

Biofertilizer potential of digestates from small-scale biogas plants in the Cuban context

Potencial biofertilizante del digestato obtenido en plantas de biogás a pequeña escala en el contexto cubano.

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ARTICLE DATA

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ABSTRACT

The residual sludge from anaerobic digestion known as digestate has been used as a valuable biofertilizer, but the effect of the substrate, the configuration of the reactor and the operating parameter changes the quality and amounts of nutrients in it. Therefore, it is necessary to know its potential characteristic of fertilizer to apply it correctly in crops of national interest. The aim of this work was to characterize the digestate generated from three biodigester technologies (fixed dome, floating drum and tubular) and three substrates: swine manure, cow manure, and co-digestion of swine and cow manure obtained in the province of Sancti Spiritus, Cuba, in terms of nutrient and matter content. For this purpose, stratified statistical sampling was carried out to ensure representative samples and descriptive statistical techniques were used to process the analyses. The digestate was divided into liquid and solid fractions according to the dry matter content (15%). The content of organic matter and ash represented around 50% for both fractions, which enhances its value as a soil conditioner. The nutrient content of both fractions showed good fertilizing properties, having a nutrient ratio ($\text{NH}_4^+:\text{PO}_4^{3-}:\text{K}^+:\text{SO}_4^{2-}:\text{Mg}^{2+}:\text{Ca}^{2+}$) in the liquid (0.002:0.80:0.10:1.00:0.89:0.93) and solid (0.0003:0.96:0.002:1.00:0.52:0.50) fractions, that would contribute to the return nutrients to the soil. The quality of the liquid fraction as irrigation water was assessed as good, according to the relationship between the concentration of the nutrients (Ca, Mg, Na and K) and hardness. Further research is needed on the appropriate dosage for the different crops, and its contribution to sustainable agriculture in the Cuban context.

Keywords: biodigester; digestate; fertilizer; irrigation water; nutrient; organic matter.

RESUMEN

El lodo residual de la digestión anaerobia conocido como digestato ha sido utilizado como un valioso biofertilizante, pero el efecto del sustrato, la configuración del reactor y los parámetros operacionales cambian la calidad y las cantidades de nutrientes en él. Por lo tanto, es necesario conocer su característica potencial de fertilizante para aplicarlo correctamente en

cultivos de interés nacional. El objetivo de este trabajo fue caracterizar el digestato generado a partir de tres tecnologías de biodigestores (campana fija, campana flotante y tubular) y tres sustratos (estiércol: cerdo, vaca y codigestión de ambos) obtenidos en la provincia de Sancti Spíritus, Cuba, en términos de nutrientes y contenido de materia. Para ello, fue realizado un muestreo estadístico estratificado para asegurar muestras representativas y se usaron técnicas de estadística descriptiva para procesar los análisis. El digestato se dividió en fracciones líquidas y sólidas de acuerdo al contenido de materia seca (15%). El contenido de materia orgánica y cenizas representó alrededor del 50% en ambas fracciones, lo que mejora su valor como acondicionador del suelo. El contenido de nutrientes mostró buenas propiedades fertilizantes, con una relación de nutrientes ($\text{NH}_4^+:\text{PO}_4^{3-}:\text{K}^+:\text{SO}_4^{2-}:\text{Mg}^{2+}:\text{Ca}^{2+}$) en las fracciones líquidas (0.002: 0.80: 0.10: 1.00: 0.89: 0.93) y sólidas (0.0003: 0.96: 0.002: 1.00: 0.52: 0.50), que contribuirían al retorno de nutrientes al suelo. La calidad de la fracción líquida como agua de riego se evaluó como buena, de acuerdo con la relación entre la concentración de los nutrientes (Ca, Mg, Na y K) y la dureza. Futuras investigaciones evaluarán la dosis adecuada de digestato para los diferentes cultivos y su contribución a la agricultura sostenible en el contexto cubano.

Palabras clave: agua de riego; biodigestor; digestato; fertilizante; materia orgánica; nutriente.

