Short Communication

Psychrophilic anaerobic digestion of guinea pig manure in low-cost tubular digesters at high altitude

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ABSTRACT

Guinea pig is one of the most common livestock in rural communities of the Andes. The aim of this research was to study the anaerobic digestion of guinea pig manure in low-cost unheated tubular digesters at high altitude. To this end, the performance of two pilot digesters was monitored during 7 months; and two greenhouse designs were compared. In the dome roof digester the temperature and biogas production were significantly higher than in the shed roof digester. However, the biogas production rate was low (0.04 m^3_{biogas} $m^{-3}_{digester}$ d^{-1}), which is attributed to the low organic loading rate (0.6 kg_{VS} $m^{-3}_{digester}$ d^{-1}) and temperature (23 °C) of the system, among other factors. In a preliminary fertilization study, the potato yield per hectare was increased by 100% using the effluent as biofertilizer. Improving manure management techniques, increasing the organic loading rate and co digesting other substrates may be considered to enhance the process.

1. Introduction

Andean communities are generally based on self-sufficient agriculture. Livestock is mainly composed of cows, llamas and guinea pigs; while the main crops are potatoes and sweet corn. In the case of the Peruvian Andes, 92% of the population living in rural areas does not have access to clean fuels for cooking. Traditionally, biomass resources like fire-wood and air-dried cattle dung have been used, generally without improved cookstoves. This practise generates indoor air emissions, especially particulate matter, creating an unhealthy environment, hazardous for human health (He et al., 2009). In this context, the implementation of low-cost household digesters to treat manure constitutes a promising solution to provide a clean fuel (biogas) for cooking and lighting (Ferrer et al., 2009). In addition, the effluent has an enormous potential to improve local crops productivity in such extreme weather conditions.

The main experiences on household digesters implementation are concentrated in China and India (Bhattacharya and Salam, 2002; Liming, 2009), where brick masonry digesters are mainly used. During the last decades, tubular polyethylene and PVC digesters have been spreading successfully in rural areas of tropical countries (Lansing et al., 2008a,b); and they have only recently been adapted to the conditions of the Andean Plateau (2500–4500 m.a.s.l) (Ferrer et al., in press). Up to date, there are only a few studies dealing with the anaerobic digestion of llama, cow and sheep manure at high altitude (Alvarez et al., 2006; Alvarez and Lidén, 2008, 2009; Ferrer et al., in press). Guinea pig manure, which is widely available in the Andes, is yet to be explored. The aim of this study is to characterize the anaerobic digestion of guinea pig manure in low-cost unheated tubular digesters implemented at high altitude.

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2. Methods

2.1. Experimental set-up

The experiments were carried out in a pilot plant located at 2800 m.a.s.l. in the National Institute for Agricultural Innovation (INIA) (Cajamarca, Peru). The tubular PVC digesters used had a total volume of 10 m^3 and a useful volume of 7.5 m^3. The hydraulic residence time (HRT) was 75 days and the organic loading rate (OLR) 0.6 kg_{VS} $m^{-3}_{digester}$ d^{-1}. The digesters differed on the greenhouse design: dome roof (D1) and shed roof (D2), in order to compare the effect of the greenhouse on process parameters such as temperature and biogas production. Design and operation parameters of low-cost digesters implemented at high altitude are described in detail by Ferrer et al. (in press).

2.2. Experimental procedures

The process was monitored during 7 months. Peruvian Andes are characterized by two seasons: a dry sunny season (DSS) with an average temperature of 13 °C, and a wet cloudy season (WCS) with an average temperature of 9 °C. This study comprises both the DSS (weeks 1–14) and WCS (weeks 15–28). Both digesters treated guinea pig manure diluted in water (1:4), with a solids concentration around 6–8%. Manure was monthly collected from farms and stored in piles. For practical reasons, it was pre-composted to ease dilution before feeding.

2.3. Analytical methods

Temperature was daily measured (9–10 am) inside greenhouses and digesters liquor by means of a sensor (Crison, MM40). Biogas production was monitored using a commercial low pressure diaphragm gas meter (Elster, BK-G 1.6). Biogas composition was weekly determined by measuring the concentration of carbon dioxide (CO_2) and hydrogen sulphide (H_2S) using colorimetric tubes (Gastec 2.2HH and Gastec 2.4H, respectively). The concentration of methane was deduced from CO_2 and H_2S contents.

