ORIGINAL ARTICLE

# Biophysicochemical study of biodigesters fed with pig and bovine manure, in Sumapaz Province, Colombia

## Estudio biofisicoquímico de biodigestores alimentados con excretas porcinas y bovinas en la provincia Sumapaz, Colombia

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**ABSTRACT:** In recent years, the construction of biodigestion systems has been implemented, achieving effective results in economic, energy and environmental matters, where the annual production of biogas has increased to significant levels with the purpose of producing electrical and heat energy (Steyer *et al*. 2006). The work aimed to evaluate the behavior of 4 biodigesters supplied with bovine and porcine excreta and to assess the biophysicochemical quality of their biols, in Fusagasuga Municipality, Cundinamarca. Five moments of analysis of variables in the field (T, HR, pH) and sampling of tributaries, effluents from four biodigesters, located in production systems (3 pigs and 1 bovine) in Fusagasugá Municipality were performed. Samples were transported to the nutrition laboratory of University of Cundinamarca, where through instrumental analytical techniques such as potentiometric tests, gravimetry, multiparametric measurement, titration and spectrophotometry, variables like pH, total dissolved solids (TDS), electrical conductivity (EC), nitrogen, phosphorus and potassium were evaluated. Biophysicochemical indicators determined in liquid fertilizers-biols, showed slightly alkaline pH values, high EC and TDS, moderately concentrated available nitrogen and potassium contents and slightly lower phosphorus values than those reported in other similar works, which allows recommending them for use as liquid biofertilizers in moderately tolerant crops. Biogas produced in Mirador and Santa Bárbara biodigesters presented the highest concentration of methane gas, significantly exceeding ($P<0.050$) the $CH_4$ obtained in Meseta and Saucita, which can be explained by the type of substrate used (pig and bovine manure) and the weather conditions of the farms studied.

***Keywords***: Anaerobic biodigestion, biofertilizer, biomass.

**RESUMEN:** En los últimos años se ha implementado la construcción de sistemas de biodigestión, consiguiendo resultados efectivos en materia económica, energética y ambiental, donde se han incrementado la producción anual de biogás en niveles significativos con el propósito de producir energía eléctrica y calorífica (Steyer et al., 2006). El objetivo evaluar el comportamiento de 4 biodigestores abastecidos con excretas bovinas y porcinas y la calidad biofisicoquímica de sus bioles, en el municipio de Fusagasugá Cundinamarca Se realizaron cinco momentos de análisis de variables en campo (T, HR, pH) y muestreos de afluentes, efluentes provenientes de cuatro biodigestores, ubicados en sistemas productivos (3 porcinos y 1 bovino) del municipio de Fusagasugá, para ser transportados al laboratorio de nutrición de la universidad de Cundinamarca, donde por medio de técnicas analíticas instrumentales como potenciometría, gravimetría, medición multiparamétrica, titulación y espectrofotometría, se evaluaron variables: pH, sólidos totales disueltos (TDS), conductividad eléctrica (CE), nitrógeno, fósforo y potasio. Los indicadores biofisicoquímicos determinados en abonos líquidos-bioles, mostraron valores de pH ligeramente alcalinos, CE y TDS altos, contenidos de nitrógeno disponible y potasio medianamente concentrados y valores de Fósforo ligeramente inferiores a lo reportado en otros trabajos similares, lo cual permite recomendarlos para su uso como biofertilizantes líquidos en cultivos moderadamente tolerantes. El biogas producido en los biodigestores Mirador y Santa Bárbara, presentaron la mayor concentración de gas metano, superando de forma significativa ($P<0.050$) al CH4 obtenido en Meseta y Saucita, lo cual se puede explicar por el tipo de sustrato utilizado (estiércol porcino y bovino) y las condiciones climatológicas de los predios estudiados.

***Palabras clave***: Biodigestión anaeróbica, biofertilizante, biomasa.

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## INTRODUCTION

The high demand in global energy consumption and the dependence on non-renewable energy sources, as well as the associated environmental problems, require the search for new technologies and energy sources (Deepanraj *et al.*, 2015). The generation of food waste is equivalent to a third of the production for human consumption in the world, being approximately 1,300 *MMt/año* Zapata (2019);. In recent years, the construction of biodigestion systems has been implemented, achieving effective results in economic, energy and environmental matters, since they have increased the annual production of biogas at significant levels with the purpose of producing electrical and heat energy (Appels *et al.*, 2011). The clean energy alternative for livestock activities such as biogas, generated by the anaerobic biodigestion of organic waste, provides a low-cost energy alternative, increases income for producers, decentralizes energy acquisition and reduces greenhouse gas emissions, maximizing the use of resources to contribute to future production savings.

Colombia is a country with high agricultural potential with high production of organic biomass, which can be used in the generation of alternative energy. The amount of excreta produced in livestock systems can exceed 80 million tons/year and it is estimated that they can reach an energy potential of approximately 71,000 TJ/year. In systems with technology, the proper use of residual biomass could generate 864 GWh/year, equivalent to 1.3% of the national energy demand.

