Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2023, 10(2):180-188

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Impact of climate change on biogas production by corn

Alioune Senghor[1], Hawa Ndiath[1], André Ndecky[1], Christoph Müller[2], Issakha Youm[1]

[1]Laboratoire des Semis Conducteurs et d'Energie Solaire (LASES), Département de Physique, Faculté des Sciences et Techniques, Université Cheikh Anta Diop, B.P. 5005 Dakar-Fann, Senegal.
[2]Institut für Pflanzenökologie, Heinrich-Buff-Ring 26, 35392 Gieβen, Germany
Corresponding Author: alsenghor83@yahoo.fr

Abstract The use of energy crops for the production of biogas occupies an increasingly important place among the methanisable substrates and is the subject of several researches, especially in developed countries. However, the plant as such is exposed to the external environment and, under the influence of parameters, it can undergo transformations both in terms of yield and quality. These external parameters, which are mainly temperature, atmospheric CO_2 concentration and precipitation, greatly influence the development phase of the plant as well as its final composition, namely its protein, lipid, carbohydrate and mineral salt content. In this article we show by a meta-analysis the effects of climate change on energy crops, especially corn.

Keywords biogas, corn, climate change

Introduction

Climate change is defined as the abiotic change in the earth's atmosphere including changes in temperature, wind, precipitation, especially the increase in temperature of the earth's atmosphere caused by particular gases such as CO_2, CH_4 and N_2O (nitrogen monoxide) which continue to increase. The plant exposed to the external environment is influenced by these parameters. Climate change can be harmful to the development of the plant, thus reducing its yield, but can also cause a drop in its quality, in particular lipids, proteins, carbohydrates and nutrients.

Proteins are an important element in the production of biogas. Some authors argue that the production of biogas depends on its protein content after testing 15 varieties of corn [1].

Using protein-rich compounds as a co-substrate resulted in high methane production after testing multiple substrates and finding the highest methane yield for protein [2].

Major biotech companies are trying to increase protein content in crops to increase methane yield. Anaerobic digestion of proteins produces 587 L of biogas with a content of 84% methane per kg of volatile solid (VS) destroyed [3].

Carbohydrates are known to be easily and quickly converted by hydrolysis into simple sugars and then fermented into volatile fatty acids (VFAs).

Starch has a positive effect on biogas due to its digestibility. Due to its high starch content, the cob is the most important part of the plant. Corn cob due to the high starch content is characterized by higher biogas production (7960 m^3/ha) compared to whole plant silage (10200 m^3/ha). The carbohydrates provide 885 L/kg VS of biogas with a 50% methane content [4]. Substrates containing lipids have the highest biogas and methane yield values such as slaughterhouse fats, STEP, cooking oil.

In combination with sewage sludge, lipids increase the usually low level of C/N in the digesters of the sewage treatment plant (wastewater treatment) and introduce an additional source of organic matter which helps to

increase the production of biogas from oversized digesters. Anaerobic digestion of fat gives 1535 I/kg VS with about 70% methane content.
Nutrients are essential for good biogas production, the optimal C/N ratio for anaerobic digestion is in the range of 20 to 30 because the microorganism consumes 30 times more C than N and nitrogen does not enter the composition of biogas but appears in the digestate in which it is the main element with phosphorus P.
N is the most important element after C, at a high C/N ratio, a low amount of gas is obtained.
Besides nutrients (C, H, O, N), metallic elements including light metal ions (Na, K, Mg, Ca, Al) and heavy metal ions (Cr, Co, Cu, Zn, Ni, etc.) also required by anaerobic bacteria because these cations play an important role in enzyme synthesis as well as maintenance of enzyme activities [5].
In addition to carbon and nitrogen, phosphorus and sulfur are also essential nutrients. Micronutrient deficiency is very common in single fermentation energy crops. The elements that methanogenic archaea need are cobalt (Co), nickel (Ni), molybdenum (Mo) and selenium (Se) and sometimes also tungsten (W). Nickel, cobalt and molybdenum are required as cofactors for reactions essential to metabolism.
Magnesium (Mg), iron (Fe) and manganese (Mn) are also important micronutrients for electron transport and the function of certain enzymes. The improvement of mesophilic biogas production from grass by 40% was obtained by daily addition of Ni, Co, Mo and Se with a decrease in VFA. It shows that the addition of Fe, Co and Ni provided 35% biogas production. Macronutrients mainly Co, Cu, Fe, Mo, Ni, Se and Zn during thermophilic digestion of OFMSW (Organic Fraction of Municipal Solid Waste) helped to increase gas generation rate by 30% and increase stability of the digester [6].
In this study, variations in temperature, carbon dioxide and precipitation are studied in particular. We will begin by showing their influence on the yield of maize before giving results on the quality of this plant. The results obtained will allow us to conclude on the future of the use of corn as a substrate for the production of biogas.

