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Biogas Production from the Co-Digestion of Rice straw with Cow Dung and Piggery Manure

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ABSTRACT

The Co-digestion of Rice Straw (RS) with either Cow dung (CD) or Pig Dung (PD) to produce biogas was studied. The objective of this study is to investigate the suitable mixing ratio of rice straw with cow dung and pig dung for enhanced biogas yield. Different mixing ratios of rice straw, cow dung and piggery dung were combined and investigated for potential biogas production at an Initial total solid (TS) of 20% in the co-digestion experiments. Results show that a maximum cumulative gas yield (CGY) of 36L/Kg of biogas was obtained in 40 days for a RS-PD ratio of 1:1. Similarly CGY of 33L/Kg, 32L/Kg and 29L/kg of biogas was obtained for RS-PD ratio of 1:2 and RS-CD ratio of 1:2 and RS-CD ratio of 1:1 respectively. Co-digestion of rice straw with piggery dung showed marginally higher biogas yields when compared to co-digestion of rice straw with cow dung suggesting that piggery dung provides a better Carbon/Nitrogen (C/N) ratio leading to increased biogas yield. The results also showed that co-digestion of rice straw with cow dung or piggery dung showed higher biogas yield when compared with mono-digestion of cow dung or piggery dung inoculated as control.

Keywords: Anaerobic digestion, Biofuels, Biogas, Biomass, Co-digestion

INTRODUCTION

The last few years has seen massive investment in Agriculture across Nigeria with particular emphasis by government to encourage increased production of rice. Rice is one of the most consumed staples in Nigeria, with consumption per capita of 32kg. Consumption has been on the increase in last decade with consumption increasing to 4.7%; almost four times the global consumption growth reaching 6.4 million tonnes in 2017 — accounting for 20% of Africa's consumption (PWC 2017). Given the importance of rice as a staple food in Nigeria, boosting its production has been accorded high priority by the government in the past 10 years. Significant progress has been recorded with rice production in Nigeria reaching a peak of 3.7 million tonnes in 2017 (PWC, 2017). Nigeria is the largest producer of rice (paddy) in Africa with an average production volume of 6 million metric tonnes. As of 2019, Nigeria ranked as the 14th largest producer of rice in the world with China being the top producing country. As of 2019, Africa had a total production volume of 14.6M, Nigeria produced about 55% and Egypt produced about 30% of the production volume (USDA, 2021).

This massive production of rice has led to a dramatic accumulation of residues like stalks and husks causing significant waste that need to be disposed. The use of solid agricultural waste from both animal and plant sources for production of biogas has been explored and studied intensely. Although the use of rice straw and rice husks provide alternative forage or silage for animal feed, its potential for use in biogas production offers a good economic prospect for the world's biofuel future as it also provides an appreciable energy and high quality fertilizer as a useful co-product (Goodman, 2020, Satlewal *et al.*, 2017, Odejimi and Udotong, 2005).

Biogas is typically composed of 50-60% methane (CH_4) and 30-40% Carbon IV oxide (CO_2) and some trace amount of water vapour, Ammonia and Hydrogen sulphide. Biogas can be used as cooking gas and natural gas for electricity especially in rural off grid communities or in agricultural farms and settlements. It has been produced from animal waste, human faeces, kitchen and municipal waste. The production of biogas from biomass involves the biological decomposition of these materials in the absence of oxygen. Biomaterials composed of carbohydrates, proteins and lipids are broken down by a consortia of microorganisms through the following stages; Hydrolysis, acidogenesis, acetogenesis and methanogenesis. Reports show a huge amount of reviews and studies on biogas produced from mono-digestion of animal waste, municipal waste (Igbum *et al.*, 2019), household waste (Al Wahaibi *et al*., 2020, Meegoda *et al*., 2018). Over the last 2 decades, there has been a considerable interest in the combination of plant residues and livestock waste as raw materials for biogas production. This process is referred to as co-digestion. It offers a worthy alternative for waste management across communities. The utilization of mono-digestion for biogas production can be limited by an imbalance in nutrients available, lack of diversified organisms and other operational factors. However, some of these challenges can be overcome by the co-digestion process. Several studies have shown that a combination of different biomasses (agricultural residues, farm waste materials, municipal waste and industrial waste) and livestock waste improves the economic viability of anaerobic digestion plants by production of higher methane gas. Other factors that can be enhanced by co-digestion process include the possible dilution of inhibitory substances, improved synergy of microorganisms from the different substrates, increasing biodegradability of organic matter (Zhang *et al*., 2013, Pages-Diaz *et al*., 2014, Kiros *et al.*, 2017Rabii *et al.*, 2019). Co-digestion can enhance biogas production from 25% to 400% over the mono-digestion of the same substrates (Cavinato *et al.*, 2010, Shah *et al*., 2015).

