ORIGINAL ARTICLE

https://cu-id.com/2177/v31n4e01

Dimensioning and Energy Potential of Biodigesters Installed in Productive Systems in the Department of Cundinamarca, Colombia

Dimensionamiento y potencial energético de biodigestores instalados en sistemas productivos del Departamento de Cundinamarca, Colombia

Yanoy Morejón Mesa[I*], **Vilma Moreno Melo**[II], **Andrés Mogollón Reina**[II]

[I]Universidad Agraria de La Habana, Facultad de Ciencias Técnicas, San José de las Lajas, Mayabeque, Cuba.
[II]Universidad de Cundinamarca, Facultad de Ciencias Agropecuarias, Sede Fusagasugá, Cundinamarca, Sumapaz, Colombia.

ABSTRACT: This research is oriented towards determining the size and energy potential of a system of biodigesters installed in six livestock production systems, which are in the provinces of Sumapaz and Ubaté, in Cundinamarca Department, Colombia. Thus, the existing animal species in the scenario are determined, since they will contribute organic waste to the biodigester; the number of animals is also determined, considering the herd movement, which would make it possible to determine the biomass generated daily with the purpose of establishing the sizing of the appropriate biodigester technology and to know the behavior of the energy parameters. Among the main results obtained, it was evidenced that the biomass generated daily was not considered for the dimensioning and establishment of the polyethylene tubular biodigesters. In addition, the biodigesters installed in the production systems at La Meseta and El Tibar are oversized by 4,8 and 1,6 times, respectively; aspect that evidences the need to increase the daily biomass generated, which is achievable by increasing of animals in the herd. The biodigesters installed in the production systems at Santa Bárbara, El Mirador, La Saucita and La Esperanza, demonstrate an under-sizing, with inferiority values of 2,9; 1,97; 1,49; 2,04 times. These results indicate that, in these scenarios, the total number of animals used for biomass production is greater than that required with respect to the installed biodigester or that the installed biodigesters cannot take advantage of the biomass generated daily.

Keywords: Renewable Energy, Livestock Production, Anaerobic Digestion, Energy Feasibility, Environmental Impact.

RESUMEN: La presente investigación se orienta en la determinación del dimensionamiento y potencial energético de un sistema de biodigestores instalados en seis sistemas de producción ganadera, los cuales se localizan en las provincias Sumapaz y Ubaté, Departamento de Cundinamarca, Colombia. Para ello se determina la especie animal existente en el escenario, dado que aportará los residuos orgánicos hacia el biodigestor, también se determina la cantidad de animales, considerándose el movimiento de rebaño, lo cual posibilitaría determinar la biomasa generada diariamente con el propósito de establecer el dimensionamiento de la tecnología de biodigestor adecuada y conocer el comportamiento de los parámetros energéticos. Entre los principales resultados obtenidos, se evidenció que en ninguno de los sistemas de producción se consideró la biomasa generada diariamente para el establecimiento de los biodigestores tubulares de polietileno sobre la base de su dimensionamiento, que los biodigestores instalados en los sistemas de producción: La Meseta y El Tibar, están sobredimensionados en 4,8 y 1,6 veces, respectivamente; aspecto que evidencia la necesidad de incrementar la biomasa diaria generada, lo cual es lograble con el aumento de animales en los rebaños; en cambio los biodigestores instalados en los sistemas de producción: Santa Bárbara, El Mirador, La Saucita y La Esperanza, evidencian un sub-dimensionamiento, con valores de inferioridad de: 2,9; 1,97; 1,49; 2,04 veces; estos resultados indican que, en estos escenarios, la cantidad de animales empleados para la producción de biomasa es superior a la requerida respecto al biodigestor instalado o que los biodigestores instalados no pueden aprovechar la biomasa generada diariamente.

Palabras clave: energía renovable, producción ganadera, digestión anaerobia, factibilidad energética, impacto ambiental.

*Author for correspondence: Yanoy Morejón Mesa, e-mail: ymorejon83@gmail.com o ymm@unah.edu.cu

Received: 26/04/2022

Accepted: 14/09/2022

INTRODUCTION

Currently, it is necessary to take advantage of renewable energy sources based on the best use of local resources which, through the best use of appropriate technologies, contribute to save conventional fuel and serve to return the soil the nutrients it needs and preserve the environment from pollution (Santos *et al.*, 2012).