Electric power in Colombia depends fundamentally on hydroelectric (70%) and thermoelectric (29.3%), wasting other renewable energy sources such as livestock residual biomass, among others (López & Ruíz, 2014). According to Esquivel *et al.* (2020) the Division of Livestock, Fisheries and Aquaculture Chains (2020), an entity joined to the Ministry of Agriculture and Rural Development, since 2019, the growth of pig production systems has been 8.8% in Colombia, which indicates an increase in organic matter (excreta). Such biomass, in most cases, does not receive adequate management in agricultural facilities Medina (2013), generating contamination mainly in water sources close to the productive systems and facilitating the spread of different vectors and pathogens in optimal environments favored by the bodies of water with sewage (Cerdán, 2020).

Biodigesters emerge as an alternative technology in the agricultural and livestock field, for the treatment and anaerobic fermentation of organic matter present in food residues, vegetable waste and animal manure, susceptible to developing such a transformation. In general, biodigesters are considered as hermetic and adiabatic containers, designed with materials that allow the development of anaerobic biodigestion (BDA) by microbial populations responsible for breaking down organic matter through four fundamental stages: hydrolysis of polymers such as proteins, carbohydrates and fats, to elementary biomolecules such as peptides, amino acids, glucose and fatty acids, among others, then the acidic genesis of these biomolecules occurs, whose products are mainly organic acids such as volatile fatty acids (propionic, butyric, isobutyric and valeric acids); acetogenic bacteria develop the third stage of BDA, called acetogenesis, with the consequent production of acetic or ethanoic acid (CH3COOH), gaseous hydrogen (H2) and carbon dioxide (CO2). Finally, methanogenesis occurs, given by methanogenic bacteria, in whose phase methane (CH4) is produced by pathways: acetoclastic (cleavage of acetic acid) and hydrogenotrophic (reaction between H2 and CO2) (Deepanraj *et al.*, 2015; Nopharatana *et al.*, 2007; Ampudia, 2011; Yu *et al.*, 2013; Valladares, 2017; López y Ruíz, 2014; Orjuela, 2015). Figures 1 and 2 summarize the enzymatic biochemical reactions developed in the BA.

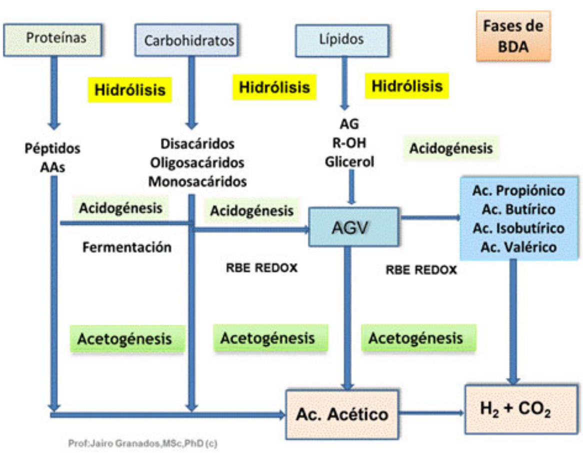


**FIGURE 1.** Early stages of anaerobic biodigestion.

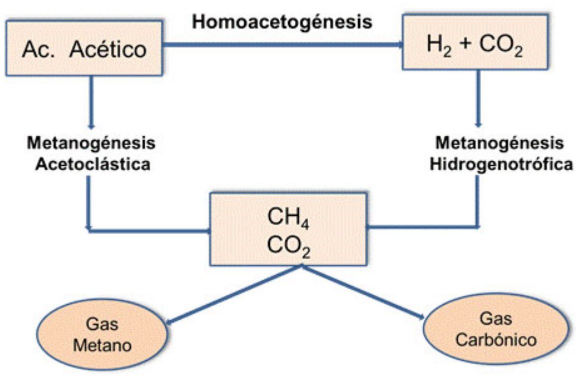


**FIGURE 2.** Methanogenic pathways in anaerobic biodigestion.

Yu *et al.* (2013) cite an alternate integral model for the generation and anaerobic pathways that degrade organic matter with associated interactions, previously developed in 1999, this simulates the co-digestion of complex wastes that have different characteristics and compositions through the main pathways. The model features enzymatic hydrolysis of undissolved carbohydrates and proteins and involves eight types of bacteria: glucose-fermenting acidogens, lipolytic bacteria, fatty acid degrading acetogens, amino acid-degrading acidogens, propionate-degrading acidogens, butyrate-degrading acidogens, valerate degradants acetogens and aceticlastic methanogens. In the case of carbohydrates, the proposed stoichiometric chemical equations for the three stages of anaerobic biodigestion are:

**Hidrólisis de polisacáridos**

$$(C_6H_{10}O_5)_{Insolubles} \longrightarrow (C_6H_{10}O_5)_{solubles} + (C_6H_{10}O_5)_{inertes}$$

**Acidogénesis**

$$(C_6H_{10}O_5)_{Solubles} = CHOS$$

$$\text{CHOS + Amoníaco} \longrightarrow \text{Biosol + Ácido acético + Ácido propiónico + Ácido butírico + gas carbónico + agua}$$

$$(C_6H_{10}O_5)_{Solubles} + 0.1115NH_3 \longrightarrow 0.1115C_5H_7NO_2 + 0.744\mathbf{CH_3COOH} + 0.50\mathbf{CH_3CH_2COOH} + 0.4409\mathbf{CH_3\text{-}(CH_2)\text{-}COOH} + 0.6909CO_2 + 0.0254H_2O$$

As shown in the equations above, the insoluble carbohydrates present in the MO of the substrate are enzymatically hydrolyzed to soluble carbohydrates (CHOS) and inert carbohydrates; subsequently, the CHOS react with ammonia, coming from protein deamination and in the presence of acidogenic bacteria, to produce organic acids: acetic (C2), propionic (C3) and butyric (C4), carbon dioxide, water and biomass residual C5H7NO2, which will constitute the so-called biosol, after this acetogenesis develops.