This paper investigates the biogas producing efficiency of anaerobic co-digestion of rice straw cow dung, piggery waste and their combinations. Researchers have reported the combination of rice straw and other animal waste at mostly laboratory scale in quantities between 250mL and 1L. Most of these studies are usually carried out at constant temperature. This paper will consider series of batch experiments carried out in 25L bioreactors and at different mixing ratios of rice straw, cow dung and piggery dung with an objective of determining the best ratio that leads to enhanced biogas yields between these substrates.

MATERIALS AND METHOD

Cow Dung (CD) and Piggery dung (PD) were collected from local farms located in Makurdi Benue State Nigeria while Rice Straw (RS) was collected from a demonstration farm in University of Agriculture Makurdi, Benue State. The rice straw was air dried and then pounded with a mortar and pestle to reduce particle size. The drum type digester system was designed and fabricated locally. It was divided into three main parts, the inlet chamber, the body and the outlet chamber and had the capacity of 25L. A thermometer was inserted through a drilled hole at the top of the drum to measure the temperature. Plastic hose were connected from the drum to the inverted measuring cylinder containing water so as to measure the volume of displaced water as the volume of gas produced. The measuring cylinder inverted with water was the main volume measurement of gas through a process called upward delivery and downward displacement. The digester was painted black to maintain the required temperature. A schematic diagram of the digester used is shown in our previous work(Ona *et al.*,2019). Series of batch experiments were carried out at ambient temperatures with varying weights of rice straw, cow dung and piggery dung making a total weight of 4kg per digester. The biomass weight was suspended in 20 L of water making a total solid loading of 20%. Mono-digestions of 4 kg of cow dung (CD) and 4kg piggery dung (PD) suspended in 20 L of water were used as controls. Different mixtures of rice straw (RS), cow dung (CS) and piggery dung (PD) were used for the experiments. These include corn RS-CD 2:1 (Rice Straw 2.667 kg, Cow dung 1. 333 kg, Water 20L), RS-CD 1:1 (Rice Straw 2 kg, Cow dung 2 kg, Water 20L), RS-CD 1:2 (Rice Straw 1.333 kg, Cow dung 2.667 kg, Water 20L), RS-PD 2:1 (Rice Straw 2.667 kg, Piggery dung 1.333 kg, Water 20L), RS-PD 1:1 (Rice Straw 2 kg, Piggery Dung 2 kg, Water 20L) and RS-PD 1:2 (Rice Straw 1.333 kg, Piggery Dung 2.667 kg, Water 20L).

The substrates were thoroughly mixed and stirred in the digesters. Each digester was manually mixed once a day to avoid stratification. The input slot was closed well with wax and hose clips to prevent leakage. The daily biogas production was recorded as Daily Gas Yields (DGY) by measurement of displaced water both in the mornings and afternoons. This is done by noting the quantity of water displaced from the gas collected in the measuring cylinder. The ambient temperature, digester temperatures and pH were measured at least twice a day both in the mornings and afternoons. Final Biogas yields were given as Cumulative Gas Yields (CGY).

RESULTS AND DISCUSSION

The results presented in this study show that Daily Gas Yields (DGY) and consequently, the Cumulative Gas Yield (CGY) varies with the different mixing ratios of rice straw, cow dung and piggery dung. It is also expected that biogas production is dependent on the carbon content as well as C/N ratios of the biomass utilized as substrates (Wang *et al*., 2012).