Anaerobic digestion is a good alternative to treat waste with high biodegradable organic matter (Flotats *et al.*, 2001; Sosa, 2017). Therefore, according to Suárez *et al.* (2018), this treatment is indicated for agro-industrial wastewater, with a high load of biodegradable organic matter discharges from the production of sugar, alcohol, meat, paper, preserves and distilleries according to Rahayu *et al.* (2015). Anaerobic digestion is also indicated to treat agricultural residues, such as slurry and manure according to Bansal *et al.* (2017), and urban waste that includes both the organic fraction of solid waste according to Biogas Association Ottawa (2015) and urban wastewater treatment plant sludge (Frankiewicz, 2015).

Precisely, the biodigester is an anthropogenically produced (produced by human activity) technology to highlight in the biotechnological process of anaerobic digestion of biomass to obtain biogas. It is a hermetic reactor with a side inlet for organic matter, an outlet at the top through which biogas flows, and an outlet to obtain effluents with biofertilizing properties, both products contribute to meeting the needs of producers and to promote organic agriculture, as an economically feasible and ecologically sustainable alternative (Zheng *et al.*, 2012).

To these aspects, it should be added the high prices of fuels and the high local rates of electricity, being factors to consider for the introduction of biodigesters or biogas plants at the national and regional level that produce energy from the use of waste of agricultural production (Parra *et al.*, 2019).

Considering the criteria described above, in different production systems located in the department of Cundinamarca, Colombia, a set of biodigesters were installed with the aim of producing biogas and biofertilizers, towards which the objective of the present investigation was oriented in determining the sizing and the energetic potentialities of the use of this technology for each productive system studied.

MATERIALS AND METHODS

Characterization of Experimental Areas

The research was carried out in six livestock production systems, four of them belonging to private producers and two to the University of Cundinamarca. Of these systems, five are located in the Sumapaz Province and one in the Ubaté Province. In all scenarios, Biodigesters with different capacities were installed with the aim of producing biogas and biofertilizers.

The diet of this pig herd was composed of concentrated flour feed, made with raw materials such as American corn, soybean cake, palm oil, wheat byproducts, molasses, calcium carbonate and Nuclei (commercial amino acids with vitamins) and in the case of cattle, their diet was basically made up of pastures and forages.

According to Cardona (2012), the most common and used grasses in Colombia, in the low tropics, are angleton, pangola and bracharias grasses depending on soil fertility and acidity, while for the high tropics the most common are kikuyu, ryegrass, orchard grass and canary-grass. Pastures in the low tropics are rich in energy, therefore, the supplement that should be given to the animal must be rich in protein, while, in the high tropics, the forages contain more protein for which it is necessary to opt for products with high energy content.

Native grasses in general terms have low nutritional value and do not provide the amount of adequate nutrients to maintain sustained production in cattle farms. In this situation, the producer, in order to continue producing (milk), would have to complement the forage deficiencies with the use of feeds that provide protein to the cattle, such as soybean paste, flour, fish or alfalfa meal, which are products that have high prices in the market, but that are essential to obtain good production of meat and/or milk, so it is necessary to look for other alternative sources that allow maintaining production at a reasonable cost (Bonilla *et al.*, 2014).

The quality and quantity of forage during the summer season in the low and high tropics is drastically reduced, causing a decrease in milk production, hence, farmers have decided to implement strategies using supplements. In the case of the low tropics, they are choosing to use forage crops such as silage to reduce production costs of forage crops and increase milk production in the dry season by 15%, resulting in greater profitability and competitiveness of dual-purpose systems (Castro *et al.*, 2016). While in the high tropics, golden fodder oats are being used because they are ideal for farms located between 2,200 and 3,000 meters above sea level, offering cattle the energy they need to withstand the dry season (Villegas & Llanos, 2014).

Another way managed by ranchers to increase the productivity of the cattle herd is to use the paddock rotation grazing system, which is based on adequately alternating the period of using with the rest time of the paddock, allowing the forage of each paddock has a recovery period and natural reseeding increasing forage production to facilitate weed control (Ruiz, 2013).

