Journal of Natural Sciences Research www.iiste.org
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online)
Vol.4, No.22, 2014

Effect of Co-Digestion on Anaerobic Digestion of Pig Slurry with Maize Cob at Mesophilic Temperature

Ademola Oyejide ADEBAYO[1]*, Simeon Olatayo JEKAYINFA[1], Bernd LINKE[2]
1. Department of Agricultural Engineering, Ladoke Akintola University of Technology, P. M. B. 4000, Ogbomoso, Oyo State, Nigeria
2. Leibniz-Institute for Agricultural Engineering (ATB), Max-Eyth-Allee 100, D - 14469 Potsdam, Germany.
* E-mail of the corresponding author: ademolaadebayo1@yahoo.com

Abstract
The 21st century faces the problem of growing energy consumption and diminishing supplies of fossil fuels, which has led to researches on the use of renewable energy sources and, consequently, the development of new technological processes of energy production. Pig slurry and maize stalk constitute nuisance to our environment and should be got rid of. Co-digestion has been found by researchers to improve the product of anaerobic digestion. This work determined the effect of co-digestion on anaerobic digestion of pig slurry with maize cob. Pig slurry and maize cobs were co-digested at ratios 3:1, 1:1 and 1:3 using the percentage volatile solid of each substrate. The experiment was carried out in a laboratory scale batch experiment. The digester was fed with pig slurry-maize cob mixtures calculated for the selected ratios based on the volatile solid (VS) concentration of the selected substrates. Co-digestion of pig slurry with maize cobs at ratios 3:1, 1:1 and 3:1 at mesophilic temperature (37^{o}C) gave biogas yields of 0.323, 0.392 and 0.486m^3/kgoDM respectively while the methane yields were 0.240, 0.305 and 0.358 m^{3}CH$_4$/kgoDM respectively. From the fresh mass of the substrate, biogas yields of 0.035, 0.057 and 0.109 m^3/kgFM were obtained for pig slurry-maize cob ratios of 3:1, 1:1 and 1:3 respectively while the methane yields from the fresh mass for the same ratios were 0.026, 0.044 and 0.080 CH$_4$/kgFM respectively. Co-digestion of pig slurry with maize cob was found to have methane concentrations of 74.30, 77.90 and 73.68% at pig slurry/maize cob combinations of 3:1, 1:1 and 1:3 respectively. The study revealed that co-digesting pig slurry with maize cob at ratio 1:3 is optimum for biogas production (yields).
Keywords: Co-digestion, pig slurry, maize cob, batch experiment, mesophilic temperature

1. Introduction

Anaerobic digestion is the multi-step biological process during which organic material is converted to biogas and digestate in the absence of oxygen. Anaerobic biodegradation of organic material proceeds in the absence of oxygen and the presence of anaerobic microorganisms. Anaerobic digestion is the consequence of a series of metabolic interactions among various groups of microorganisms. It occurs in four stages, hydrolysis/liquefaction, acidogenesis, acetogenesis and methanogenesis (Kangle *et al.*, 2012**).**

Another promising means of achieving multiple environmental benefits and producing an energy carrier from renewable resources is anaerobic digestion. It has been established that biogas (product of anaerobic digestion) reduces the emission not only of greenhouse gases, but also of nitrogen and sulphur oxides, hydrocarbons, and particles (Borjesson and Berglund, 2006). Biogas, the gas produced when organic matter of animal or plant ferments in an oxygen-free environment occurs naturally in swamps and spontaneously in landfills containing organic waste. It can also be induced artificially in digestion tanks to treat sludge, industrial organic waste, and farm waste (Igoni, *et al*., 2008). Biogas primarily consists of methane (CH_4) and carbon dioxide (CO_2), with varying amounts of water, hydrogen sulphide (H_2S), oxygen and other compounds (Madu and Sodeinde, 2001, Keefe and Chynowet, 2000).