The feedstock and effluent were characterized in terms of total solids (TS), volatile solids (VS), total kjeldahl nitrogen (TKN), ammonia nitrogen (N-NH_4), total phosphorous (P-P_2O_5), potassium (K-K_2O), pH and Electrical conductivity (CE), *Escherichia coli* and *Salmonella* following standard methods (APHA, 1998). Total coliforms (TC) were analyzed according to the Mexican Official Standards (NOM, 1994).

2.4. Crops fertilization

A preliminary study was carried out in order to analyze the potential of the effluent as biofertilizer for potato (*Solanum tuberosum*) crops. Three treatments were compared: D1 effluent (T1), D2 effluent (T2) and a control without fertilizer (T3). Three replicates of each treatment were randomly distributed in experimental parcels. Each replicate consisted of 15 potato plants. The amount of effluents (T1 and T2) was determined considering a total application of 50 kg of nitrogen per hectare (Jacob and Uexküll, 1968). The potato yield per hectare was quantified to compare the results.

2.5. Statistics

The statistical significance of experimental results was evaluated by the Paired *t*-test, which tests the mean difference between paired observations; with a significance level (α) of 5%, using the Minitab 15.1 Statistical Software.

3. Results and discussion

3.1. Temperature

During the whole experimental period, ambient temperature ranged between 14 and 23 °C, while greenhouses temperature ranged between 24 and 40 °C (Fig. 1a). The values measured inside the dome roof (D1) were significantly higher than inside the shed roof (D2); around 30 and 26 °C, respectively (Table 1). Compared to ambient and greenhouses temperature, liquors temperature was fairly constant (Fig. 1b) and only slightly higher in the dome roof digester (23.2 vs. 22.8 °C) (Table 1). The results obtained were statistically different because the values measured in D1 were systematically higher than in D2; however the differences were rather small. Notice that the influence of the season on liquors temperature was only minor (Fig. 1b).

Apart from this, the dome roof showed some practical advantages compared to the shed roof design; for instance it eased digester maintenance labours like weed removal and PVC bags repairing. In terms of costs, there were no significant differences between both models.

3.2. Biogas production and composition

Biogas production in digesters D1 and D2 is shown in Table 1. The results obtained were significantly higher in the dome roof (D1) compared to the shed roof (D2) digester, average values being 0.040 and 0.036 $m^3_{biogas}\ m^{-3}_{digester}\ d^{-1}$, respectively (Table 1). In both digesters, biogas production was higher during the dry sunny season in comparison with the wet cloudy season, especially in D1 (0.045 vs. 0.034 $m^3_{biogas}\ m^{-3}_{digester}\ d^{-1}$). In terms of specific gas production, the results obtained were 0.061 and 0.058 $m^3_{biogas}\ kg_{VS}{}^{-1}$ in D1 and D2, respectively (Table 1). Again, the results were statistically different because the values measured in D1 were systematically higher than in D2; however the differences were rather small in all cases.

Regarding biogas composition, there were no statistical differences between CO_2 (34.58–36.47%) and H_2S (around 0.19%) in D1 and D2 (Table 1). The results suggest methane contents above 60% in both digesters, within the range reported in the literature (Alvarez et al., 2006; Alvarez and Lidén, 2008; Ferrer et al., in press). According to this, the methane production rate was only slightly higher in D1 than in D2 (0.024 vs. 0.021 $m^3_{CH4}\ m^{-3}_{digester}\ d^{-1}$).

Under the conditions assayed, the amount of biogas produced was low (around 0.04 $m^3_{biogas}\ m^{-3}_{digester}\ d^{-1}$) compared to that obtained with low-cost tubular digesters in tropical regions (0.1–0.35 $m^3_{biogas}\ m^{-3}_{digester}\ d^{-1}$) (Lansing et al., 2008a, 2010a). This is mainly attributed to the low temperature (22–23 °C) and OLR (0.6 $kg_{VS}\ m^{-3}_{digester}\ d^{-1}$) of the system. The specific biogas production (around 0.06 $m^3_{biogas}\ kg_{VS}{}^{-1}$) was slightly lower than the values reported for llama, cow and sheep manure digestion under similar ambient conditions (18–25 °C, high altitude) but with a higher OLR (2 $kg_{VS}\ m^{-3}_{digester}\ d^{-1}$) (Alvarez and Lidén, 2008). According to Alvarez et al. (2006), the process is mainly affected by temperature, followed by HRT and OLR; and it can be improved by codigesting a mixture of manures, with a maximum OLR up to 4–6 $kg_{VS}\ m^{-3}_{digester}\ d^{-1}$ (Alvarez and Lidén, 2009). In this sense, guinea pig manure digestion could be enhanced by codigesting other local substrates, such as cow manure, and increasing the OLR. Previous studies also point out the OLR importance in order to increase biogas production and reduce implementation costs of low-cost tubular digesters (Ferrer et al., in press).