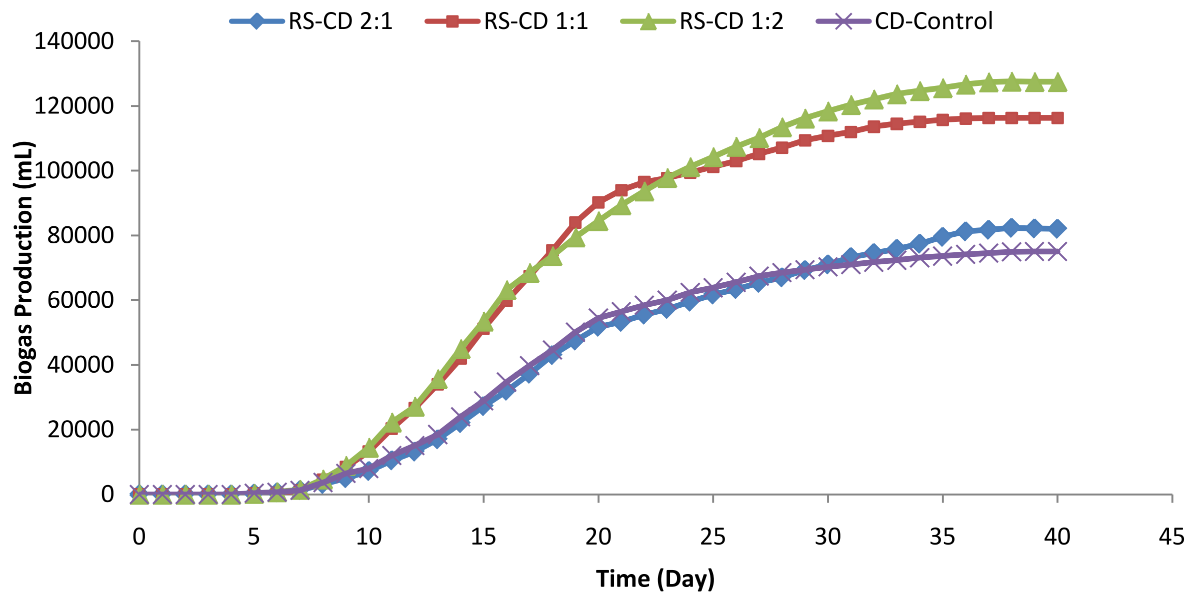

Figure 1: Progress curve showing the Cumulative Gas Yield (CGY) for the co-digestion of Rice Straw (RS) with Cow Dung (CD) at different mixing ratios with a retention time of 40 days

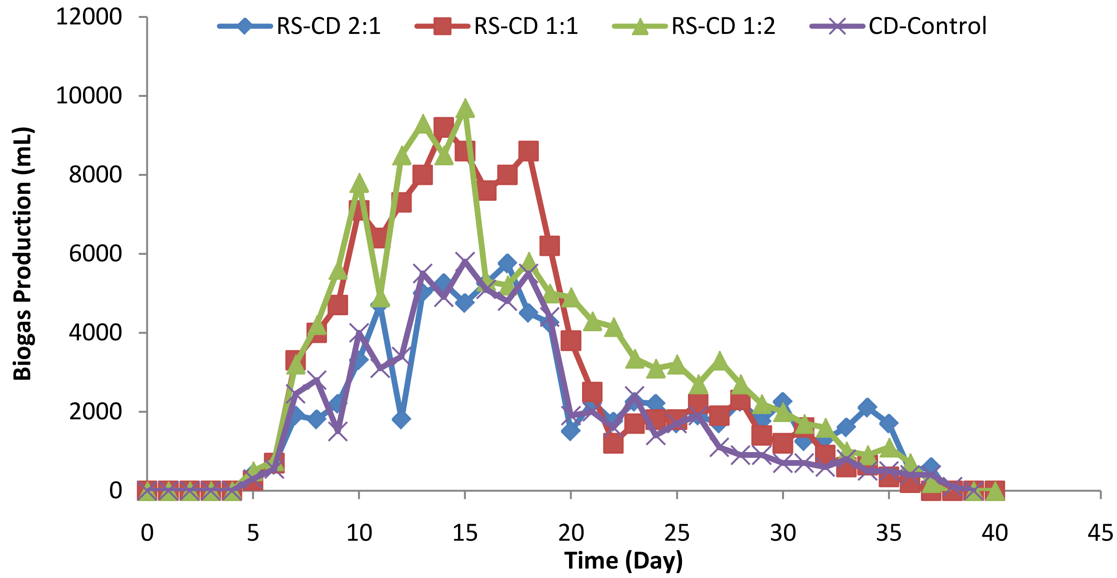

Figure 2: Progress curve showing the Daily Gas Yield (DGY) for the co-digestion of Rice Straw (RS) with Cow Dung (CD) at different mixing ratios with a retention time of 40 days