Regarding the behavior of climatic variables, in the case of Sumapaz Province, the behavior of temperature and humidity varies depending on the time of year, obtaining the following values according to climate variability: in warm climate: 24 °C to 28 °C (9,21%), in temperate climate: 18 °C to 23 °C (54%), in cold climate: 12 °C to 18 °C (32,2%) and in the case of Ubaté Province, the warm season lasts 3,7 months (December - April), and the average daily high temperature is over 19°C. The warmest month of the year in Ubaté is May, with an average maximum temperature of 18 °C and a minimum of 10 °C. The cool season lasts 2.4 months, (June-September), and the average daily maximum temperature is less than 18 °C. The coldest month of the year in Ubaté is January, with an average minimum temperature of 7 °C and a maximum of 19 °C, the relative humidity ranges between 75…90% throughout the year.

Methodology for Dimensioning and Installation of Polyethylene Tubular Biodigesters

To calculate the design parameters of a tubular polyethylene biodigester, it is necessary to know the input data, and those that must be determined (Table 2).

The daily amount of material (Bmd) is directly related to the amount of biomass that is generated, whether it is domestic, agricultural or animal waste. In addition, the maximum amount obtained, and the production increase plans must be considered.

The amount of daily biomass generated (Bmd), is determined through the following expression:

$$Bm_d = Ca \times Ce \times Rp \times Rt, kgday^{-1}$$

where: Ca- Number of animals; Ce-Amount of excreta per animal, kg/day; Rp- Ratio between the average live weight of the animal population and the tabulated equivalent live weight; Rt- Fraction between the stabling time with respect to the duration of the day, h/day

$$Bm_d = Ca \times Ce \times \left(\frac{PVp}{PVe}\right) \times \left(\frac{Te}{24h}\right), kg \cdot day^{-1}$$

where:

PVp-Average live weight of the animal population, kg; PVe- Tabulated live weight equivalent; Te-Hours of the day that the animal remains stabled, h/day

The daily volume of material (mixture of manure and water) (Vdm) is the sum of the residual and the dilution of the biomass (residual and water).

$$\text{Vdm} = (1 + N) \cdot Bmd, m^3 \cdot day^{-1}$$

where:

N: Excreta-water ratio, L/ kg, it is required to know that the density of water is: 1000 kg/m^3.

Meanwhile, the volume of the biodigester (Vbiodig) is calculated considering the value of the volume of material (mixture of manure and water) Vdm that enters the biodigester and the retention time TRH.

TABLE 1. Agricultural systems selected for research

Producer	Vereda (country road)	Production system	Municipality	Province	Productive goal
Alirio Herrera	Bermejal	La Meseta	Fusagasugá	Sumapaz	Dairy bovine
Álvaro Rodríguez	Jordán Bajo	Santa Bárbara	Fusagasugá	Sumapaz	Swine production
Avelino Godoy	Guayabal	El Mirador	Fusagasugá	Sumapaz	Swine production/crops
Naiceline Castro	Tierra Negra	La Saucita	Fusagasugá	Sumapaz	Swine production
Universidad de Cundinamarca	Guavio Bajo	La Esperanza	Fusagasugá	Sumapaz	Swine production / Dairy bovine
Universidad de Cundinamarca	Palogordo	El Tibar	Ubaté	Ubaté	Swine production

TABLE 2. Input and output data required for the design of an anaerobic biodigester

Parámeters	Unit
Imput data	
Amount of daily biomass generated (Bm_d)	kg day^{-1}
Excrets-water ratio (N)	L kg^{-1}
Biogas yield (Y)	m^3 kg^{-1}
Hydraulic retention time (HRT)	day
Output date	
Daily volume of material (mixture of manure and water) (Vdm)	kg day^{-1}
Biodigester volume, (V_{biodig})	m^3
Daily volume of biogas produced (G)	m^3 day^{-1}
Biogas holding volume (V_2)	m^3
Surge Tank Volume (Vtc)	m^3

$$V_{biodig} = \text{Vdm} \cdot TRH, m^3$$

Subsequently, the daily volume of biogas (G) produced is calculated:

$$G = Y \times B_{md}, m^3 \cdot day^{-1}$$

where:

Y- Biogas yield, $m^3 \cdot kg^{-1}$

The biogas yield (Y), is determined by the expression:

$$Y = \frac{X}{C_e}, m^3 \cdot kg^{-1}$$

where:

X- energy conversion coefficient of the excreta produced daily, that is, the daily production of biogas depending on the type of organic waste, m^3/day.