INTRODUCTION

Anaerobic digestion (AD) has proven to be an economically feasible technology for the cyclic use of large-scale and small-scales organic waste (Huang *et al.*, 2016; Alkhalidi *et al.*, 2019). It is a widely used to convert organic material into energy-rich biogas and the residual sludge known digestate (Alburquerque *et al.*, 2012). Digestate can be used as a biofertilizer for arable land, enabling recirculation of plant nutrients, and thus reducing the need for fossil fuel-dependent inorganic fertilizers (Alkhalidi *et al.*, 2019). The rapid development of biogas plants in European countries has increased the recycling of waste for energy generation, while producing large quantities of digestate (Franchino *et al.*, 2016). There has been a tendency in the last decades of increased emphasis on improved sustainability in agriculture and preservation of natural resources, thus changing the focus of digestate processing from nutrient removal and disposal, to integrated nutrient recovery and recycling (Drosg *et al.*, 2015). This contributes to promoting the circular economy in the agroindustrial sector, relevant aspect at present (Suárez *et al.*, 2019). The use of digestate has great importance, especially in developing countries, not only because inorganic fertilizers are often too expensive, but also

because recycling nutrients from organic sources is essential.

The concentration variability of macronutrients, micronutrients and matter in digestate depends on substrate type, the anaerobic digestion performance and the digestate posttreatment like type of solid-liquid separation (Makádi *et al.*, 2012; Akhiar *et al.*, 2017). When digestate is obtained from different manures, the nutrient composition is greatly dependent on several factors such as digestion type (omnivore, ruminant), sex, species, age and diet of the animals, as well as the geographical and climatic conditions of the regions (Lukehurst *et al.*, 2010; Risberg *et al.*, 2017).

In Cuba, researchers have been mainly focused on the direct application of digestate on beans (Negrin Brito & Jiménez Peña 2012), tomatoes (Utria-Borges *et al.*, 2008; López Dávila *et al.*, 2017a), carrot, radish (Hernández *et al.*, 2008) and onion (López Dávila *et al.*, 2017b). These authors focused on digestate application to crops and its effect on plants. In all cases, they obtain benefits in terms of crop yield. However, very few information was found on the characteristics of the digestate applied (considering the type of biodigester and the substrate used for AD) in the Cuban context; which

leads to excessive application of nutrients in crops becoming toxic for plants. The characterization of Cuban digestate in terms of nutrient and matter contents can enable to assess it as biofertilizer and use it safely, with possible positive impacts on crop yields and reduction in the use of inorganic fertilizer. Therefore, the aim of this work is to characterize the digestate obtained in the province of Sancti Spíritus, Cuba, in terms of nutrient and matter content, considering the type of biodigester and the substrate used during AD processes. To this end, the objectives were (i) to classify the digestate in terms of liquid and solid fraction, (ii) to determine the content of matter and nutrients using classical and instrumental analytical techniques, as well as (iii) to evaluate the liquid fraction as irrigation water. The characterization of the digestate can determinate its biofertilizer potential, which has positive environmental impact due to the recirculation of nutrients from substrates considered waste and the decrease in the demand of inorganic fertilizer. Which help reduces the exploitation of natural reserves and also the high pollution that is generated in the industrial manufacture of these inorganic fertilizer.

MATERIALS AND METHODS

The methods applied to fulfill the objective of this research are described in this section. Firstly, overviews of the existing biodigester technologies in Sancti Spíritus (21°56'02"N 79°26'38"W), Cuba are briefly described. Later, the methods for the sampling procedure, the physical-chemical analysis and the characterization as irrigation water are also explained.

Biodigester technologies. The most widespread biodigesters in Cuba are: fixed dome biodigester, floating drum biodigester and tubular biodigester (Suárez-Hernández *et al.*, 2018).

Fixed dome biodigesters. Consist of a closed system, usually built of masonry and under ground

level. These biodigesters have a fixed dome-shaped cover that contains the biogas inside, an inlet to feed the substrate, and a digestate outlet that allow solid and liquid phases separation to produce digestate in both states, without mechanical process. The lack of agitation in this technology allows the solids to form flocs and precipitate to the bottom of the reactor (increasing the solid retention time), while in the compensation tank the liquid digestate comes out by overflow. The sludge, together with other non-degraded materials that precipitate, is extracted every 15 or 30 days and forms the solid digestate.

Floating drum biodigesters. are formed by a masonry cylinder in its lower part (with a stop to support the bell), and a floating bell storing the gas in the upper part. Inside the reactor, the substrate flows uniformly allowing a better contact of the microorganism and the substrate, and a higher degradation of the organic matter with respect to fixed dome biodigesters. The digestate is collected as sludge.

Tubular biodigesters. are formed by a bag resistant to environmental conditions. The substrates are fed by the inlet pipe and occupy the bottom of the bag while the upper part serves as a container for the biogas generated during the operation. Once the fed substrate has been digested, the digestate leaves the bag through the outlet pipe, coming out in the form of sludge, similar to the floating drum biodigester.