**Acetogénesis propiónica**

$$CH_3CH_2COOH + 1.764H_2O + 0.0458NH_3 \longrightarrow 0.0458C_5H_7NO_2 + 0.9445\mathbf{CH_3COOH} + 2.804H_2 + 0.902CO_2$$

**Acetogénesis butírica**

$$CH_3\text{-}(CH_2)\text{-}COOH + 1.7818H_2O + 0.0544NH_3 + 0.0544CO_2 \longrightarrow 0.0544C_5H_7NO_2 + 1.8909\mathbf{CH_3COOH} + 1.8909H_2$$

According to the above equations, acetogenesis indicates two pathways: propionic, through which propionic acid reacts with water and ammonia, producing biosol, acetic acid, hydrogen and carbon dioxide and then, there is butyric, where butyric acid reacts with water, ammonia and carbon dioxide, generating biosol, acetic acid and gaseous hydrogen.

Finally, methanogenic bacteria are responsible for producing the enzymatic biochemical reactions of methanogenesis, according to the following equations:

**Metanogénesis Hidrogenotrófica**

$$2.804H_2 + 0.0162NH_3 + 0.7413CO_2 \longrightarrow 0.0016C_5H_7NO_2 + 0.6604\mathbf{CH_4} + 1.45H_2O$$

**Metanogénesis Acetoclástica**

$$CH_3COOH + 0.022NH_3 \longrightarrow 0.022C_5H_7NO_2 + 0.945\mathbf{CH_4} + 0.066H_2O + 0.945CO_2$$

According to these chemical expressions, two pathways are observed through which methanogenesis develops. The first corresponds to hydrogenotrophy, in which gaseous hydrogen reacts with ammonia and carbon dioxide, generating methane gas and water, while by the acetoclastic route, the input biomolecules are: acetic acid and ammonia which, when reacting, produce biosol, methane, water and carbon dioxide.

This research analyzed the biophysicochemical effects of organic matter from pig and bovine excreta, acting as tributaries in membrane biodigesters, on anaerobic fermentation processes and characteristics of biogas and biosol (effluents), in four farms in Sumapaz Province, Colombia.

## MATERIALS AND METHODS

### Experiment Location

The installation of the biodigesters was carried out in four farms (Table 1) near Fusagasugá Municipality Cundinamarca, Colombia, with conditions of altitude: 1600 meters above sea level, average temperature: 19.1ºC, average relative humidity of 80%, annual rainfall of 140mm; the municipality is located 59 km to the southwest of Bogotá. For the execution of the research project, four properties were previously selected, as already indicated, from a total of 21 agricultural production systems surveyed and characterized. The chosen productions had the willingness of their owners, easy to moderate access to the facilities, as well as the generation of enough amount of organic matter suitable for anaerobic fermentation processes in energy production. The intervention process on the selected systems was divided into four phases: adaptation, installation, operation and data/sampling, in the field, which will be described later.

### Experimental Stage

According to Figure 3, once the first phase was executed, the biodigestion-geomembrane system was installed (Figure 4) in the indicated properties, later, data were recorded in the field (Temperature (ºC), humidity relative (%), pH, biogas outlet pressure (kPa)) and sampling (excreta and biols), which was carried out at time intervals of two weeks (15 days) for 90 days, for a total of 6 samples (Figure 5). Likewise, biogas production was evaluated in a hydropneumatic tank, by means of the water displacement method in a test tube, and the concentration of gases (CH4, CO2, H2S and NH3) was measured using a digital multiparameter gas analyzer A-ALT5X-ALK;

### Raw Material: Excreta and Sampled Biols

The pig and bovine excreta used in this experimental study were collected in the four farms described in Table 1. This biomass is a highly desirable substrate for anaerobic digestion due to its

**TABLE 1.** Selected production systems-Fusagasugá Municipality, Cundinamarca, Colombia

| Farm name | Sidewalk | Municipality | Productive purpose | Abbreviation |
|---|---|---|---|---|
| La Meseta | Bermejal | Fusagasugá | Dairy cattle | LMS |
| Santa Bárbara | Jordán Bajo | Fusagasugá | Pig farming | STB |
| El Mirador | Guayabal | Fusagasugá | Pig farming/crops | EMD |
| La Saucita | Tierra Negra | Fusagasugá | Pig farming | LST |