Method

Many studies on the effect of change on the yield and quality of the plant have been made with various methods. These are difficult experiments to perform because parameters such as CO_2 concentration, and especially precipitation, are difficult to control. Nevertheless, there are a large number of publications with results that can range from simple to double.
This is how we opted for meta-analysis as a method, which is a collection of data from studies thus carried out in a field in order to have a broad overview of the variation of a parameter considered and to be able to draw a general conclusion. We will start by collecting data on the effect of the increase in CO_2 on the yield and quality of the plant by different methods, then we will do the same for temperature and precipitation.
Studies on the combination of these parameters will also be consulted before drawing a general conclusion on their effects on the plant. This will allow us to have an idea about the future of the use of energy crops for the production of biogas.

Effect of CO_2 on corn

Effect of CO_2 on yield

The atmospheric concentration of CO_2 continues to increase and is estimated at 2 ppm/year on average during the period 2002-2011.
This increase could reach 400 to 500 ppm in 2050 according to IPCC projections where the normal, i.e. the ambient concentration, is around 350 ppm [7]. Different approaches have been used to assess the impact of climate change on plant yield and quality.
The most used methods are: FACE (free air CO_2 field enrichment), OTC (open top field chamber), CTC (control top field chamber), GC (green chamber), CEA (control environmental approach). Most studies examining the future impact of rising CO_2 on plants use simulations (crop models or climate change scenarios) [8].
Table 1 shows the results of a meta-analysis of corn responses to elevated CO_2. Considered as a "fertilizer", the rise in CO_2 leads to a potential increase in the yield of the plant. C4 type plants (maize, sorghum, millet, sugar

cane) do not benefit too much from the rise in CO_2, nevertheless a positive effect is noted on the yield of the plant and this effect varies according to the method used.

For an increase of 200 and 300 ppm in atmospheric concentration and using a method other than FACE, the excess biomass is between 20 and 30%. A meta-analysis of 79 species showed an increase in biomass of between 28 and 35%, as well as a negligible increase for C4 plants (8%) against (26%) for C3 plants **[9]**. There is a significant variation of 5% for maize.

In a phytotron, by doubling the concentration i.e. to 700 ppm, the maize yield increases by 14% whereas under OTC at 550 ppm the maize seed increases by 53.7% and the harvest index 2.9% [10], [11].

Table 1: Effect of CO_2 elevation on plant

Plants	Methods	Concentration (ppm)	Yield en %
Corn	OTC	700	14
	Simulation	550	53,7

Effect of CO_2 on corn quality

The quality of a plant represents the constituent elements giving it its value, these are mainly proteins, lipids, carbohydrates, micro and macro elements.

Effect of CO_2 on proteins

The decrease in protein concentration is the most negative effect noted when the plant is exposed to elevated CO_2. Table 2 shows us the response of different cereals under different methods and at different concentrations.

The results obtained by OTC, FACE and chamber studies showed that the rise in CO_2 significantly decreases the protein concentration for all cereals except sorghum under certain conditions. By combining FACE and experimental chamber, we note a decrease of -4.6% for maize. Considering only the FACE method, we find the same percentage of reduction, results obtained by meta-analysis carried out on 143 species **[12]**.