For all types of biodigesters, the volume of the compensation tank (Vtc) is equivalent to the volume of gas produced, that is, it ranges between 25…30% of the volume of the biodigester.

RESULTS AND DISCUSSION

Dimensioning of the Biodigester

For the correct dimensioning of the biodigester, it is necessary to determine the following parameters:

- Amount of daily biomass generated (Bmd);
- Daily volume of material (mixture of manure and water) (Vdm);
- Volume of the biodigester (Vbiodig);
- Volume of the compensation tank (Vtc).

The obtained results from each of these parameters are represented in Table 2, these values are obtained from the herd movement conceived by the owner of the farm during the month of April 2022.

Potential Energy Input

In order to determine the potential energy supply to be obtained based on the number of animals available, the following parameters must be determined:

- Biogas productivity (Y);
- Daily volume of biogas (G).

To determine the energy contribution of the animal population in each production system, it is necessary to consider that for every 50 kg of swine, 2,25 kg of excreta are obtained, generating 0,10 m^3 of biogas/day, and for every 350 kg of cattle (specifically dairy cows) 10 kg of excreta are obtained, generating 0,36 m^3 of biogas/day, for the mixture a ratio of 1:1 excreta-water is established (for both species) and with a retention time recommended 40 days (Table 3).

As evidenced in Table 4, the installation of biodigesters in agricultural production units constitutes an energetically viable option, to which the contribution to the conservation and care of the environment should be added.

It is valid to point out that the correct dimensioning of this type of technology favors the maximum use of the waste obtained in the productive scenarios, this criterion is based on the differences represented in the aforementioned table, evidencing that in the farms: La Meseta, el Tibar and Santa Bárbara, the volume of the installed biodigester is not used to the maximum, in the case of the first two farms the number of animals does not cover the potential of the installed biodigester and in the case of the third, the installed digester only uses approximately 35 % of the energy potential to be obtained. In La Esperanza Agro-Environmental Unit, it can be seen that the installed biodigester is also not capable of assimilating the amount of biomass generated daily, so it could be considered to reduce the amount of bovine excreta supplied or to install a biodigester with greater capacity.

Based on the results obtained and shown in Table 4, the design of the appropriate biodigester for each production system was carried out, these results can be seen in Table 5.

As shown in Table 5, the biodigesters installed in the production systems: La Meseta and El Tibar, are oversized by 4,8 and 1,6 times, respectively; this element evidences the need to increase the daily biomass generated, which is achievable with the increase of animals in the herds, whether they are pigs or cattle. On the other hand, in the case of the biodigesters installed in the production systems: Santa Bárbara, El Mirador, La Saucita and La Esperanza, a sub-dimensioning is observed, showing that the biodigesters installed in these production systems have dimensions smaller than those that could potentially be installed, finding inferiority values of 2,9; 1,97; 1,49; 2,04 times; these results indicate that in these scenarios, the number of animals used for biomass production is greater than that required with respect to

TABLE 3. Energy supply from animal population in each production system

Production System	Raw material source	Animal / day	Average Mass , kg	Bmd, kg/day	Y, m^3/kg	G, m^3/day
La Meseta	Bovine	20	400	25,71	0,036	**0,92**
Santa Bárbara	Swine	992	99	4 360,84	0,044	**191,87**
El Mirador	Swine	73	75	246,37	0,044	**10,84**
La Saucita	Swine	50	83	186,75	0,044	**8,21**
La Esperanza	Swine/Bovine	15/50	92/415	358,52	0,080	**28,68**
El Tibar	Swine	21	85	80,32	0,044	**3,53**