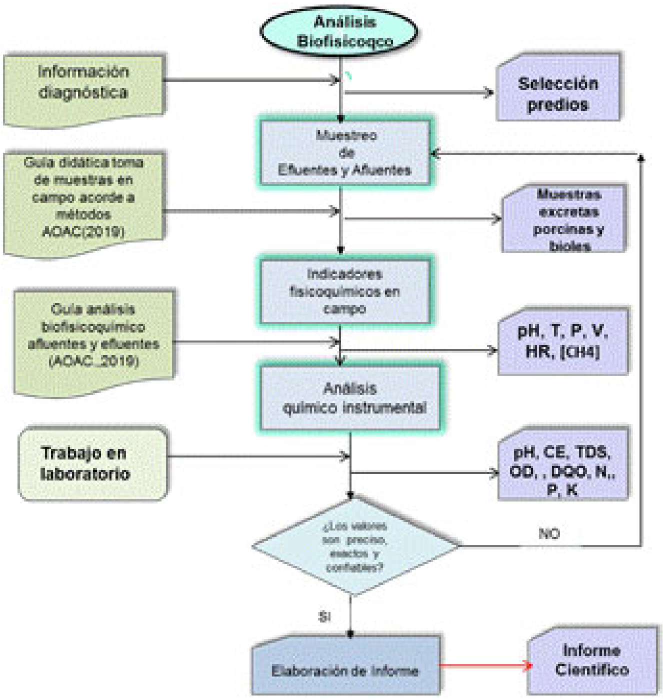


**FIGURE 3.** Stages developed to carry out biophysicochemical analysis of influents and effluents from biodigesters.


**FIGURE 4.** Membrane biodigesters evaluated in the experiment.

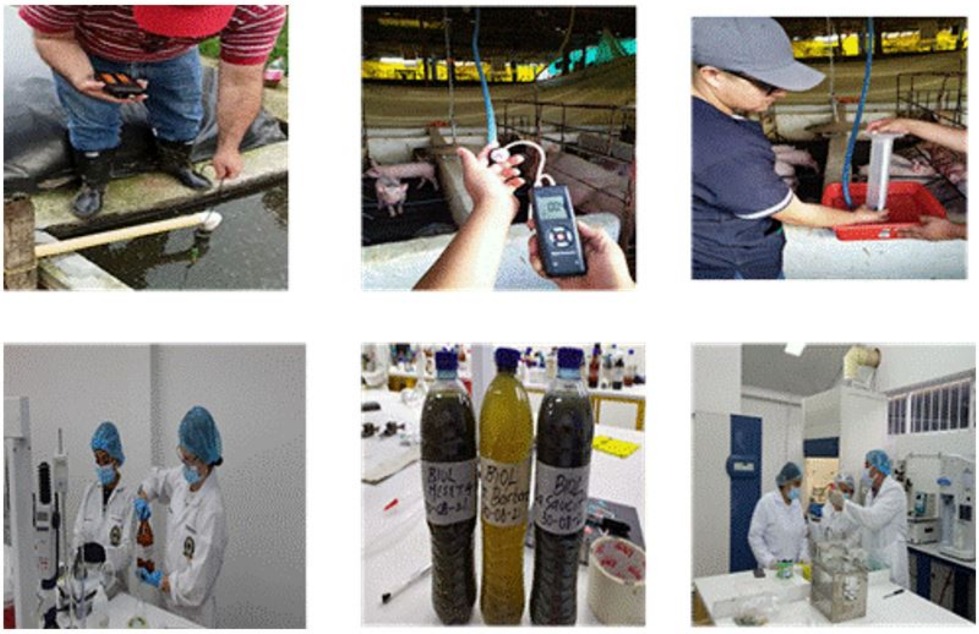

**FIGURE 5.** Field and laboratory data collection.

greater biodegradability and biogas/methane yield, due to the amount of material organic they possess. Furthermore, nutrient content analysis showed that the samples contained well-balanced nutrients for anaerobic microorganisms Appels *et al.* (2011) in Styrofoam cellars with ice and transported to the nutrition laboratories of Cundinamarca University, at Fusagasugá Campus, where they were stored in a refrigerator at 4ºC, for subsequent biophysicochemical analysis

### Biophysicochemical Analysis of Excreta and Biols

Total solids (TS) and volatile solids (SV), chemical oxygen demand (COD) of the substrate and digestate were determined according to the standard method (APHA, 1992). Total dissolved solids-TDS, electrical conductivity (EC) and pH in affluent, digestate and biols, were determined using a Hanna Instruments multiparameter meter (2019). Organic carbon (CO) was determined by the modified Walkey Black spectrophotometric method according to García & Ballesteros (2005), while $N-NO_3$ and $P-PO_4$ were found in a Hanna Instruments multiparametric photometer - HI 83399. The composition of $CH_4$ , $CO_2$, $H_2S$ and $NH_3$ in the biogas was measured using a digital multiparameter gas analyzer A-ALT5X-ALK. Biogas (Vac) and methane ($\mu CH_4$) production values were analyzed using modified Gompertz and Moned kinetic mathematical models (Nopharatana *et al.*, 2007; Pommier *et al.*, 2007; Deepanraj *et al.*, 2015).