Maize seems to belong to this range because for a concentration of 550 ppm, there is a decrease of -11%. On the other hand, other authors report a small or almost no decrease in protein concentration **[13]**, **[14]**, **[15]**.

Table 2: Effect of CO_2 elevation on proteins.

Plants	Methods	Concentration of CO_2 (ppm)	Variation of protein
Corn	FACE and chambre	546-586	-4,6%
	FACE	Elevated CO_2	-4,6%
	OTC	550	-11%

Effect of CO_2 on lipids and carbohydrates

Carbohydrate accumulation on the leaves is the most observed and universal response for C3 plants under CO_2 elevation. This is due to the decrease in nitrogen from -13% to -26%. If starch and hemicellulose observe a slight increase, this does not alter the concentration of lignin and cellulose. CO_2 elevation has no overall effect on total lipid fractions **[16]**.

Effect of CO_2 on macro and micro elements

The decrease in concentration of micro and macroelements is observed for all plants with a few exceptions. Table 3 shows the variation of macro and micro elements of different under high concentration.

With several study methods and at 550 ppm, elements such as calcium, magnesium and manganese decrease by -9.7%, -4.2% and -4.9% respectively, while there is an increase in elements potassium, phosphorus and iron by +3.9%, +1.1% and +1.2% respectively under CTC. Under OTC and GC, still at 500 ppm, there is a decrease for all the elements (-12.4%, -19.5%, -14.5%, -7.2%, -12.3%, -18, 3% and -13.1%) respectively for the elements (K, P, Ca, Mg, S, Fe and Zn) **[17]**.

At 550 ppm, nitrogen and phosphorus decrease by 11% and 19% respectively, while potassium increases by 5% for maize **[18]**.

Table 3: Effect of CO_2 elevation on minerals.

Cereals	Method	Concentration of CO_2 (ppm)	Effect on macroelements	Effect on micro-elements
Corn	FACE	546-586	-5,7(Mg), -2,7(Ca), +2,1(S), -2,7(K),	-5,2(Mn), -5,8(Fe)
	FACE and chambre	546-586	-7,1(P), -11(N), -19(P), +5(K)	-5,2(Mn), -5,8(Fe)
				-4,2(Mn), -9,9(Cu), -5,2 (Zn)
	OTC	550		

The iron concentration reached +33% under FACE. In his meta-analysis, Myers observes that on average all macro and micro elements decrease except K and Ca for corn.

Effect of temperature rise on the plant

Effect of temperature on yield

Global temperature has increased by about 0.74°C between 1906 and 2005. In the next 30 to 50 years, expected temperature changes are expected to be in the range of 2 to 3°C and could reach 6.4°C at the end of this century thus influencing soil temperature in agricultural areas **[19]**.

Under the influence of temperature rise, crop yield can be affected at any time from sowing to grain maturity but it is during flowering when the number of grains is established and during l filling stage that the rise in temperature has a greater impact on the harvest. Heat affects both plant growth and development.

The most significant factor in yield loss in cereals is the reduction in the development phase leading to a decrease in the perception of light during the shortened life cycle and a disturbance of the processes linked to carbon assimilation **[20]**. Table 4 gives us the variation in the yield of certain plants under the influence of temperature.

On average, flowering can be partially triggered by high temperatures while low temperature can reduce energy consumption and increase sugar storage **[21]**. In temperate zones the optimum average temperatures for maximum grain yield are between 14 and 18°C.

On the other hand, as the ripening processes of cereals are linked to specific temperature values, moderate increases in the average temperature of 1 to 2°C lead to shorter filling periods negatively affecting the yield components.

Studies have shown that the grain yield of cereals decreased by 4 to 10% due to the increase in the seasonal average temperature of 1°C **[22]**.

Yield loss associated with global warming for C3 type plants can reach 6% per °C compared to 8% for C4 plants **[23]**.

By a simulation method, the yield of cereals in Africa in 2050 is condemned to decrease (-5% for maize) **[24]**. On the other hand, in Southern Africa, maize production is expected to decrease by around 30% in 2030 **[25]**.