Co-digestion is the simultaneous digestion of a homogenous mixture of two or more substrates. Traditionally, anaerobic digestion was a single substrate, single purpose treatment. Recently, it has been realized that AD as such became more stable when the variety of substrates applied at the same time is increased. The most common situation is when a major amount of a main basic substrate (e.g. manure or sewage sludge) is mixed and digested together with minor amounts of a single, or a variety of additional substrate (Braun, 2002). The use of co-substrates usually improves the biogas yields from anaerobic digester due to positive synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates (Mata-Alvarez *et al.*, 2000). Co-digestion of cassava peels with poultry, piggery and pig waste has been found to result into increase in biogas production (Adelekan and Bamgboye, 2009). Several researchers have studied biogas generation from animal and agricultural wastes (Dunlop, 1978; Mohmoh *et al*, 2008; Jash and Basu, 1999). According to Callaghan *et al*. (1999), co-digestion of pig slurry with fruit and vegetable waste yielded more cumulative biogas production than the digestion of pig slurry alone.

High methane yield can be achieved through co-digestion of manure with energy crops and or their residues. Co-digestion with animal manure or sewage sludge as base feedstock is an effective way to improve buffer capacity and achieve stable performance (Sosnowski *et al*., 2003; Murto *et al*., 2004; Mshandete *et al*., 2004; Umetsu *et* *al*., 2006). Also, the addition of readily biodegradable organic matter into animal manure digester could significantly increase biogas production due to the changes of feedstock characteristics. This work studied the effect of co-digestion on anaerobic digestion of pig slurry with maize cob at mesophilic temperature (37^{o}C).

2. Materials and Methods

2.1 Sources of organic materials

Maize plants were harvested from the Institute for Animal Breeding and Animal Husbandry (ABAH), Ruhlsdorf / Grosskreutz, Germany and the cobs were separated for experimentation. Pig slurry was also obtained from the same institute (ABAH).

2.2 Methodology

All samples were kept in the laboratory at a +3°C after size reduction prior to feeding into the digester. The amount of substrate and seeding sludge weighed into the fermentation bottles were determined in accordance to German Standard Procedure VDI 4630 (2004) using the equation 1:

$$\frac{oTS_{substrate}}{oTS_{seeding\ sludge}} \leq 0.5 \qquad 1$$

Where:

$oTS_{substrate}$ = organic total solid of the substrate and;

$oTS_{seeding\ sludge}$ = organic total solid of the seeding sludge (the inoculum)

Batch experiments were carried out in lab-scale vessels with two replicates as described by Linke and Schelle (Linke and Schelle, 2000). A constant temperature of 37°C was maintained through a thermostatic cabinet heater (Plate 1). Anaerobically digested material from a preceding batch experiment was used as inoculum for this study. Characteristic chemical parameters of the inoculum used are summarized in Table 1. Vessels (0.9 litre capacity) were filled with 800g of the stabilized inoculum. At the beginning of the experiment, anaerobically digested material from a preceding batch experiment was used as inoculums for this study. The substrates fed into the digestion bottles were calculated using equation (3) and found to be 37.6g CS / 0MS (100% Pig slurry with no maize cob), followed by16.15 g PS / 0.93 g MC (75%PS and 25%MC), 9.43 g PS/ 1.62 g MC (50%PS and 50%MC), 5.39 g PS/2.78 gMC and (25%PS and 75%MC). These calculated amounts of the substrates (using equation 3) were added to 800g inoculums to ensure compliance of the oDM feedstock to ODM inoculum ratio being less or equal 0.5 as it is recommended in VDI 4630 (equations 1 and 2). Two digestion vessels were also filled with 800g of inoculums only as control. The biogas produced was collected in scaled wet gas meters over a defined period of time ranging from 30 to 40 days depending on the substrate being investigated. This duration of the test fulfilled the criterion for terminating batch anaerobic digestion experiments given in VDI 4630 (daily biogas rate is equivalent to only 1% of the total volume of biogas produced up to that time). The volume of the gas produced was measured daily. Besides, other gas components, methane (CH_4) and carbon dioxide (CO_2) contents were determined four times during the batch fermentation test using a gas analyser GA 2000. The tests were conducted in two replicates. Plate 1 shows the set up of the batch experiment conducted at mesophilic temperature (37^{o}C).