## RESULTS AND DISCUSSION

### Physicochemical Analysis of Raw Material

The analysis of pig excreta indicated that they have a pH between 8.36 and 8.53, electrical conductivity in the range of 1.04 mS/cm to 1.85 mS/cm; total dissolved solids in the range of 0.98% to 1.33%; dissolved oxygen (3.16 g/dL-6.10 g/dL); humidity (52.54%-70.45%); organic carbon in the range of 1.89% to 2.57%; total nitrogen in the range of 1.97% to 2.98%; phosphorus (0.57ppm -0.75ppm); potassium (0.11%-0.13%) and chemical oxygen demand (55.65g/L-62.76g/L). These results are in the ranges reported by Gutierrez & Ochoa (2019), who determined the energy potential for biogas production, from the anaerobic co-digestion of rice husk co-substrate with pig excreta.

The analysis of bovine excreta showed pH between 7.70 and 7.6, electrical conductivity in the range of 1.33 mS/cm to 1.76 mS/cm; total solids in the range of 15.33% to 17.04%; dissolved oxygen (3.31 g/dL-4.00 g/dL); humidity (52.54%-70.45%); organic carbon in the range of 1.84% to 2.01%; total nitrogen in the range of: 1.77% to 1.98%; phosphorus (0.32ppm -0.92ppm), potassium (0.52%-1.05%) and chemical oxygen demand (51.76g/L-60.97g/L). The values obtained in this experiment are similar to those reported by Ampudia (2011) in an experiment that investigated the anaerobic biodigestion of agro-industrial organic waste and cattle manure.

### Behavior of Temperature-T(ºC)

The temperature averages of all the farms for each day sampled did not exhibit wide differences, nor a clear trend in relation to the days, as shown in Figure 6, the temperature at 45 days was 25.26 ± 1.26 °C being lower than that presented at 60 days with a value of 25.51 ± 1.43 °C. The highest average temperature was reached at 30 days with a value of 25.66 ± 1.51°C and the lowest at 45 days with 25.26 ±

1.26°C. The temperature variations did not present great differences, being the coefficient of variation below 10% and La Meseta property the one that presented the lowest average temperature during the entire experimental phase with 25.20 °C followed by Santa Bárbara with 25.47 °C. Although some variability was observed between the averages, the analysis of variance determined that no statistical differences were detected (P>0.050) between the biodigesters for the variable temperature.

**Relative Humidity-RH(%)**

Analyzing the graph of Figure 7, it is found that the relative humidity values of the biodigesters originating from Meseta and Saucita showed similar behavior with percentages in the range of 50 to 55, while Santa Bárbara marked a slight downward trend with data between 55 % and 60%, being higher than LMT and LST. In opposition to this, the biodigester of Mirador property indicated a tendency to increase RH from 30 days, with values that ranged from 55% to 65%.

**Biophysicochemical Quality of the Biols Obtained in the Four Biodigesters Evaluated**

Table 2 presents physicochemical values and concentration of nitrogen, phosphates, available phosphorus and potassium in the liquid fertilizers-biols studied.

When the results shown in Table 2 are analyzed, comparing them with the soil analysis interpretation table of the Agustín Codazzi-IGAC geographic institute (2017), it is deduced that the biols obtained in these four biodigesters are slightly alkaline (Pantoja Cleves & Méndez Dúarte, 2017). Regarding electrical conductivity, the LST and EMD biodigesters generated S3-type biols with high salinity, which is limiting for tolerant crops, while LMS and STB biols classified as S2 with medium salinity, also limiting for moderately tolerant crops. These values correspond to the percentages of total dissolved solids, since increasing EC also increases TDS, a similar effect occurs when EC decreases, causing a decline in dissolved solids in biols from LMS and STB.

Regarding the total nitrogen described in Table 2, it was observed that the LMS biodigester showed a biol with a high concentration of this bioelement, in contrast, EMD indicated biol with a low concentration of N, while the LST and STB biodigesters generated similar residual biomass, with medium concentration.

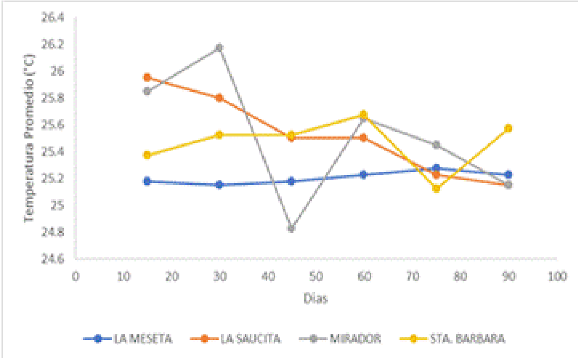


**FIGURE 6.** Behavior of temperature over time for the properties studied.

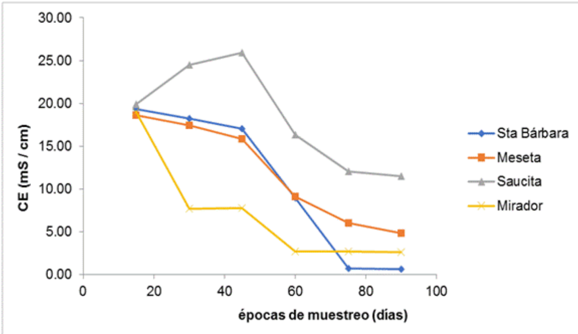


**FIGURE 7.** Behavior of the electrical conductivity of the biols obtained from the effluents of the four biodigesters evaluated.