Results from Figure 1 and 2 shows the highest Cumulative Gas Yield (CGY) and Daily Gas Yields (DGY) obtained from the co-digestion of rice straw and cow dung. It can be observed that the mixture of RS-CD 1:2 has the highest CGY of 127L while a 50:50 combination of RS-CD 1:1 was lower with 116.3L. This relatively higher biogas yield from both experiments when compared to yields from mixtures with RS-CD 2:1 and the experimental control where only Cow dung (CD-Control) is used is probably as a result of increased C:N ratio that comes from the higher protein content expected in cow dung. Another possible reason is that cow dung might also have microbial flora that promote cellulolytic activities that facilitates a faster breakdown of cellulose and hemicellulose in Rice Straw. This is supported by studies carried out by González*et al.*, 2014 stating that ruminants produce microbes that aid the breakdown of complex carbohydrates.

The progress curve in figure 1 shows that experiments with higher cow dung content (both RS-CD 1:1 CD and RS-CD 1:2) have similar patterns of biogas yield until a difference is observed between day 18 and day 23 where a drop in biogas yield is observed for RS-CD 1:1. This might be due to nitrogen limitation within the RS-CD 1:1 where microorganisms involved in biogas production become less productive because lower amount of cow dung is utilized when compared to RS-CD 1:2. It is also possible that the higher available cellulose/hemicellulose content expected with rice straw in RS-CD 1:2 provides higher amount of substrate for the microbes to digest. Figure 2 shows that peak production of biogas occurred for all categories of mixtures of rice straw and cow dung between day 10 and day 16 with gas yields of between 5000-9700mL/day. There is a significant drop in gas yields after day 20 for all experiments with gas yields of less than 2000 mL/day however it is only in mixtures of RS:CD 1:2 that daily gas yields are still higher when compared to all other experiments ranging from 3300-5000mL per day after day 20 up until day 27. This can be attributed to greater amount of cellulose available for digestion by the synergy of microbial activities. It can also be observed that the control experiment with only CD showed very similar lower biogas yields with experiments carried out at a mixing ratio of RS-CD 2:1 between 0 hour and 30 hours however increased biogas yield is observed for RS-CD 2:1. This might be as a result of increased contribution of the lignocellulose materials in rice straw.