Quantitative evaluation of the results gained in batch anaerobic digestion tests included the following steps: standardizing the volume of biogas to normal litres (1_N); (dry gas, t_0=273 K,p_0=1013hPa) and correcting the methane and carbon dioxide contents to 100% (headspace correction, VDI 4630). Readings were analysed using Microsoft Excel spread sheet together with “Table curve” computer software. Accumulated biogas yields over the retention time were fitted by regression analysis using Hill-Kinetic equation in order to determine the maximum biogas and methane potentials of the selected substrates.

The amount of substrate fed into the digester was calculated using equation (2).

$$\frac{oTS_{substrate}}{oTS_{seeding\ sludge}} \leq 0.5 \qquad 2$$

Where:

$oTS_{substrate}$ = organic total solid of the substrate and;

$oTS_{seeding\ sludge}$ = organic total solid of the seeding sludge (the inoculum)

Equation (2) can be modified to read

$$p_i = \frac{m_i . c_i}{m_s c_s} \qquad 3$$

Where

p_i= mass ratio=2 ; m_i= amount of inoculum, g

c_i=Concentration of inoculum, oDM in % Fresh mass

m_s= amount of substrate,g
c_s= Concentration of substrate, oDM in % fresh mass

Readings of the gas production (ml), air pressure (mbar), gas temperature (^oC) and time of the day were taken on daily basis throughout the period of the experiment. The gas was analysed with the use of gas analyser GA 2000 at least twice per week for the four weeks of the experiments. Biogas production and gas quality from maize cob (MC) and pig slurry (CS) were analyzed in batch anaerobic digestion test at 37°C according to German Standard Procedure VDI 4630 (2004). The gas factor was calculated as well as the fresh mass biogas and methane yield with the volatile solid biogas and methane yields also determined on daily basis. The amount of gas formed was converted to standard conditions (273.15 K and 1013.25 mbar) and dry gas. The factor was calculated according to equation 3.

$$F = \frac{(p - P_{H_2O}).T_o}{(t + 273.15).p_o} \quad 4$$

Where
T_o= 273.15 ^oC (Normal temperature)
t= Gas temperature in ^oC

P_o= 1013.25 mbar (standard pressure)
P= Air Pressure

The vapour pressure of water P_{H_2O} is dependent on the gas temperature and amounts to 23.4 mbar for 20^oC. The respective vapour pressure of water as a function of temperature for describing the range between 15 and 30^oC is given as in equation 4

$$P_{H_2O} = y_o + a.e^{b.t} \quad 5$$

Where:
y_o = -4.39605; a = 9.762 and b= 0.0521

The normalized amount of biogas volumes is given as

$$Biogas[N\,ml] = Biogas[ml] \times F \quad 6$$

Normalized by the amount of biogas, the amount of gas taken off of the control batch is given as

$$Biogas[N\,ml] = (Biogas[Nml] - Control[Nml]) \quad 7$$

The mass of biogas yield in standard liters / kg FM fresh mass (FM) is based on the weight
The following applies:
1 standard ml / g FM=1 standard liters / kg FM = 1 m^3 / t FM

$$Mass\,of\ biogas\ yield = \sum \frac{Biogas[N\,ml]}{Mass[g]} \quad 8$$

The oDM biogas yield is based on the percentage of volatile solids (VS) in substrate

$$oDM\ biogas\ yield = \sum \frac{Biogas[N\,ml).100]}{Mass[g].VS[\%FM]} \quad 9$$

$$CH_{4corr.} = \frac{CH_4[vol\%].100}{(Mass[g] + CO_2[vol\%])} \quad 10$$

$$Fresh\,Mass\,Methane\ yield = \frac{Fresh\,mass\,biogas\ yield \times CH_{4corr.}}{100} \quad 11$$

$$oDM\ Methane\ yield = \frac{oDM\ biogas\ yield \times CH_{4corr.}}{100} \quad 12$$

2.2 Substrates and Analytical Procedures

Samples of pig slurry(PS) and maize cob (MC) were investigated for Fresh matter (FM), organic Dry Matter (105^oC), Organic Dry Matter in % fresh mass, Volatile fatty acids (VFA), pH, NH_4-N, Conductivity (LF), Organic dry matter in % of fresh mass (oTS). The inoculum for the batch anaerobic digestion tests was also analyzed for the following parameters DM, ODM, pH, organic acids and the electrical conduction. All analyses were performed according to German standard methods (Linke and Schelle, 2000).