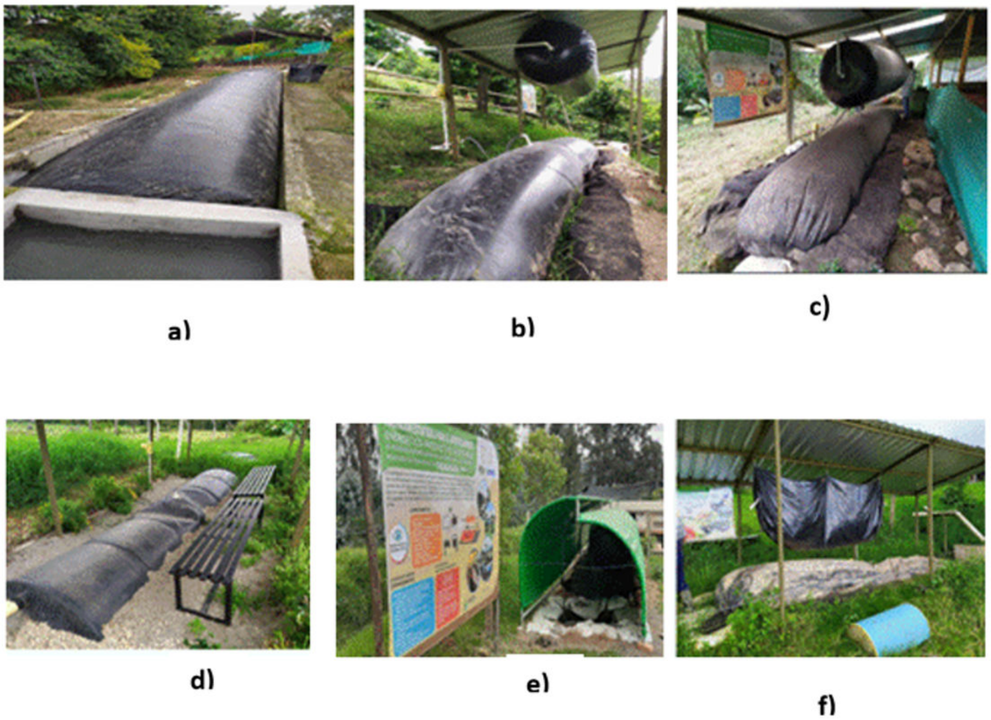

FIGURE 1. Biodigesters installed in the selected farms:
a) Santa Bárbara, b) El Mirador, c) La Saucita, d) La Esperanza, e) El Tibar, f) La Meseta.

TABLE 4. Energy potential depending on the biodigester installed in each production system

Dimensioning of installed biodigesters	Premises (Selected production systems)					
	La Meseta	Santa Bárbara	El Mirador	La Saucita	La Esperanza	El Tibar
V_{biodig}, m^3	10	120	10	10	14	10
V_{tc}, m^3	3,3	39,2	3,3	3,3	4,6	3,3
V_{gas}, m^3	3,3	39,2	3,3	3,3	4,6	3,3
Energetic parameters						
Y, m^3/kg	0,036	0,044	0,044	0,044	0,080	0,044
G, m^3/día	0,92	71,2	10,84	8,21	28,68	3,53
Potential energy savings						
Electricity, kWh	1,6	128,6	19,5	14,7	51,6	6,3
Natural gas, m^3	0,5	42,7	6,5	4,9	17,2	2,1
Wood charcoal, kg	0,3	21,4	3,2	2,5	8,6	1,0
Wood, kg	2,5	192,2	29,2	22,2	77,4	9,5
Fuel, L	0,7	56,9	8,6	6,6	22,9	2,8
Alcohol fuel, L	1,1	85,4	12,9	9,8	34,4	4,2
Fuel oil, L	0,6	49,8	7,5	5,7	20	2,5

the installed biodigester or that the installed biodigesters cannot take advantage of the biomass generated daily due to their capacity. In the specific case of the Santa Bárbara farm, it is evident that the volume of the biodigester installed is well below what should be installed, based on the number of existing animals and the amount of matter generated daily; this element considerably limits the energy potential, only in this specific case, the daily volume of biogas increases considerably and therefore, the potential energy savings would increase.