The amount of phosphorus analyzed indicated that the biodigesters of the farms LST, LMS and STB, produced biols with a medium concentration of P, in contrast EMD showed a high concentration of this important indicator of fertilizer. In relation to the potassium content, it was highlighted that the LST biol revealed a very high concentration of K, LMS generated biol with a high concentration and the STB and EMD biodigesters originated liquid manure with medium potassium concentration. Electrical conductivity and nitrogen content of the biols evaluated in this research resulted in higher values than those reported by Acosta (2019) in a study that evaluated physical, chemical, microbiological characteristics and agronomic effectiveness of the liquid biol fertilizer obtained by anaerobic digestion of pig manure. In contrast, when comparing the concentration (ppm) of phosphate, phosphorus and potassium in the biols, it was found that what was determined by Acosta (2019) yielded higher values.

**TABLE 2.** Physicochemical indicators of liquid fertilizers-biols, from the four biodigesters evaluated

| Property | pH | CE (dS /m) | TDS (%) | N (ppm) | $PO_4^{(3-)}$ (ppm) | P(ppm) | K (ppm) |
|---|---|---|---|---|---|---|---|
| LST | 7.79 | 19.73 | 1.01 | 2300 | 51.90 | 16.70 | 1440 |
| LMS | 7.52 | 13.40 | 0.64 | 3100 | 59.03 | 19.40 | 970 |
| STB | 7.61 | 12.85 | 0.65 | 2100 | 49.20 | 15.80 | 530 |
| EMD | 7.55 | 19.05 | 0.75 | 1500 | 78.30 | 25.00 | 540 |

**Behavior of the Electrical Conductivity (CE) of the Biols Obtained in the Effluents from Sumapaz Biodigesters**

The electrical conductivity corresponds to a physicochemical variable related to the capacity of the solutions to transport and allow the flow of electrons generating electric current, therefore, the more electrolytic the solutions, the more conduction potential there will be, such property depends on the concentration and mobility of electrolytes, such as minerals (cations), salts (anions), dissociated acids and bases, which produce electron flows in aqueous solution.

Then, CE is strongly influenced by temperature, total dissolved solids (TDS), pH and concentration of salts and minerals that are present in the evaluated sample.

What is described in Figure 7, indicates that the electrical conductivity of the biols sampled in the 6 seasons, showed a marked decrease in the 4 properties evaluated, being more noticeable in Santa Bárbara and Mirador. In contrast, Meseta and Saucita behaved in a similar way, in such a way that in this last farm the maximum EC values occurred at 30 days (24.50 mS/cm) and 45 days (25.90 mS/cm), respectively. When the graph is observed in detail, it can be seen that at the beginning of the sampling (15 days) the values were similar, however, at 45 days Santa Bárbara increased the EC (25.90 mS/cm), while Santa Bárbara (17.83 mS /cm) and Meseta (15.83 mS/cm) obtained relatively intermediate values on this same sampling date. The final EC values, revised at 90 days, corresponded in ascending order as follows: Sta Bárbara (0.67 mS/cm), Mirador (2.65 mS/cm), Meseta (4.85 mS/cm) and Saucita (11.51 mS/cm).

**Behavior of the pH of Biols Obtained in Effluents from Sumapaz Biodigesters**

Taking into account that pH is a physicochemical variable related to the potential of mobilized hydrogen ions in a solution, allowing to define its acidity or basicity by virtue of the water dissociation constant (kW), the biols were examined potentiometrically to characterize this property, finding the behavior shown in Figure 8.

Observing the behavior of the pH of the biols in the six (6) sampling dates shown in Figure 8, the following can be analyzed: Santa Bárbara showed values in the range from neutral to strongly alkaline, Meseta was in the range from neutral to slightly alkaline, while Saucita and Mirador biols presented slightly alkaline pH at all sampling times. It is important to highlight the variability of the pH in the biols obtained from Santa Bárbara farm, since the values indicate a strong decrease from 8.75 to 6.75 in 75 days, ending at 7.49.

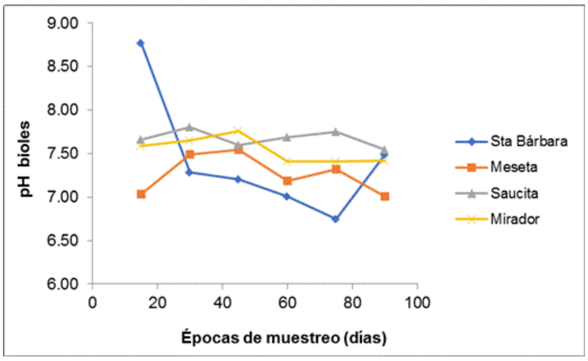


**FIGURE 8.** Behavior of pH of biols obtained from the effluents of the four biodigesters evaluated.

Based on the previous values, the pH averages were determined for the biols generated by the biodigesters of each property, obtaining that they are liquid fertilizers of a slightly alkaline type.