Digestate collection. The number of samples was calculated using the methodology established by Vivanco (2005) through equation 1:

$$n = \frac{NZ^2 \cdot pq}{d^2 (N-1) + Z^2 \cdot pq} \quad (1)$$

Where:

n: number of digesters to be sampled

- p : proportion of digesters in operation ($p = 0.8$)
 q : proportion of digesters out of operation ($1 - p$) ($q = 0.2$)
 N : size of the population (number of digesters)
 Z : deviation from the mean value accepted to achieve the desired level of confidence, based on the 95% confidence level, with $Z = 1.96$.
 d : level of absolute precision, referring to the amplitude of the confidence interval desired in the determination of the average value of the variable under study. This value was taken as 0.16.

Taking into account the existence of several types of digesters in the province of Sancti Spíritus and the different types of substrates, it is necessary to carry out a random stratified sampling procedure (descriptive analysis), to ensure that each technology and substrate are proportionally represented in the final sample. For that aim, equation 2 was used (Vivanco, M, 2005):

$$fh = \frac{n}{N} \quad (2)$$

Where:

fh: fraction of the stratum; n: sample size;

N: population size.

The following operating parameters: temperature range, hydraulic retention time, reactor volume, feeding substrate and methane productivity were considered in the descriptive analysis and evaluation in the equation 1 and 2.

The digestate was taken in all cases at the biodigesters outlet. The collection of samples in tubular and floating drum biodigesters was carried out by using a valve located in the lower part of the biodigesters. In the fixed dome biodigesters, the liquid and solid fractions were collected separately as the technology allows that. The liquid fraction was taken from the compensation tank, prior to the exit of the pos-treatment system (lagoons); while the solid fraction was collected from the sludge

outlet at the biodigester bottom. All samples were stored in sterile glass bottles and kept in freezing at -20°C to avoid biodegradation until their analysis.

Physical - chemical analyses. As the liquid digestate is highly colored and turbid due to the presence of suspended matter, all digestate were converted to ashes. The ashes were used for determining sodium, potassium, sulfate, phosphate, calcium and magnesium, matters content, electrical conductivity and ammonium nitrogen were determinate in fresh samples.

For the physical-chemical characterization of digestate, *The Standard Methods for the Examination of Water and Wastewater* (APHA 2012) were used. The content of dry matter (DM, %) (section 2540-B), fixed matter (ash, %) (section 2540-E) and organic matter (OM, %) (section 2540-E), were determined by gravimetric methods. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined by complexometric titration (sections 3500-Ca-B and 3500-Mg-B, respectively); Orthophosphate (section 4500- PO_4^{3-} -C) and sulfate (section 4500- SO_4^{2-} -E), by spectrophotometry; and ammonium nitrogen by (Kjendalh) (section 4500- NH_4^{+} -C). In addition, it was determined Potassium $\text{K}_2\text{O-K}$ (section 3500-K-B) and sodium $\text{Na}_2\text{O-Na}$ (section 3500-Na-B), by flame photometry, whereas the electrical conductivity (EC) were determined by conductimetry (section 2520-Salinity-B).

Characterization as irrigation water. To assess the quality of the liquid fraction of digestate as water for irrigation, the sodium adsorption ratio (SAR) (Del Valle, 1992) and the Kelly ratio (KR) (Quispe Mamani, 2016) were used (Equations 3 and 4, respectively). In addition, the relationship of both parameters with the hardness and electrical conductivity was taken into account to classify the quality of digestate as irrigation water.

$$SAR = \frac{c(Na)}{\frac{\sqrt{c(Ca)+c(Mg)}}{2}} \quad (3)$$

$$KR = \frac{c(Ca)}{c(Ca)+c(Mg)+c(Na) \times 100} \quad (4)$$

Where $c(Na)$ is the sodium concentration (meq L^{-1}), $c(Ca)$ is the calcium concentration (meq L^{-1}) and $c(Mg)$ is the magnesium concentration (meq L^{-1}).

Statistical analysis. All statistical descriptive analysis (biogas technology and substrate used frequency as well as predominant nutrient and matter contents per substrate) performed in the selection and evaluation of technologies and samples were done with SPSS software, version 23.0 (SPSS, 2013). The analyses were performed in triplicate, the central tendency and dispersion statistics (mean, standard error of the mean, and ranges) were calculated as shown in the figures and tables of the study.