The low biogas production may also be attributed to the quality of organic matter in manure and its management. First of all, in Andean rural areas harsh climatic conditions and frost-tolerant forages give a rather different animal diet compared to that of low-land developed countries (Alvarez and Lidén, 2008, 2009); resulting in manure with reduced proteins and lipids contents and increased amounts of material difficult to digest (Alvarez et al., 2006). Secondly, the digestibility and net energy content of animal excreta is greatly influenced by species; for example it has been demonstrated that the digestibility of poultry excreta is higher than that of pig slurry, while the digestibility of rabbit slurry is similar to the solid fraction of pig slurry (Flachowsky and Hennig, 1990). Although no values have been found for guinea pig manure, low digestibility might be assumed by comparison with rabbit slurry. Finally, we should bear in mind that guinea pig manure was pre-composted to ease dilution before digesters feeding, prompting the aerobic decomposition of easily degradable

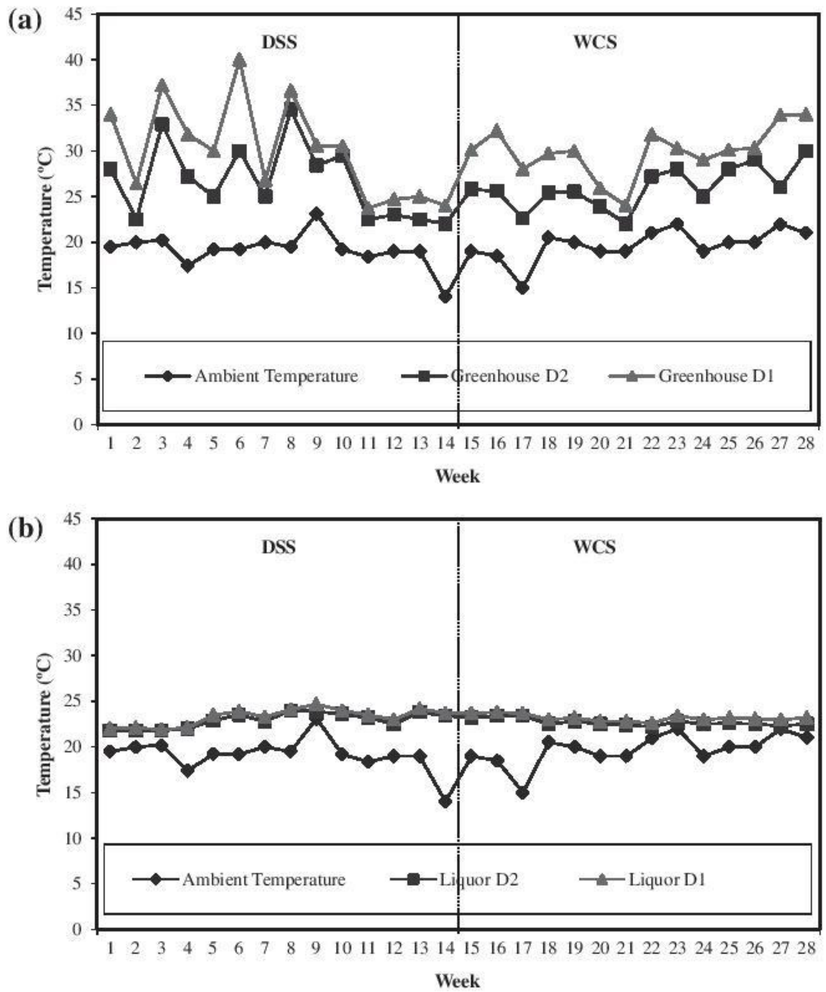

Fig. 1. Weekly average of (a) ambient and greenhouses temperature, and (b) ambient and digesters liquor temperature, during the dry sunny season (DSS) and wet cloudy season (WCS).

Table 1
Comparison of the performance of digesters D1 and D2.