3. Results and Discussion

Table 1 shows the results of the chemical analysis of the selected substrates before digestion. The cumulative biogas and methane productions obtained from batch digesters are shown in Figures 1-4.

3.1 Substrates

The dry matter (DM), organic dry matter (oDM), NH_4-N, Crude Fibre, N, P, K, pH, and the conductivity of the selected substrates determined are as shown in Table 1 (Kirchgeßner, 1997; Mähnert *et al.*, 2002).

3.2 Biogas production

The tested samples showed monophasic curves of accumulated biogas production. After a steep increase, biogas production decreased resulting in a plateau of the cumulative curve. The maximum biogas rate was achieved in the first week of digestion experiment (Figs 1, & 2). More than 90% of the biogas yields were obtained between first and second week of anaerobic digestion. Biogas production using CS and MC showed a linear curve with progressive increase in biogas production with time (Figs. 1 & 2). The fresh-mass and organic dry matter biogas production are as shown in Figures 1 & 2 while the fresh mass and organic dry matter biogas yields of are as shown in Figures 3 & 4. The figures give the results from the duplicates of the substrate.

3.3 Co-Digestions of Pig Slurry with Maize Cob

The co-digestion of pig slurry with maize cob revealed that at ratios 3:1, 1:1 and 1:3; biogas (FM) yields of 0.035, 0.057 and 0.109 m^3/kg_{FM} respectively were produced while methane yields (FM) were 0.026, 0.044 and 0.080 m^3CH_4/kg_{FM} respectively. The biogas yields (oDM) of pig slurry co-digested with maize cob at the same ratios were found to be 0.323, 0.392 and 0.486 m^3/kg_{oDM} while the methane yields (oDM) were respectively found to be 0.240, 0.305 and 0.358 m^3CH_4/kg_{oDM} when experimented at mesophilic temperatures. The high nitrogen content of maize cob (10.17 g/kgFM) must have influenced the yields obtained when co-digested with pig slurry with low nitrogen content (7.49 g/kgFM). Statistically, co-digestion of pig slurry with maize stalks and cobs (co-digestions 3 and 4) showed that there were significant differences between both the yields and the substrate ratios at 95% confidence level. The highest yields were recorded at 1:3. Thus, co-digestion of pig slurry with maize cobs showed increase in the yields both from fresh mass and the organic dry matter contents of the selected substrates. This agrees with the results of previous researches that co-digestion aids biogas and methane yields (Callaghan *et al*., 1999; Umetsu *et al*., 2006; Murto *et al*., 2004).

Figures 1- 4 show the results obtained from the batch co-digestion of pig slurry with maize cob at mesophilic temperature. Figure 5 shows the effect of co-digestion at different volatile solid constituents of the selected substrates on biogas and methane yields.

Conclusion

The study has shown that co-digesting pig slurry with maize cob at different ratios result into an increase in both biogas and methane yields. Also, co-digestion ratio of 1:3 of pig slurry and maize cob was adjudged the best in terms of biogas and methane yields. Further works could be carried out on other residues constituting nuisance to the environment. Effect of co-digesting other residues at various ratios could also be looked into.

Acknowledgments

The first author is grateful to the Deutscher Akademischer Austauschdienst (DAAD) Germany for her financial support through the award of Research Scholarship for Doctoral Candidates to carry out this work at the Leibniz- Institute for Agricultural Engineering, Potsdam-Bornim, Germany.

REFERENCES

Adelekan , B.A. and Bamgboye, A. I. (2009): Comparison of Biogas Productivity of Cassava Peels Mixed in Selected Ratios with Major Livestock Waste Types, *African Journal of Agricultural Research* Vol. 4 (7), pp. 571-577.