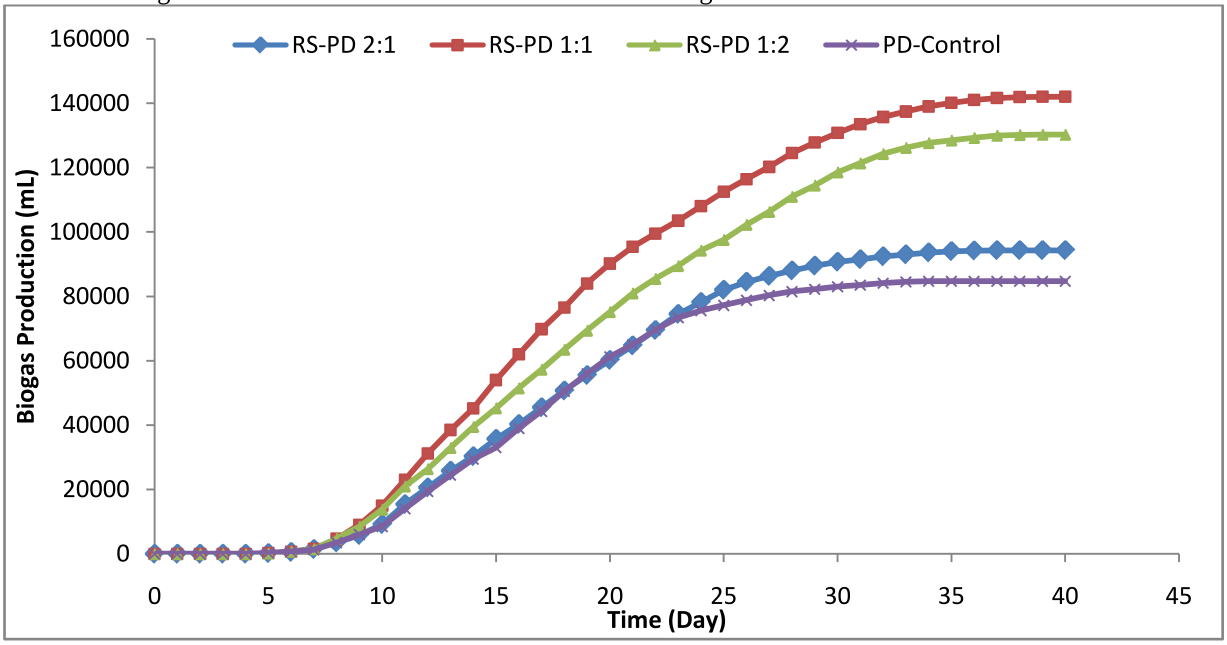

Figure 3: Progress curve showing the Cumulative Gas Yield (CGY) for the co-digestion of Rice Straw (RS) with Piggery Dung (PD) at different mixing ratios with a retention time of 40 days

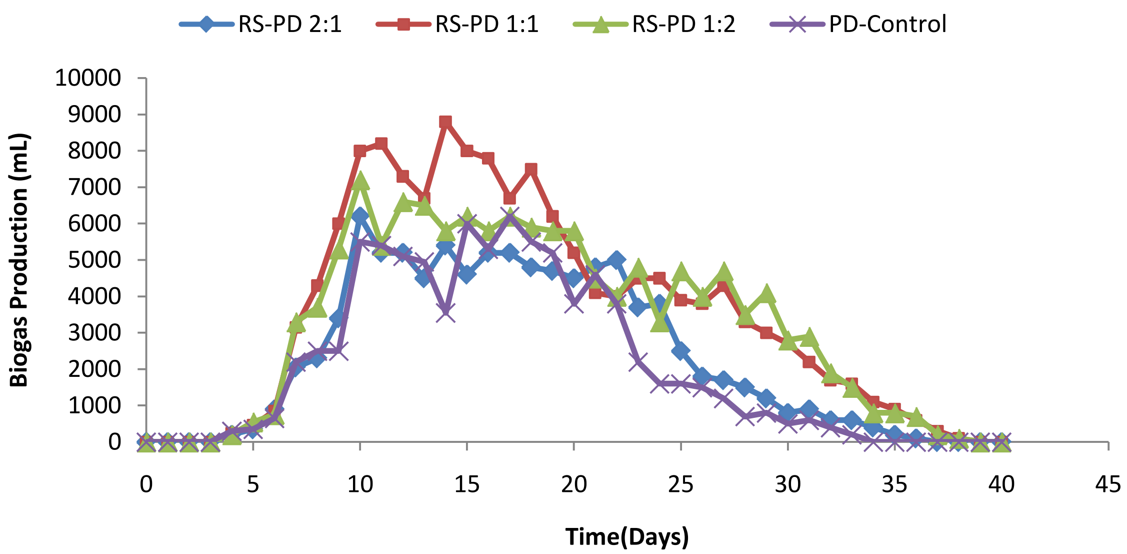

Figure 4: Progress curve showing the Daily Gas Yield (DGY) for the co-digestion of Rice Straw (RS) with Piggery Dung (PD) at different mixing ratios with a retention time of 40 days

Figure 3 shows results from the co-digestion of rice straw and piggery dung. Results show that a mixing ratio of RS-PD 1:1 produced the highest cumulative Gas Yield of 142L. This was followed by 130L for the RS-PD 1:2. Lower yields of 94L and 86L are observed for RS-PD 2:1