Parameter	Full period		Dry sunny season		Wet cloudy season	
	D1	D2	D1	D2	D1	D2
Temperature:greenhouse (°C)	30.02 ± 4.15*	26.11 ± 3.48	30.09 ± 5.31*	26.64 ± 4.09	29.95 ± 2.74*	25.57 ± 2.80
Temperature:liquor (°C)	23.23 ± 0.69*	22.81 ± 0.64	23.29 ± 0.92*	22.93 ± 0.82	23.18 ± 0.36*	22.69 ± 0.39
Biogas production rate (m^3_{biogas} $m^{-3}_{digester}$ d^{-1})	0.040 ± 0.01*	0.036 ± 0.01	0.045 ± 0.01*	0.038 ± 0.01	0.034 ± 0.01*	0.033 ± 0.01
Specific biogas production (m^3_{biogas} $kg_{VS}{}^{-1}$)	0.061 ± 0.02*	0.058 ± 0.02	–	–	0.061 ± 0.02*	0.058 ± 0.02
Carbon dioxide (% CO_2)	34.58 ± 5.7	36.47 ± 3.8	27.86 ± 3.59	32.25 ± 0.92	37.95 ± 2.08	38.58 ± 2.45
Hydrogen sulphide (% H_2S)	0.19 ± 0.05	0.19 ± 0.05	0.25 ± 0.01	0.25 ± 0.01	0.16 ± 0.02	0.16 ± 0.02

* Stand for significantly higher values between paired columns (α = 5%).

compounds. In the future, management techniques should be modified to maintain the biogas potential of the feedstock.

3.3. *Effluent quality*

In our low-cost tubular digesters without mixing, manure sedimentation resulted in the retention of most of the total and volatile solids from the influent, over 90% according to Table 2. Besides, the biodegradation of manure led to a reduction of the organic content from 67.62% VS/TS in the influent to 45.54% VS/TS in the effluent, without statistical differences between digesters (Table 2). In general, nutrients concentrations (nitrogen, phosphorus and potassium) were relatively low, due to feedstock dilution (1:4) before feeding and solids sedimentation (>90%) in the digesters. This is a drawback if the effluent is to be used for crops fertilization, since the volume of effluent needed to fulfil the fertiliser dose is really high compared to alternative biofertilizers such as compost.

Besides, pathogen indicators were reduced by 1–2 log units, from 10^9 to 10^8 MPN mL^{-1} total coliforms and from 10^9 to 10^7 MPN mL^{-1} *E. coli*. According to this, the process was capable of reducing the concentration of total coliforms and *E.coli* by 97% and 99%, respectively, which is in accordance with previous

Table 2
Average feedstock (before 1:4 dilution manure:water) and effluent characteristics.

Parameter	Feedstock		Effluent		
	Unit	Value	Unit	Value (D1)	Value (D2)
TS	(%)	25.96 ± 4.73	(%)	0.70 ± 0.08	0.68 ± 0.09
VS	(% TS)	67.61 ± 2.44	(% TS)	44.22 ± 5.13	46.87 ± 4.35
TKN	(% TS)	0.84 ± 0.01	mg L^{-1}	380.47 ± 37.89	352.29 ± 35.78
$N-NH_4$	(% TS)	0.10 ± 0.02	mg L^{-1}	211.38 ± 12.27	210.20 ± 10.30
$P-P_2O_5$	(% TS)	0.39 ± 0.03	mg L^{-1}	214.50 ± 36.97	246.30 ± 30.88
$K-K_2O$	(% TS)	1.45 ± 0.09	mg L^{-1}	726.61 ± 2.27	689.63 ± 3.87
pH		8.82 ± 0.39		7.14 ± 0.11	7.16 ± 0.21
CE	(μS cm^{-1})	17.95 ± 2.35	(μS cm^{-1})	8.00 ± 0.9	8.30 ± 1.4
Total Coliforms	MPN mL^{-1}	5.10E + 09	MPN/ml	1.70E + 08	–
E. coli	MPN mL^{-1}	1.70E + 09	MPN/ml	1.70E + 07	–
Salmonella	P/A 25 g	Not detected	P/A 25 g	Not detected	–

Note: No significant differences were found between the effluents of D1 and D2 (α = 5%).

findings (Coté et al., 2005; Lansing et al., 2010b). Nevertheless, pathogens concentration in the effluent was far above the limit imposed by the World Health Organization (WHO) for wastewater reuse in restricted agriculture (10 MPN mL^{-1}) (WHO, 2006). Complete pathogen destruction is unlikely in anaerobic digesters operating at low temperature (22–23 °C). For this reason, post-treatment techniques such as sand filtration or planted wetlands and solar (UV) disinfection should be evaluated, to protect human health after effluents agricultural application or discharge in water bodies.