Figure 9 shows average values of electrical conductivity and pH of the biols sampled in each farm.

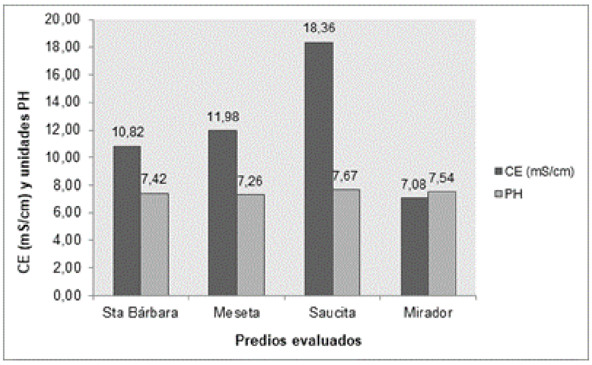


**FIGURE 9.** Average pH and EC values of biols obtained from biodigester effluents, Sumapaz region.

According to Figure 9, it can be deduced that the average EC of the biols from Saucita (18.36 mS/cm) exhibited the highest value, followed by Meseta (11.98), Santa Bárbara (10.82) and Mirador (7.08) with the EC lower, therefore, the Saucite biols presented high salinity, which can be limiting for tolerant crops. Biols from Santa Bárbara and Meseta have medium salinity that makes them limiting for moderately tolerant crops and Mirador generated biols with low salinity. In relation to the average pH, it is highlighted that the values correspond to slightly alkaline biols, as noted in previous paragraphs.

**Behavior of Total Dissolved Solids (TDS) in the Evaluated Biols, obtained at Sumapaz**

Total dissolved solids correspond to the mass (g, mg) of solids (minerals, organic and inorganic salts) that are present in a given volume of biol (1L or 100mL), thus its units can be expressed as gTDS/

100mL, equivalent to %TDS or mg TDS/L, which is the same as ppm TDS.

Figure 10 shows the behavior of the TDS values of biols obtained in effluents from Sumapaz biodigesters, in the seasons sampled.

The TDS of the biols sampled in the 6 seasons, showed a marked decrease in the 4 properties evaluated, being more noticeable in Santa Bárbara and Meseta. In contrast, Mirador and Saucita obtained TDS values higher than the others, in such a way that in the last mentioned properties, the maximum TDS data occurred at 45 days (0.98% and 1.48%), respectively. When the graphs are observed in detail, it can be seen that at the beginning of the sampling (15 days) the values were similar in Mirador, Meseta and Santa Bárbara, however, in Saucita it was notoriously higher (1.27%); the final TDS values, revised at 90 days, corresponded in ascending order as follows: Meseta (0.24%), Mirador (0.30%), Santa Bárbara (0.34%) and Saucita (0.56%). The average TDS for the biols obtained in the biodigesters of each property are indicated in Figure 11.

According to Figure 11, it can be deduced that the average TDS of the biols from Saucita (1.00%) exhibited the highest value, followed by Mirador (0.75%), Santa Bárbara (0.65%) and Meseta (0.64%) with lower TDS. Therefore, Saucite biols presented high salinity, which can be limiting for tolerant crops, while biols from Santa Bárbara and Meseta have medium salinity that makes them limiting for moderately tolerant crops.