RESULTS AND DISCUSSION

Digestates were collected from 20 biogas digesters (according to the results from equation 1), located 11 in Cabaiguán municipality ($22^{\circ}05'02''\text{N } 79^{\circ}29'43''\text{W}$) and 9 in Banao town ($21^{\circ}82'86''\text{N } 79^{\circ}56'86''\text{W}$). To ensure representative samples, three strata were formed in accordance with the type of biogas digester (Table 1), which consists of 13 fixed dome, 1 floating

drum and 6 tubular biogas digesters, (according to equation 2). In addition, in accordance with the type of substrates, three strata were also considered consisting of 13 swine manure (SM), 2 cow manure (CM) and 5 codigestion of swine and cow manure (SCM) (equation 2).

Table 1 shows, the operating parameters: temperature range (mesophilic) and hydraulic retention time (HRT) (15–50 days), were equal for all plants; while reactor volume ($1.8\text{--}50 \text{ m}^3$) and feeding ($2\text{--}4 \text{ kg of volatile solid/day/m}^3$) were different. The methane productivity of all plants was $0.5 \text{ m}^3 \text{ reactor/day}$.

As 50% of the digestate produced in Sancti Spiritus, corresponds to fixed dome biogas digesters treating SM, they were the higher strata (13 biogas digesters). This can be attributed to the decentralized pig production in Cuba, the necessity for SM treatment in situ and the high dissemination of fixed dome biogas digesters (Sosa *et al.*, 2014). For that reason, this substrate and this technology were chosen for a more detailed analysis in the present study.

Digestate characterization

Dry matter. The content of dry matter (DM), organic matter (OM) and ash for SM digestate (solid and liquid fractions) obtained from fixed dome biogas digesters is shown in Figure 1.

Table 1. Operating parameters and methane productivity for small-scale biogas digesters which produced the digestates studied.

Biogas digesters types	Reactor Volume (m^3)	Temperature range	Feeding (kg/day/m^3)	HRT (days)	Methane productivity ($\text{m}^3 \text{ reactor/day}$)
Fixed dome	20-50	Mesophilic	2	15-50	0.5
Floating drum	1,5	Mesophilic	2	15-50	0.5
Tubular	3	Mesophilic	2-4	15-50	0.5

HRT: hydraulic retention time.

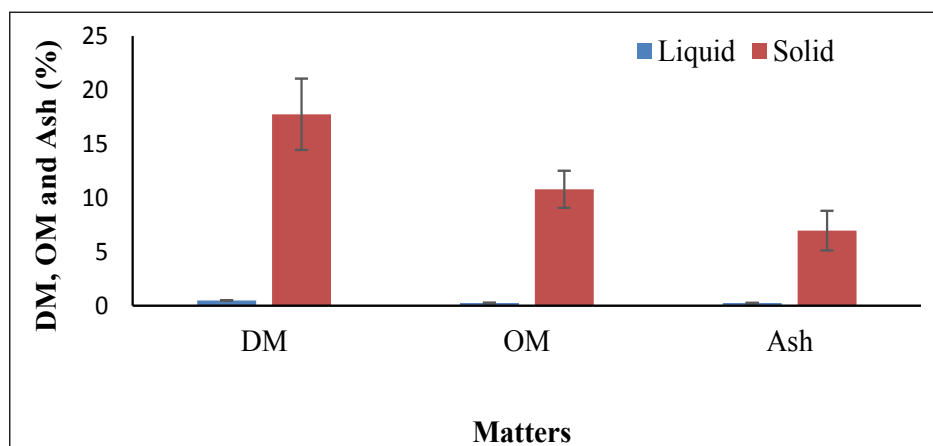


Figure 1. Contents of dry matter (DM), organic matter (OM) and ash in swine manure (SM) digestate (solid and liquid fractions) obtained from fixed dome biodigesters. The bars indicate the standard deviation.

The solid fraction of the digestate showed a DM content of $17.77 \pm 3.30\%$ (Figure 1), being considered as a solid digestate, following the approach of Makádi *et al.* (2012), who suggested this classification for DM content in digestate above 15%. For that reason, SM digestate (solid fraction) obtained from fixed dome biodigesters can be considered as biofertilizer rich in stable and fibrous material which should have a positive effect on soils by minimizing erosion and improving water-holding capacity and soil structure, especially when they are used on sandy soils (Bermejo *et al.*, 2010). The liquid fraction of this digestate presented a very low DM content (average $0.48 \pm 0.03\%$), due to the large dilution of the SM occurring when more than 40 L of water per animal head are used during the cleaning of piggeries (Sosa *et al.*, 2014).