3.4. Crops fertilization

The results of the preliminary study showed that the potato yield increased from 12.75 kg ha^{-1} in the control without fertilizer (T3), to 26.25 and 25.87 kg ha^{-1} with D1 (T1) and D2 (T2) effluents. A similar effect of T1 and T2 was expected, since there were no differences between D1 and D2 effluents composition (Table 2). The results obtained highlight the benefits of using the effluent as biofertilizer, increasing the potato yield per hectare by 100%. This is an important issue, since it can lead to economic benefits from potato sales, which could help recovering the investment cost of the system.

4. Conclusions

This study was focused on the anaerobic digestion of guinea pig manure in low-cost unheated tubular digesters at high altitude. In addition, two greenhouse designs were compared. In the dome roof digester the temperature and biogas production were significantly higher than in the shed roof digester. However, the biogas production rate was low (0.04 $m^3_{biogas}\ m^{-3}_{digester}\ d^{-1}$), which is attributed to the low OLR (0.6 $kg_{VS}\ m^{-3}_{digester}\ d^{-1}$) and temperature (23 °C), among other factors. In a preliminary fertilization study, the potato yield per hectare was increased by 100% using the effluent as biofertilizer.

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References

Alvarez, R., Villca, S., Lidén, G., 2006. Biogas production from llama and cow manure at high altitude. Biomass Bioenergy 30, 66–75.
Alvarez, R., Lidén, G., 2008. The effect of temperature variation on biomethanation at high altitude. Bioresour. Technol. 99, 7278–7284.
Alvarez, R., Lidén, G., 2009. Low temperature anaerobic digestion of mixtures of llama, cow and sheep manure for improved methane production. Biomass Bioenergy 33 (3), 527–533.
APHA, 1998. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, 20th ed. American Water Works Association and Water Environment Federation, Washington, USA.
Bhattacharya, S.C., Salam, P.A., 2002. Low greenhouse gas biomass options for cooking in the developing countries. Biomass Bioenergy 22, 305–317.
Coté, C., Masse, D.I., Quessy, S., 2005. Reduction of indicator and pathogenic microorganisms by psychrophilic anaerobic digestion in swine slurries. Bioresour. Technol. 97 (4), 686–691.
Ferrer, I., Gamiz, M., Almeida, M., Ruiz, A., 2009. Pilot project of biogas production from pig manure and urine mixture at ambient temperature Ventanilla (Lima, Peru). Waste Manag. 29 (1), 168–173.
Ferrer, I., Garfí, M., Uggetti, E., Ferrer-Martí, L., Calderon, A., Velo, E., in press. Biogas production in low-cost household digesters at the Peruvian Andes. Biomass Bioenergy doi:10.1016/j.biombioe.2010.12.036.
Flachowsky, G., Hennig, A., 1990. Composition and digestibility of untreated and chemically treated animal excreta for ruminants – A review. Biological Wastes 31 (1), 17–36.
He, K., Lei, Y., Pan, X., Zhang, Y., Zhang, Q., Chen, D., 2009. Co-benefits from energy policies in China. Energy 35 (1), 4265–4272.
Jacob, A., Uexküll, V., 1968. Fertilization. Edición revolucionaria. Instituto del Libro. La Havana, Cuba.
Lansing, S., Víquez, J., Martínez, H., Botero, R., Martin, J., 2008a. Quantifying electricity generation and waste transformations in a low-cost, plug-flow anaerobic digestion system. Ecol. Eng. 34, 332–348.
Lansing, S., Botero, R., Martin, J., 2008b. Waste treatment and biogas quality in small-scale agricultural digesters. Bioresour. Technol. 99, 5881–5890.
Lansing, S., Martin, J., Botero, R., Nogueira da Silva, T., Dias da Silva, E., 2010a. Methane production in low-cost, unheated, plug-flow digesters treating swine manure and used cooking grease. Bioresour. Technol. 101, 4362–4370.
Lansing, S., Martin, J., Botero, R., Nogueira da Silva, T., Dias da Silva, E., 2010b. Wastewater transformations and fertilizer value when co-digesting differing ratios of swine manure and used cooking grease in low-cost digesters. Biomass Bioenergy 34, 1711–1720.
Liming, H., 2009. Financing rural renewable energy: a comparison between China and India. Renew. Sustainable Energy Review 13, 1096–1103.
Norma Official Mexicana (NOM), 1994. NOM-111-SSA1-1994. Determination of bacteria coliforms. Technique of the Most Probable Number. Secretaría de Salubridad y Asistencia, México, D.F.
World Health Organization (WHO), 2006. Guidelines for the safe use of wastewater, excreta and greywater. Volume IV: Excreta and greywater use in agriculture. WHO press, France.