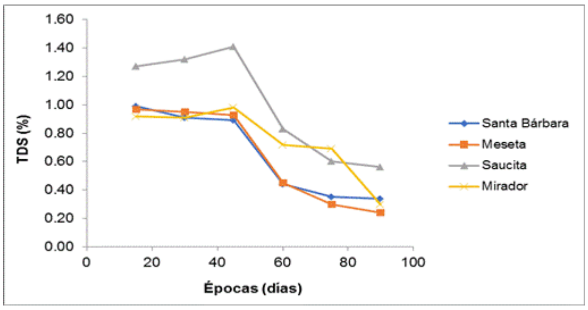


**FIGURE 10.** Average TDS values in biols obtained from biodigesters effluents in Sumapaz region.

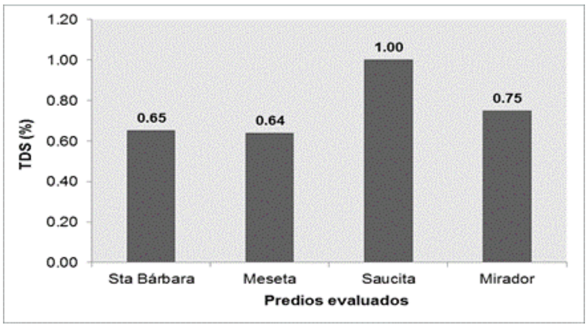


**FIGURE 11.** Average TDS values in biols obtained from biodigester effluents, Sumapaz region.

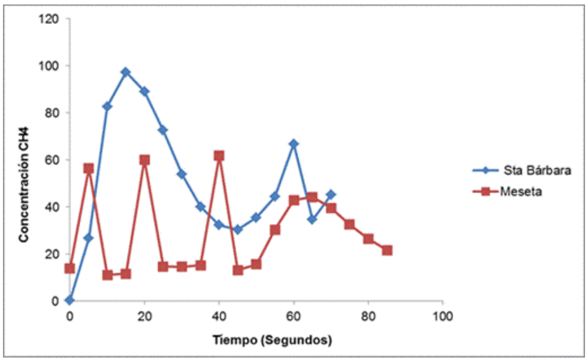


**FIGURE 12.** Methane gas concentration values evaluated in Santa Bárbara and La Meseta properties.

## Concentration of Methane Gas in the Biogas Produced in the Evaluated Biodigesters

Graph in Figure 12 shows the kinetics of methane gas in two evaluated properties, in such a way that Sta. Bárbara exhibits the highest concentration at the beginning of the measurement, generating a maximum value of 97.3 at 15 s, with a marked decrease until 33.5 in 50 s to then rise to 66.8 in 60 s and finish with a value of 45.2 at 70 s. In contrast, Meseta showed maximum values of 56.6; 60.1 and 61.9 in times of 5 s, 20 s and 40 s, respectively, with undulating behavior. Later, methane gas marks a parabolic trend with a minimum point of 21.5 in 85 s, consequently, there is a better production of methane gas in Santa Barbara farm.

Figure 13 shows comparative graphs of the kinetic behavior of methane gas in the biodigesters located on Saucita and Mirador farms.

Figure 13 shows that despite the fact that methane gas in Saucita behaved in a sustained manner with a polynomial trend, marking a maximum value of 64.6 at 30 s and a limit value of 35.3 in two min, the farm on Mirador, presented higher concentrations of methane gas in the range of 80.7 to 95.7, with marked decreases in a wave form to minimum values with a range of 19.5 to 33.8.

When the average concentration of methane gas in each farm is taken, the graph indicated in Figure 14 is obtained.

The average values presented in Figure 15 indicate that the biodigesters installed in Santa Bárbara and Mirador properties generated higher concentration and quality of methane gas, in such a way that the behavior was as follows: Mirador surpassed Santa Bárbara in 13.49, the same that to Meseta and Saucita in 34.37 and 36.9 respectively, then the biogas produced by the biodigesters implemented in these properties, was of higher quality in the viewpoint, followed by Santa Bárbara, Meseta and Saucita, determined this by the concentration of methane gas.

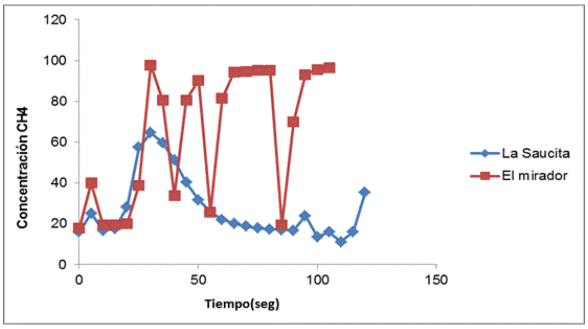


**FIGURE 13.** Methane gas concentration values evaluated in Saucita and Mirador biodigesters.

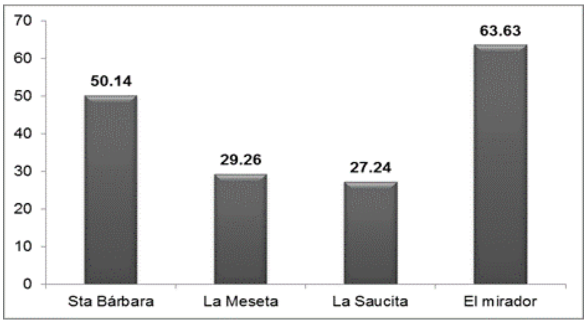


**FIGURE 14.** Average methane gas concentration in the biodigesters evaluated in Fusagasugá.

## CONCLUSIONS

- The substrates evaluated as raw material to supply the biodigesters showed appreciable differences in their composition, in such a way that, pig excreta showed higher alkalinity than bovine manure, likewise, nutrients such as CO, NT, P and K presented higher values in pig excreta, which makes them more attractive for anaerobic biodigestion.
- Variables such as temperature, pH and relative humidity, significantly affected the enzymatic biochemical reactions in the anaerobic biodigestion stages of the four biodigesters evaluated, which was evidenced in high concentrations of methane gas, specifically in Mirador and Santa Bárbara farms.
- The biophysicochemical indicators determined in liquid fertilizers-biols, obtained from the anaerobic biodigestion of the four biodigesters studied in the municipality of Fusagasugá, showed slightly alkaline pH values, high EC and TDS, moderately concentrated available nitrogen and potassium contents and phosphorus values slightly lower than those reported in other similar works, which allows them to be recommended for use as liquid biofertilizers in moderately tolerant crops.
- The kinetic behavior of physicochemical variables such as EC, TDS and pH showed downward trends over time, with logarithmic or exponential modeling, which is suggested to be analyzed in detail.
- The biogas produced in Mirador and Santa Bárbara biodigesters presented the highest concentration of methane gas, significantly exceeding ($P<0.050$) the $CH_4$ obtained in Meseta and Saucita, which can be explained by the type of substrate used (pig and bovine manure) and the weather conditions of the farms studied.

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