Borjesson, P., Berglund, M. (2006): Environmental systems analysis of biogas system Part I: Fuelcycle emissions, *Biomass and Bioenergy*, No. 30, pp. 469 – 485.

Braun. R. (2002): Potential of Co-digestion. http://www.novaenergie.ch/iea-bioenergytask37/Dokumente/final.PDF. Accessed on May 3, 2013

Callaghan, F. J., Wase, D. A. J., Thayanithy, K., and Forster, C. F. (1999): Co-digestion of waste organic solids: batch studies. Biores. Technol. 67:117–122.

Dunlop, CE (1978). *In Single Cell Protein II,* Tannenbaum S.R. and Wans D.LC. (Eds) MIT Press CambrIdge, Massachusetts, pp 244-262.

Igoni, A. H., Ayotamuno, M.J., Eze, C.L., Ogaji, S.O.T., Probert, S.D. (2008): Designs of anaerobic digesters for producing biogas from municipal solid-waste, *Applied Energy* 85: 430–438

Jash, T; Basu. S(1999). Development of a Mini- Biogas Digester for Lighting in India, ENERGY 24; 409-411.

Kangle, K.M., Kore, S.V., Kore, V.S. and Kulkarni, G.S. Recent Trend in Anaerobic Codigestion: A Review: *Universal Joint of Environmental Research and Technology*, 2(4):210-219

Keefe, D.M., and Chynoweth, D.P. (2000). Influence of phase separation. Leachate recycle and aeration on treatment of municipal solid waste in simulated landfill cells. *Bioresource Techno* 72, 55-66.

Kirchgeßner, M. 1997. Tierernährung. 10th edition, Verlags Union Agrar, Frankfurt a. M., 582 p.
Linke, B. and Schelle, H. (2000).Solid State Anaerobic Digestion of Organic Wastes. Agricultural Engineering into the Third Millenium.*AgEng Warwick 2000. Paper Number 00-AP*-025, 101-102, 2-7 July 2000.
Madu, C. and O. A. Sodeinde. 2001. Relevance of biomass in the sustainable energy development in Nigeria. In Proc. National Engineering Conference and Annual General Meeting of the Nigerian Society of Engineers, 220 - 227.
Mähnert, P.M, Heiermann, M., Pöch, H, Schelle and Linke, B. (2002). Alternative Use for Grassland Cuts - Forage Grasses as Biogas Co-substrates (Verwertungsalternativen für Grünlandbestände – Futtergräser als Kosubstrat für die Biomethanisierung). Landtechnik; 5: 260-261.
Mata-Alvarez, J.; S. Mace; P. Llabres. 2000. Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource Technology* **74**: 3-16.
Momoh, O.L. Yusuf; Nwaogazie, L. Ify (2008): Effect of Waste Paper on Biogas Production from Co-digestion of Cow Dung and Water Hyacinth in Batch Reactors J. Appl. Sci. Environ. Manage. *December*, 2008 Vol. 12 (4) 95 – 98.
Mshandete, A., Kivaisi, A., Rubindamayugi, M., and Mattiasson, B. (2004). Anaerobic batch codigestion of sisal pulp and fish wastes. Biores. Technol. 95:19–24.
Murto, M., Björnsson, L., and Mattiasson, B.(2004). Impact of food industrial waste on anaerobicco-digestion of sewage sludge and pig manure. J. Environ. Manage. 70:101–107.
Sosnowski, P., Wieczorek, A., and Ledakowicz, S.(2003): Anaerobic co-digestion of sewage sludgeand organic fraction of municipal solid wastes. Adv. Environ. Res. 7:609–616.
Umetsu, K., Yamazaki, S., Kishimoto, T., Takahashi, J., Shibata, Y., Zhang, C., Misaki, T., Hamamoto, O., Ihara, I., and Komiyama, M. (2006). Anaerobic co-digestion of dairy manure and sugar beets. Intl. Congr. Ser. 1293:307–310.
Verein Deutscher Ingenieure, VDI 4630 Entwurf. (2004): Vergarung organischer Stoffe (Green paper: Fermentation of organic materials). Beuth Verlag GmbH, D-10772 Berlin