Organic matter. The efficiency of OM conversion through mesophilic (i.e. 35°C) or thermophilic (i.e. 55°C) AD is generally in the range of 13–65%, and depends on the type of substrate fed to the biodigester, as well as on anaerobic reactor parameters, such as the Organic Loading Rate (OLR) and the HRT (Menardo *et al.*, 2011). In the solid and liquid fractions of the SM digestate, OM represented more than 50% of DM, agreeing

with the values reported by Marcato *et al.* (2008). These high OM values can be attributed to several aspects: 1) the high OLR and short HRT applied to fixed dome biodigesters in piggeries; as the number of pigs increases during the time for the same biodigester volume; and 2) the low removal efficiency ($<50\%$) of organic matter reported for fixed dome biodigesters due to its cylindrical shape that does not ensure a uniform path of the substrate inside the biodigester (Montalvo and Guerrero, 2003).

These aspects induce a rise of the more recalcitrant molecules in digestates, such as lignin, cutin, humic acids, steroids, complex proteins. These non-degraded stable carbon compounds are beneficial for the soil, being potential humus precursors with high biological stability (Kalakodio *et al.*, 2017; Diacono *et al.*, 2019). This allows increase fertility, functionality, microbial activity, aeration, and water storage capacity in the soil (Kalakodio *et al.*, 2017).

Ash. The ash content in the solid and liquid fractions was 39% and 50%, respectively. During AD, organic compounds are broken down by bacteria resulting in the production of methane and

carbon dioxide. Thus, as a result of the digestion process, a number of changes in the solid content can be expected; including a substantial reduction (up to 25%) in the total solids and a consequent increase in the ash content (as %DM), due to the conservation of minerals and the organic matter removal (Fageria and Moreira, 2011).

Matter content of the remaining digestates. A summary of DM, OM and Ash for the remaining digestates available in Sancti Spíritus is provided in Appendix A. The DM content of the digestate solid fraction obtained from fixed dome biodigester during the treatment of SCM, rendered similar values ($17.50 \pm 1.89\%$) with respect to fixed dome biodigester using SM only. However, a lower DM content was obtained in tubular and floating drum biodigesters ($7.08 \pm 0.10\%$ and $4.42 \pm 0.20\%$, respectively) treating CM. Tubular biodigesters using SM and SCM reported a DM content of $1.02 \pm 0.03\%$ and $6.10 \pm 0.30\%$, respectively. Organic matter and ash represented from 40-50% and from 20-40% of DM, respectively. These values make the digestates available in Sancti Spiritus, a suitable soil amendment, based on its matter content.

Nutrient content. Figure 2 shows the nutrient content of SM digestate in term of nitrogen ($\text{NH}_4^+\text{-N}$),

phosphorous ($\text{PO}_4^{3-}\text{-P}$), sulfates ($\text{SO}_4^{2-}\text{-S}$), calcium ($\text{Ca}^{2+}\text{-Ca}$), magnesium ($\text{Mg}^{2+}\text{-Mg}$) and potassium ($\text{K}^+\text{-K}$) concentrations ($\text{g kg}^{-1}\text{DM}$).

Nitrogen. The $\text{NH}_4^+\text{-N}$ concentration in biofertilizers is of great importance as it is immediately available to the plant. The concentrations of $\text{NH}_4^+\text{-N}$ in the liquid and solid fractions were 0.06 ± 0.00 and $0.01 \pm 0.00 \text{ g NH}_4^+ \text{ kg}^{-1} \text{ DM}$, respectively. The N content of the digestate was a consequence of its preservation during AD (Tambone *et al.*, 2010; Drosch *et al.*, 2015). During organic matter degradation, part of the organically bound nitrogen is reduced to the NH_4 form, (Kuusik *et al.*, 2017). The $\text{NH}_4^+\text{-N}$ is concentrated in the digestate by the degradation of the proteins available in the fed substrate (Kryvoruchko *et al.*, 2009). Typically, pigs include a high protein content in their diet (e.g., animal feed, food waste and slaughterhouse waste), as part of these proteins are not assimilated by the pigs, being expelled in the excreta; they are degraded to NH_4^+ during the AD process and released in the liquid digestate mainly.