CONCLUSIONS

- It is evident that in none of the production systems the daily biomass generated was considered for the establishment of the polyethylene tubular biodigesters based on their dimensioning.
- The biodigesters installed in the production systems: La Meseta and El Tibar, are oversized by 4,8 and 1,6 times, respectively; aspect that shows the need to increase the daily biomass generated,

TABLE 5. Biodigester sizing suitable for each production system

Dimensioning of installed biodigesters	Premises (Selected production systems)					
	La Meseta	Santa Bárbara	El Mirador	La Saucita	La Esperanza	El Tibar
V_{biodig}, m^3	2,05	348,8	19,7	14,9	28,6	6,4
V_{tc}, m^3	0,6	115,1	5,9	4,4	8,6	1,9
V_{gas}, m^3	0,6	115,1	5,9	4,4	8,6	1,9
Energetic parameters						
Y, m^3/kg	0,036	0,044	0,044	0,044	0,080	0,044
G, m^3/día	0,92	191,8	10,84	8,21	28,68	3,53
Potential energy savings						
Electricity, kWh	1,6	345,2	19,5	14,7	51,6	6,3
Natural gas, m^3	0,5	115	6,5	4,9	17,2	2,1
Wood charcoal, kg	0,3	57,5	3,2	2,5	8,6	1,0
Wood, kg	2,5	517,8	29,2	22,2	77,4	9,5
Fuel, L	0,7	153,4	8,6	6,6	22,9	2,8
Alcohol fuel, L	1,1	230,2	12,9	9,8	34,4	4,2
Fuel oil, L	0,6	134,3	7,5	5,7	20	2,5

which is achievable with the increase of animals in the herds.

- The biodigesters installed in the production systems: Santa Bárbara, El Mirador, La Saucita and La Esperanza, show an under-sizing, with inferiority values of 2,9; 1,97; 1,49; 2,04 times. These results indicate that, in these scenarios, the number of animals used for biomass production is greater than that required with respect to the installed biodigester or that the installed biodigesters cannot take advantage of the biomass generated daily.
- The proper dimensioning of the anaerobic digestion technology is closely related to the biomass generated daily and therefore, to the number of animals in the production system.
- The implementation of these alternative technologies contributes to energy savings and the conservation and preservation of the environment, which is reflected in the values of potential energy savings obtained.

REFERENCES

BANSAL, V.; TUMWESIGE, V.; SMITH, J.U.: "Water for small-scale biogas digesters in Sub-Saharan Africa", *GCB Bioenergy*, 9(2): 339-357, 2017, ISSN: 1757-1693, e-ISSN: 1757-1707.

BIOGAS ASSOCIATION OTTAWA: *Biogas Association Ottawa Municipal guide to biogas*, *[en línea]*, Inst. Biogas Association Ottawa, Institucional, Ottawa, Canada, 2015, *Disponible en:* https://biogasassociation.ca/resources/municipalguidetobiogas, *[Consulta: 4 de junio de 2016]*.

BONILLA, J.A.; BUSTAMANTE, G.J.J.; VIDAL, D.M.L.: *Manual de producción de Ganado lechero en el estado de Nayarit*, Ed. Centro Nacional de Investigación Regional Pacifico, primera ed., México, Publicación Especial No. 1., 2014, ISBN: 978-607-37- 0387-1.

CARDONA, M.J.: *Módulo Pastos y especies forrajeras: Pastos y especies forrajes como sustento alimenticio más abundante y barato para bovinos.*, Ed. Fedegan, 2012, ISBN: 978-958-8498-42-3.

CASTRO, R.E.; SIERRA, A.A.M.; MOJICA, R.E.; CARULLA, F.J.; LASCANO, A.C.: "Uso múltiple de leguminosas como abono verde, en rotación con maíz, y heno, para producción de leche", *Ciencia y Tecnología Agropecuaria*, 17(1): 17-29, 2016, ISSN: 0122-8706.

FLOTATS, R.X.; CAMPOS, P.E.; PALATSI, C.J.; BONMATÍ, B.A.: "Digestión anaerobia de purines de cerdo y codigestión con residuos de la industria alimentaria", *Porci; Monografías de actualidad*, 65: 51-65, 2001, ISSN: 1130-8451.

FRANKIEWICZ, T.: "People's Republic of China Urban Municipal Waste and Wastewater Program", *[en línea]*, En: *Technology, Process and Evaluation Best Practices for Utilizing Organic and «Kitchen» Waste from the Municipal Solid Waste Stream» Workshop. Global Methane Initiative*, Ningbo, China, p. 16, 2015, *Disponible en:* http://communitybysesign.co.uk/.

PARRA, O.D.L.; BOTERO, L.M.A.; BOTERO, L.J.M.: "Biomasa residual pecuaria: revisión sobre la digestión anaerobia como método de producción de energía y otros subproductos", *Revista UIS Ingenierías*, 18(1): 149-160, 2019, ISSN: 2145-8456,
DOI: 10.18273/revuin.V18No.2-2019013.