Plate 1: Experimental set up for batch digestion

Table 1: Chemical properties of substrates

Parameter	Analysis	
	Pig Slurry	Maize Cob
Dry Matter, DM (105^{o}C)-%	11.77	36.10
Organic Dry Matter (oDM, %DM)	84.05	97.30
Organic Dry Matter (%FM)	9.89	35.13
NH_4-N (g/kgFM)	1.22	<2
Crude Fibre (%DM)	26.75	28.32
Fat (% DM)	-	1.14
Potassium (% DM)	2.05	1.27
Ethanol (g/l)	0.12	<0.04
Propanol	<0.04	<0.04
Total Acetic Acid	0.88	8.12

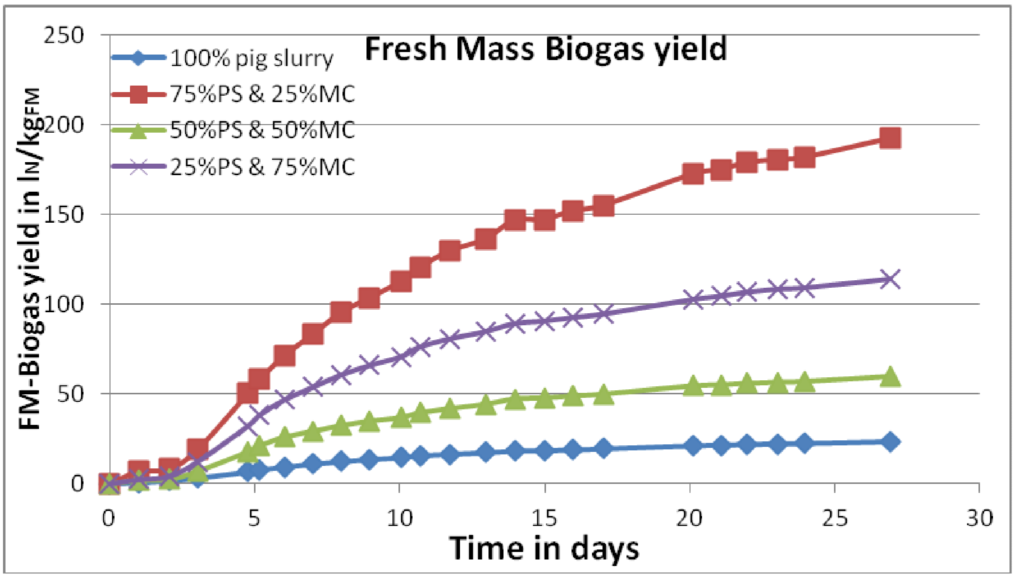

Figure 1: Fresh-mass biogas yields of pig slurry co-digested with maize-cob

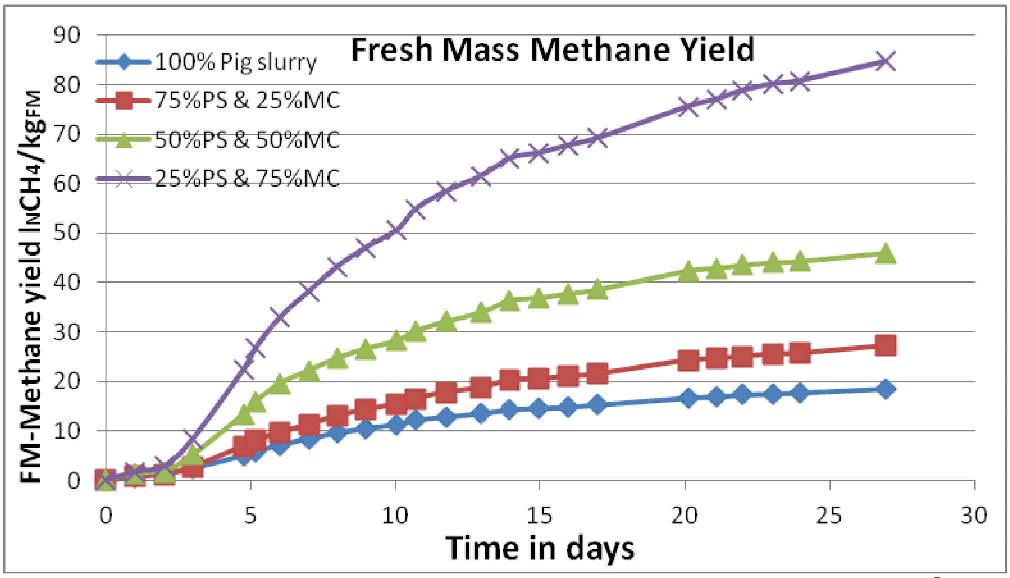

Figure 2: Fresh-mass methane yields of pig dung co-digested with maize-cob at 37°C