For that reason, values between 1.00 and 1.80g of $\text{NH}_4^+ \text{ kg}^{-1} \text{ DM}$ has been considered as typical for the liquid digestate obtained from biogas plants treating SM (Rossi and Mantovi, 2012; Tigini

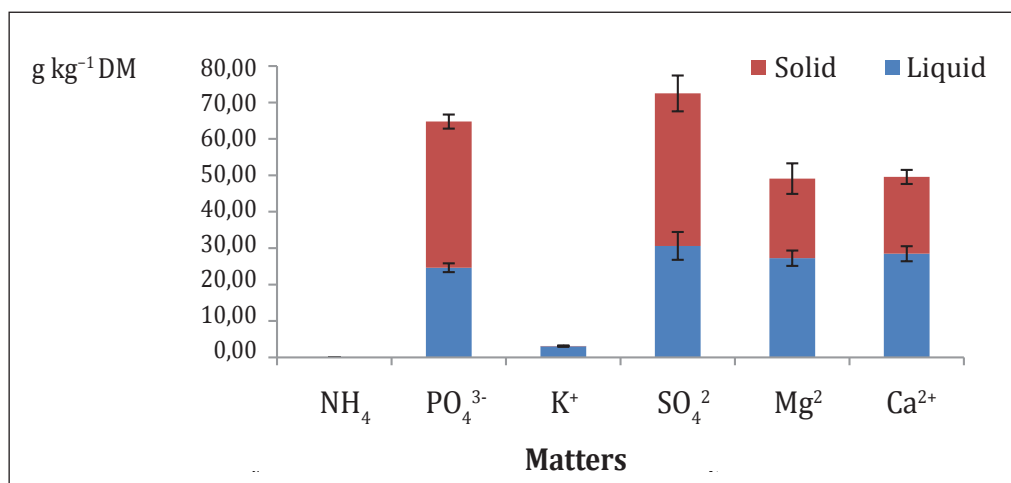


Figure 2. Nutrient content expressed in g per kg of dry matter (DM), in the swine manure (SM) digestate (solid and liquid fractions). The bars indicate the standard deviation.

et al., 2016). However, in this study the $\text{NH}_4^+\text{-N}$ concentration in the liquid fraction was $0.06 \text{ g of } \text{NH}_4^+ \text{ kg}^{-1} \text{ DM}$, being 60% of the typical values reported (Rossi and Mantovi, 2012; Tigrini *et al.*, 2016). The higher concentration of N for the liquid fraction with respect to the solid fraction, agreed with Tampio, Marttinen and Rintala (2016), who stated that solid-liquid separation is increasing in application during digestate treatment for the extraction of nitrogen from the liquid fraction.

Phosphorous. The phosphorus content of digestate is expressed as total phosphorus or as phosphate equivalents. The AD process does not affect the content of phosphate in digestate, which is mostly dependent on the content in the substrate (Drosg *et al.*, 2015). The concentration of $\text{PO}_4^{3-}\text{-P}$ obtained in this study for the liquid fraction digestate, was $14.63 \pm 1.20 \text{ g kg}^{-1} \text{ DM}$, agreeing with the values reported in Albuquerque *et al.* (2012), being 7 times higher than the values ($1 \text{ to } 2 \text{ g } \text{PO}_4^{3-} \text{ kg}^{-1} \text{ DM}$) reported by Rossi and Mantovi (2012).

The concentration of $\text{PO}_4^{3-}\text{-P}$ for the solid fraction digestate was $40.14 \pm 1.93 \text{ g kg}^{-1} \text{ DM}$, showing that phosphorous is mainly accumulated in the solid fraction of digestates, which agree with the values reported by Tampio *et al.* (2016) (Figure 2). Phosphates are a limited non-renewable resource, which is as an essential plant nutrient that cannot be replaced by other substances (Shepherd *et al.*, 2016). Therefore, the use of this digestate for the Cuban agriculture can generate economic and environmental benefits, by substituting P-rich commercial biofertilizers; which is of prime importance in the recycling of limiting nutrients like phosphorous.

Potassium. Potassium concentrations of $0.09 \pm 0.00 \text{ g kg}^{-1}$ and $3.06 \pm 0.17 \text{ g kg}^{-1} \text{ DM}$ were obtained for the solid and liquid fractions of the

digestate, respectively. Albuquerque *et al.* (2012) reported values from 50 to 1000 times higher for the liquid and solid fractions, respectively. As potassium degradation during AD is negligible, the differences found in potassium concentration can be attributed to the pig diet in the different regions. For example, pigs Cuban farms eats cereals but also home-made food such as cassava and sweet potato yogurt (Almaguel *et al.*, 2016) castrated males and females in equal proportion of 85 days old with an average initial weight of 30.0 kg. The pigs were distributed according to a random blocks design in four experimental treatments and 12 replicates per treatment (position inside the pen).