RAHAYU, A.S.; KARSIWULAN, D.; YUWONO, H.; TRISNAWATI, I.; MULYASARI, S.; RAHARDJO, S.; HOKERMIN, S.; PARAMITA, V.: "Handbook POME-to-biogas project development in Indonesia", *Winrock International, United States of America*, : 8-19, 2015.

RUIZ, E.: *Guía Técnica: Manejo de pastos y rotación de Potreros*, *[en línea]*, Ed. Agrobanco, Perú, Agrobanco. Perú. Recuperado de: http://www. agrobanco. com. pe/data/uploads/ctecnica/034-c-pasturas. pdf, 2013, *Disponible en:* http://www.agrobanco.com.pe/data/uploads/ctecnica/034-c-pasturas.pdf.

SANTOS, A.I.; MEDINA, M.N.; MARTÍN, S.T.; MACHADO, M.Y.: *La Educación Agropecuaria en la Escuela Cubana Actual*, Ed. Editorial "Félix Valera Morales"., Centro de Estudio de la Educación Ambiental ed., Santa Clara, Villa Clara, Cuba, Centro de Estudio de la Educación Ambienta, 2012.

SOSA, R.: "Indicadores ambientales de la producción porcina y ganadera", En: *VII Seminario Internacional de Porcicultura Tropical*, *VII Seminario Internacional de Porcicultura Tropical*, Instituto de Investigaciones Porcinas, La Habana, Cuba, 2017.

SUÁREZ, H.J.; SOSA, C.R.; MARTÍNEZ, L.Y.; CURBELO, A.A.; FIGUEREDO, R.T.; CEPERO, L.L.: "Evaluación del potencial de producción del biogás en Cuba", *Pastos y Forrajes*, 41(2): 85-92, 2018, ISSN: 0864-0394, e-ISSN: 2078-8452.

VILLEGAS, P.; LLANOS, C.: *Cultivar avena para ensilas, opción para predios lecheros especializados*, *[en línea]*, Contextoganadero, 2014, *Disponible en:* http://www.contextoganadero.com/reportaje/cultivar-avena-para-ensilar-opcionpara-predios-lecheros-especializados.

ZHENG, Y.H.; WEI, J.G.L.; FENG, S.F.; LI, S.F.; JIANG, G.M.; LUCAS, M.; WU, M.; NING, T.Y.: "Anaerobic fermentation technology increases biomass energy use efficiency in crop residue utilization and biogas production", *Renewable and Sustainable Energy Reviews*, 16(7): 4588-4596, 2012,
DOI: https://doi.org/10.1016/j.rser.2012.03.061.

Yanoy Morejón Mesa, Profesor Titular. Facultad de Ciencias Técnicas, Universidad Agraria de La Habana, Cuba. Correo: ymorejon83@gmail.com o ymm@unah.edu.cu.
Vilma Moreno Melo, Profesora, Universidad de Cundinamarca, Facultad de Ciencias Agropecuarias, Sede Fusagasugá, Cundinamarca, Sumapaz Colombia, e-mail: vilma@ucundinamarca.edu.co.
Andrés Mogollón Reina, Profesor, Universidad de Cundinamarca, Facultad de Ciencias Agropecuarias, Sede Fusagasugá, Cundinamarca, Sumapaz Colombia, e-mail: amogollon@ucundinamarca.edu.co .
AUTHOR CONTRIBUTIONS: Conceptualization: Y. Morejón, V. Moreno. **Data curation:** Y. Morejón, V. Moreno. **Formal Analysis**: Y. Morejón, V. Moreno, A. Mogollón. **Investigation:** Y. Morejón, V. Moreno, A. Mogollón. **Methodology:** Y. Morejón. **Project administration:** V. Moreno, A. Mogollón . **Validation:** Y. Morejón, V. Moreno, A. Mogollón. **Visualization:** Y. Morejón, V. Moreno, A. Mogollón. **Writing - original draft:** Y. Morejón, V. Moreno. **Writing - review & editing:** Y. Morejón, V. Moreno, A. Mogollón.

The authors of this work declare no conflict of interest.