Table 4: Yield variation as a function of temperature

Cereals	Temperature (°C)	Method	Decline in yield (%)
Maïs	+1	Simulation	2→9
	+1	Simulation	10
	35	CC	15→38
	+1	Simulation	10
	+2	Simulation	14
	+3	Simulation	21
	+1,5	OTC	4,9

The maximum growth period should be 2 to 4 days for maize with respective production variations of 5.7% to 19.1%. The results indicate that the production potential decreased by 2.5% to 12.5% in all studies due to temperature elevation [26].

An increase of 1°C is equivalent to a 5.6-20% relative change, i.e. a 3-10% drop in yield [27]. A variation of 1.5°C leads to a reduction in the growth period of 10 days [28].

Cereals in temperate and subtropical zones grow best between 20 and 30°C.

Maize yield increases until the temperature reaches 29°C and continuously decreases above this temperature.

A warming of 1°C at maximum temperatures decreases the yield by 2 to 9%. The optimum temperature for maize seed development is between 27 and 32°C [29].

In sub-Saharan Africa and in the southeast, yields are negatively affected by the temperature which generally exceeds 30°C, a loss of 10% per 1°C of warming is estimated [30]. A rise of 1°C, 2°C and 3°C respectively reduces the yield by 10%, 14% and 21% [31]. In OTC, with a 1.5°C increase in ambient temperature, corn kernels decrease by 4.9% [32].

The rice becomes sterile if it is exposed to a temperature above 35°C for more than one hour during flowering and therefore does not produce any seeds.

Effect of temperature rise on grain quality

An increase in temperature during grain filling decreases its weight, which leads to a reduction in grain yield due to the reduction in starch biosynthesis.

An increase in grain protein content was observed for 4 maize varieties. The increase is greater at the grain filling stage than at the beginning of the filling stage.

Starch content, grain number and size are affected by temperature.

Experiments have shown that changes in the composition of protein fractions under the effect of heat are due to the altered amount of nitrogen accumulated during filling [33].

Of 37 studies, 25 showed a decrease in synthesis at high temperature. The lipid concentration decreases significantly with temperature.

Fatty acids decrease considerably for wheat down to 777 mg at 4°C above room temperature against 1322 mg [34].

Starch is one of the major indices of cereal quality. Heat decreases the starch content of corn [35]. Cereals in temperate and subtropical zones grow optimally between 20 and 30°C, between 30 and 40°C the starch content is reduced by 2 to 33%.

A slight increase and decrease was observed in macro and microelement for certain elements such as potassium (+1.7%), calcium (+1.9%), sulfur (+1.8%), zinc (+2.5 %), while others are declining; this is the case for phosphorus (-2.2%), magnesium (-0.8%), manganese (-2.6%), iron (-0.6%), aluminum (-15%), and cobalt (-22.5%). The C/N ratio remains unchanged under the effect of temperature, whereas the concentration of lipids decreases by 7.1% and that of starch by 5% for barley [36], [37].

Effect of precipitation on the plant

Effect of precipitation on yield

The change in precipitation can have both positive and negative effects. In general, heavy rainfall corresponds to an increase in production. The variability of heavy rains leads to an increase in the variability of soil moisture which alters the productivity of the pasture.

Agricultural production is also negatively impacted by the flood. Excess precipitation causes soil moisture.

Drought or lack of water is considered to be the biggest factor limiting plant growth and production. The unavailability of water leads to a decrease in seasonal evapotranspiration, total dry matter, grain yield and harvest index.

Maize yield increases with rainfall. The best yield corresponds to a percentage of 150% while with 25% of rain the lowest yield is obtained [38].

Effect of precipitation on plant quality

An increase in intra-annual rainfall variability is predicted due to global warming leading to long periods of drought and intense rainfall with huge impacts on agriculture. Productivity is altered directly by climate change and indirectly by nutrient variation.