Sulfates. A high sulfate concentration of the solid and liquid fractions was observed, with average concentrations of 41.89 ± 4.92 and $30.61 \pm 3.82 \text{ g kg}^{-1} \text{ DM}$, respectively (Figure 2). These values were similar to those reported by Chen *et al.* (2010), who states that this is also related to the proteins consumption in the pigs diet.

Calcium and Magnesium. In the solid and liquid fractions, the Ca:Mg ratio was around 1:1; being these values lower than those reported by (Negrin Brito and Jiménez Peña, 2012) for a digestate obtained from the AD of agricultural waste and manure (88 Ca% and 12 Mg%DM). A further discussion will be provided in the next section about Ca and Mg concentrations in the liquid fraction of the SM digestate.

In general, AD enables the attainment of a final product (digestate) with good fertilizing properties, having a nutrient ratio ($\text{NH}_4^+:\text{PO}_4^{3-}:\text{K}^+:\text{SO}_4^{2-}:\text{Mg}^{2+}:\text{Ca}^{2+}$) in the liquid ($0.002:0.80:0.10:1.00:0.89:0.93$) and solid ($0.0003:0.96:0.002:1.00:0.52:0.50$) fractions, that would contribute to return macronutrients to the soil after AD of SM. A summary of the nutrient content for the digestates available in Sancti Spíritus is provided in Table 2.

Table 2. Nutrient and matter content of the digestate taken from fixed dome, tubular and floating drum digesters when using different substrates (n=3).

Characteristic	Fixed dome				Tubular		Floating drum	
	SM		SCM		SCM		CM	
	Liquid	Solid	Liquid	Solid	Liquid		CM	
DM (%)	0.48 ± 0.03	17.77 ± 3.30	0.55 ± 0.01	17.50 ± 1.89	1.02 ± 0.03	6.10 ± 0.30	7.08 ± 0.01	4.42 ± 0.02
OM (%)	0.24 ± 0.04	10.78 ± 1.72	0.17 ± 0.01	11.69 ± 0.82	0.58 ± 0.07	2.39 ± 0.17	4.99 ± 0.76	3.05 ± 0.42
Ash (%)	0.24 ± 0.03	6.96 ± 1.84	0.18 ± 0.01	5.48 ± 0.57	0.43 ± 0.05	1.20 ± 0.19	2.09 ± 0.23	1.37 ± 0.01
NH ₄ ⁺ - N (g kg ⁻¹ DM)	0.06 ± 0.00	0.01 ± 0.00	0.04 ± 0.00	0.003 ± 0.00	0.04 ± 0.00	0.002 ± 0.00	0.003 ± 0.00	0.001 ± 0.00
PO ₄ ³⁻ -P (g kg ⁻¹ DM)	24.63 ± 1.20	40.14 ± 1.93	11.93 ± 0.81	17.03 ± 0.34	13.29 ± 1.32	7.23 ± 0.22	6.64 ± 0.02	12 ± 0.06
K ⁺ - K (g kg ⁻¹ DM)	3.06 ± 0.17	0.09 ± 0.00	2.65 ± 0.31	0.06 ± 0.02	1.45 ± 0.27	0.25 ± 0.02	0.16 ± 0.01	0.36 ± 0.16
SO ₄ ²⁻ -S (g kg ⁻¹ DM)	30.61 ± 3.82	41.89 ± 4.92	18.67 ± 1.51	45.00 ± 1.29	29.92 ± 1.55	68.13 ± 4.80	12.82 ± 0.02	56.32 ± 0.23
Ca ²⁺ - Ca (g kg ⁻¹ DM)	28.47 ± 2.06	21.09 ± 1.94	18.50 ± 1.70	31.54 ± 2.83	15.82 ± 1.68	4.47 ± 0.30	12.23 ± 0.15	7.80 ± 0.26
Mg ²⁺ - Mg (g kg ⁻¹ DM)	27.24 ± 2.10	21.87 ± 4.42	20.27 ± 1.00	7.79 ± 1.08	10.74 ± 0.93	1.27 ± 0.38	5.51 ± 0.17	4.48 ± 0.21
pH	7.30 ± 0.02	7.34 ± 0.03	7.24 ± 0.21	7.49 ± 0.29	7.20 ± 0.09	7.11 ± 0.08	7.18 ± 0.08	7.09 ± 0.01
EC (μS cm ⁻¹)	1.04 ± 0.01	1.31 ± 0.02	1.15 ± 0.04	1.05 ± 0.04	1.37 ± 0.09	1.46 ± 0.11	1.33 ± 0.01	1.47 ± 0.01

SM: swine manure, CM: cow manure, SCM: Co-digestion of swine and cow manure, DM: Dry matter, OM: Organic matter, EC: Electrical conductivity.

