 ratio. By playing on this ratio, that is to say by increasing the quantity of dung, we can expect better results as shown by Froseth.

CONCLUSION

If the rise in CO_2 can be considered beneficial to the growth of the plant, it decreases on the other hand the concentration of the fundamental basic elements in particular the protein and mineral content. The rise in temperature, on the other hand, is detrimental to the growth of the plant and also causes a drop in the content of certain nutrients such as minerals. Their combined effects do not lead to compensation for losses caused individually. Thus the use of energy crops to produce biogas is in the future threatened by the fact that the key elements that microorganisms need to produce the latter are negatively affected by the effect of climate change in particular.

This experimental study shows the possibility of increasing the yield of biogas and methane through co-digestion and the substitution of water for the benefit of sludge. Thanks to this method, we managed to obtain satisfactory results which exceed those found in the literature by 8.5 I. We were also able to confirm the thesis supported by several authors, namely the effect of co-digestion on the increase methane yield with a content of 62%. We have also seen the advantage of using silage, which allows better degradation and therefore speeds up the process a little. Good results have been obtained by dispensing with water in anaerobic digestion, a substance that some authors considered to be fundamental.

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