A long and extreme drought leads to a movement of proteins, nitrogen and soluble carbohydrates from the leaf to the root, thus reducing the nutritional value of the plant. Aridity also affects the nitrogen nutrition of the superficial part of the plant because of the use of nitrogen by the soil. Nevertheless, the protein content is bound to increase under aridity.

An increase in precipitation coincides with a slight decrease of 0.1% in nitrogen, whereas when the precipitation decreases from 0.7% below normal the concentration of nitrogen also decreases even if the precipitation increases from 25 to 75 % for corn.

An increase in intra-annual precipitation decreases the total forage yield by 19% and leads to an increase in its quality indicated by a high protein content and low fiber while there is a reduction in the nitrogen and protein content. due to drought [39].

The C/N ratio is not affected by precipitation, nor is the total protein concentration and the crude fiber concentration. The reduction in precipitation reduces the concentration of sodium and copper by 20% and 10.3% respectively while the other nutrients are not affected [40].

Combined effects

Combined effects of temperature and CO_2 elevation on maize

While some evidence indicates that the rise in CO_2 can compensate for the negative effect of heat on photosynthesis and plant development, some authors claim the opposite [41].

Nevertheless, it should be emphasized that the effect of the rise in CO_2 and temperature on the plant is not additive, which implies that combining the effects of these two parameters cannot be predicted from knowledge of their individual effects [42]. An increase in CO_2 at a particular temperature simulates an increase in efficiency, while an increase in temperature at a particular concentration of CO_2 causes a decrease in efficiency.

By doubling the concentration of CO_2 up to 700 ppm, a decrease of -10.5, -23.6, and -34% respectively in efficiency is observed for high temperatures of 3, 4 and 5°C [43].

The development rate of maize is located around 32°C under ambient or high CO_2 concentration and 34°C as the optimum temperature for the plant in the presence of CO_2. At 700 ppm, the DM rate is 159, 108, 104, 107 and 75 g/plant respectively for temperatures of 19, 25, 31, 35 and 38°C [44].

When the CO_2 concentration is 550 ppm and the high temperature 1.5°C, the total biomass increases as well as the mass of the samples whereas for the same concentration and a temperature of 3°C above ambient there is a decrease in the mass of the samples and in the total biomass [45].

Combined effects of precipitation with CO_2 and temperature.

The study of the combined effect of precipitation and CO_2 or with temperature has been little done. This is due to the fact that the study of the impact of precipitation is a bit tricky because this parameter is difficult to control. However, rare studies have shown that plants are more sensitive to temperature rise than to precipitation [46].

The loss in yield observed due to the rise in temperature can be compensated by precipitation. A 20% and 40% increase in rainfall can compensate for a loss caused by a rise of 2°C and 5°C respectively [47].

Due to climatic, geographical and cultural differences, there is an inconsistency in the results obtained. For example, for an increase of 1.5°C and 30% precipitation, corn yield decreases by 7% in the United States and increases by 23% in China, whereas for the same temperature and a decrease of 30% of precipitation, productivity increases by 41% in the United States and by 11% in China [48].

However, some authors argue that a 40% drop in precipitation leads to a drop in yield even if the concentration of CO_2 increases and the temperature increases by 2°C [49].

Conclusion

The use of energy crops for the production of biogas is threatened and can be slowed down by the harmful effects of climate change such as the rise in temperature and the high concentration of CO_2. These effects affect both the yield (rise in temperature) and the quality of the plant (rise in the concentration of CO_2 and temperature). The protein content which is fundamental to biogas production is negatively affected by CO_2 as well as nutrients; which is reflected in the production of biogas.

The combined effects show a non-complementarity between the parameters. The study of the effect of precipitation is a bit tricky and rare because it is a difficult parameter to study and master.

On the strength of these results and these observations, the use of other forms of substrates must be a subject of reflection or a means of enriching the plants before use in substrates because the forecasts announce a continual rise in temperature and in the concentration of CO_2.

Nevertheless, plants respond in different ways and some are less sensitive to climate change and can be considered the energy crops of the future.

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