Liquid fraction of digestate as irrigation water. The liquid fraction generated from SM was assessed as water for irrigation based on its content of interchangeable ions, EC and hardness. Table 3 shows the experimental measurements, the calculations of these parameters and their acceptance criteria.

SAR and KR were calculated according to equations described by Del Valle (1992) and Quispe Mamani (2016), respectively. The SAR value was 0.03 for the liquid digestate, indicating its low sodification power. In general, the higher the SAR, the less suitable the water is for irrigation (Aboukarima *et al.*, 2018) in the order $305 > 240 > 137 > 104 > 65$ mm/h for SAR of 3.34, 3.52, 4.14, 4.18, and 7.60, respectively. The results showed that 180 min after the initial time of measurement in the sandy-loam soil, the final infiltration rates were in the range of 21.1–44.0 mm/h for the different qualities of water considered in this study, with an average value of 33.8 mm/h. Hence, the infiltration rate is sensitive to the SAR of the applied water. The final infiltration rate (IRf). That is either diminish the soil permeability, reducing the formation of crusts that can modify the physical-chemical properties of the soil with the consequent deterioration of the crop yield (Lesch and Suarez, 2009). Moreover, the KR value for the liquid digestate (<28%) was lower than

the optimum value (higher than 35%) for plant growing (Quispe Mamani, 2016), because of the higher proportion of Mg with respect to Ca, and the low contribution of Na concentration (see Eq. 4). In terms of hardness, the digestate was considered as very hard water (78.5°F) because its values were higher than the acceptance criterion of 54°F.

According to the diagram for the interpretation of the irrigation water value (Riverside Standards) (Olías *et al.*, 2005), digestate was classified as C3S1. That is, digestate has highly saline waters ($EC\ 1320\ \mu S\ cm^{-1}$); therefore, there must be good drainage conditions, salinity must be controlled and only plants that are resistant to salinity should be cultivated. On the other hand, it presents a low alkalization hazard ($SAR=0.03$), so it can be used without serious damage to plant development.

Besides, according to the Wilcox Standard (Olías *et al.*, 2005), which takes into account the percentage of Na over the other cations (Ca, Mg and K) and the EC, it was obtained that the digestate of Sancti Spiritus is in the category from “good” to “admissible”, representing a potential alternative to increase agriculture sustainability in the Cuban context. Further studies are needed on the appropriate dosage for the different crops.

Table 3. Evaluation of swine manure liquid fraction digestate as water irrigation.

Parameters	EC ($\mu S \cdot cm^{-1}$)	Hardness (°F)	SAR	KR (%)
Liquid digestate	1320.00	78.50	0.03	28.22
Acceptance requirements	< 750 Excellent 750 – 3000 Good >3000 Unacceptable	0-22 Sweet 32-54 Hard > 54 Very hard	< 10 Optimum	> 35 Optimum

SAR: Sodium Adsorption Ratio, KR: Kelly's ratio, EC: Electrical conductivity.

CONCLUSION

The digestates obtained in biodigesters in the province of Sancti Spiritus, Cuba were characterized in terms of nutrient and matter content. Most of the digestate samples (50%) were taken from fixed dome biodigesters treating SM because they were widely available in Sancti Spiritus.

The highest dry matter content (DM) was obtained for the solid digestate sampled from fixed dome biodigesters, with values above 17%, being considered as stable and fibrous material which should have a positive effect on soils, by minimizing erosion and improving water-holding capacity and soil structure.

The nutrient content of both digestates showed good fertilizing properties, having a nutrient ratio ($\text{NH}_4^+:\text{PO}_4^{3-}:\text{K}^+:\text{SO}_4^{2-}:\text{Mg}^{2+}:\text{Ca}^{2+}$) in the liquid (0.002:0.80:0.10:1.00: 0.89:0.93) and solid (0.000 3:0.96:0.002:1.00:0.52:0.50) fractions, that would contribute to the return of organic matter and nutrients to the soil in a short-term period.

Swain manure treated in fixe dome biodigester was the one that produced the most nutrient-rich digestate, therefore, it was the one with the highest biofertilizing potential.

The quality of the liquid fraction as irrigation water was assessed as good, according to the relationship between the concentration of the nutrients (Ca, Mg, Na and K) and hardness, agreeing with the water classification for irrigation of the Wilcox and Riverside standards.

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