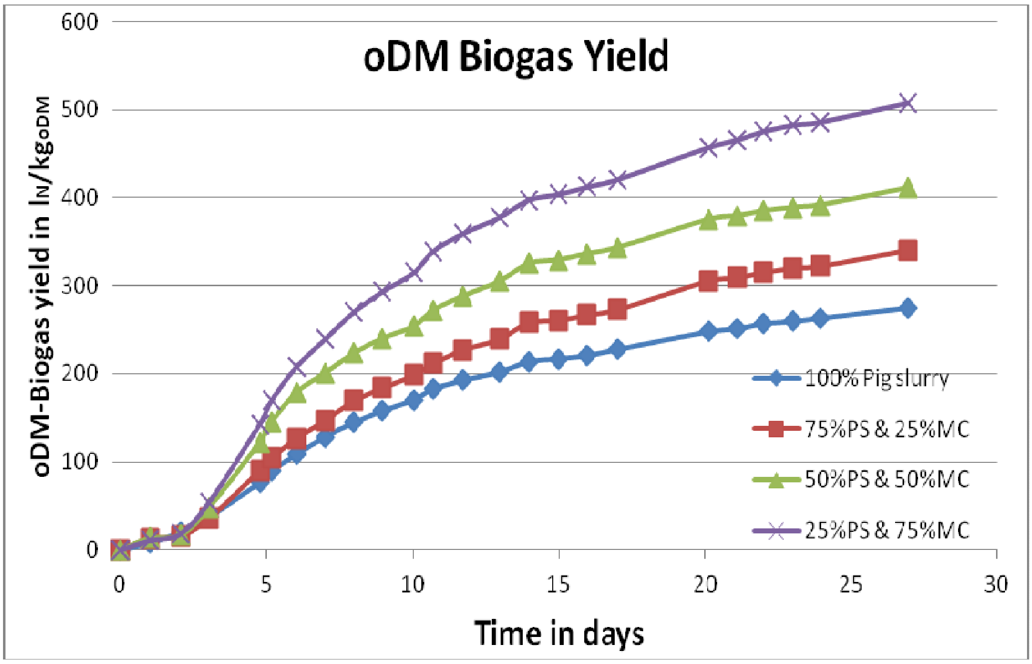

Figure 3: oDM biogas yields of pig slurry co-digested with maize-cob

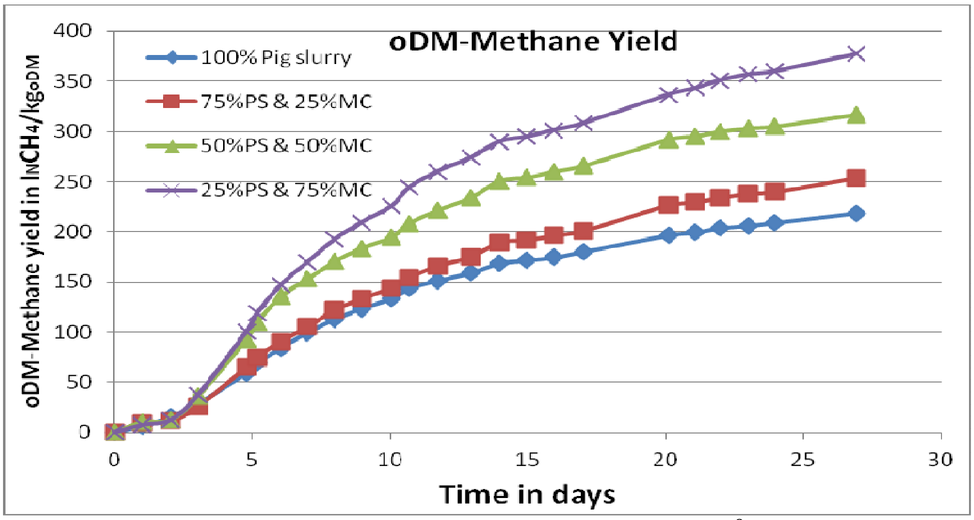

Figure 4: oDM methane yields of pig slurry co-digested with maize-cob at 37^{o}C

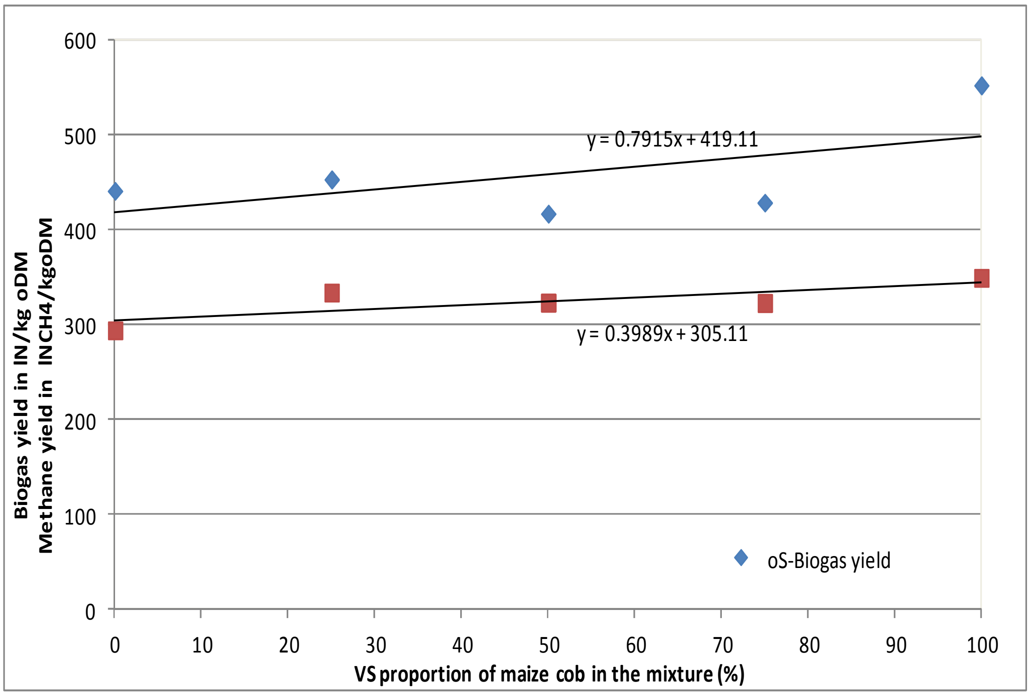

Figure 5: Co-digestion of pig slurry with maize cob

The IISTE is a pioneer in the Open-Access hosting service and academic event management. The aim of the firm is Accelerating Global Knowledge Sharing.

More information about the firm can be found on the homepage:
http://www.iiste.org

CALL FOR JOURNAL PAPERS

There are more than 30 peer-reviewed academic journals hosted under the hosting platform.

Prospective authors of journals can find the submission instruction on the following page: http://www.iiste.org/journals/ All the journals articles are available online to the readers all over the world without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. Paper version of the journals is also available upon request of readers and authors.

MORE RESOURCES

Book publication information: http://www.iiste.org/book/

IISTE Knowledge Sharing Partners

EBSCO, Index Copernicus, Ulrich's Periodicals Directory, JournalTOCS, PKP Open Archives Harvester, Bielefeld Academic Search Engine, Elektronische Zeitschriftenbibliothek EZB, Open J-Gate, OCLC WorldCat, Universe Digtial Library , NewJour, Google Scholar