and PD control respectively. Figure 4 show that biogas production starts at day 5 for all co-digestion experiments. Results from figure 4 also show that the daily gas yield (DGY) of RS-PD 1:1 and RS-CD 1:2 were maximum between days 10 and day 20 showing gas yields of between 6500mL-7700mL per day. Although the DGY drops significantly for RS-CD 1:2 after day 13, the biogas yields for RS-PD 1:2 continue to be high until day 20 giving the highest CGY. This can be attributed to the higher nitrogen content present in piggery dung therefore providing a higher C/N ratio for metabolism of the microbes. The drop in biogas production between days 10 and day 20 for other mixtures might also be due to nitrogen limitation for microbes involved in biogas production. Results also show that biogas production can be affected by ambient temperatures with low yields observed on days with temperature less than 20^0C. It can be observed from figure 4 that Day 11 and Day 13 shows a drop in biogas production as ambient temperature recorded on those days werebellow 20^0C.Figure 5 shows average ambient temperature recorded during digestion. It was also observed that the biogas can be trapped as a result of stratification in the digester however the trapped gases are released on agitation of the digester. Co-digestion mixtures with RS-CD 2:1 and control experiments carried out with only PD show lower biogas yields of less than 100L. This might be caused by lower C/N ratio and the lower biomass quantity when only PD is used for the control experiment. A comparison of co-digestion of rice straw with cow dung (RS-CD) on one hand and rice straw with piggery dung (RS-PD) on the other hand is shown in Figure 6. It can be observed that the co-digestion of rice straw with piggery dung showed marginally higher biogas yield when compared with the co-digestion of rice straw with cow dung. Earlier literature has shown that when only piggery slurry or cattle slurry is used as substrate, piggery slurry produces higher biogas yields than cattle slurry(Appels *et al.*, 2008, Mnkeni and Austin 2009, Budiyono *et al*., 2010). Figure 6 also shows that while RS-CD 1:2 gave the maximum CGY when compared to RS-CD 1:1, the reverse is the case with the co-digestion of rice straw with piggery dung where RS-PD 1:1 gave the higher CGY when compared with RS-PD 1:2. Experiments carried out with higher biomass (RS-CD 1:1 and RS-PD 1:1) provides more lignocellulose materials for anaerobic digestion therefore it is expected to yield more biogas provided that nutrients like Nitrogen are adequate for the microbes to use at optimal conditions. This is because more lignocellulose materials lead to higher carbon content. Several reports in literature show that rice straw has high carbon content and so if the recalcitrance of cellulose is broken down by the microbes; it guarantees a high biogas yield. Darwin *et al.* 2014 reports that rice straw has a total cellulose and hemicellulose content of 55.2%. Other reports in literature give the carbohydrate content of rice straw with glucose (41–43.4%), xylose (14.8– 20.2%), arabinose (2.7–4.5%), mannose (1.8%) and galactose (0.4%) (Karimis *et al.,*2006). Jeya et al., 2009 also reported that rice straw contains 36.8% cellulose and 25.8%hemicellulose. However, because piggery and cow dungs are used as co-substrates, it is expected that other factors like the C/N ratio of rice straw, piggery dung and cattle dung will play a major role in biogas yield. Jusoh *et al*., 2003 reported a C/N of 61.3 for rice straw while other studies have reported a rice straw C/N ratio of between 44.0–74.2 (Li *et al.,*2015, Gu*et al.,* 2014, Ye *et al.*,2013 Lim *et al.,* 2012). Piggery dung and cattle dung are reported to have a C/N ratio of 13.0-14.2 and 7.0-10.8 respectively (Wang *et al*., 2006, Zhang *et al.,* 2013, Biosantech *et al.*,2013, Hills 1981). From these results, it can be understood that a combination of rice straw and piggery dung should provide a better C/N ratio resulting in higher yields of biogas compared to a co-digestion of rice straw and cattle dung.

Other studies have been reported where rice straw is combined with kitchen waste and pig manure in an optimal ratio of 0.4:1.6:1 having a C/N ratio of 21.7. This study reported the production yield of 674.4 L/kg which was higher than that of the digestion of rice straw or pig manure alone by 71.67% and 10.41%, respectively(Ye, 2013). Darwin *et al.* 2014 also carried out a study at a laboratory scale of 500 mL with rice straw and piggery waste at 3% total solid and a C/N ratio of 10.6:1. This study produced a maximum methane yield of 141.4±3.70 mL/g volatile solids (VS) added. Both of these studies are significantly different from this study because they were carried out at laboratory scale. These studies were also carried out at much lower total solid concentration (between 3 and 6% total solid) at constant temperature and agitation.

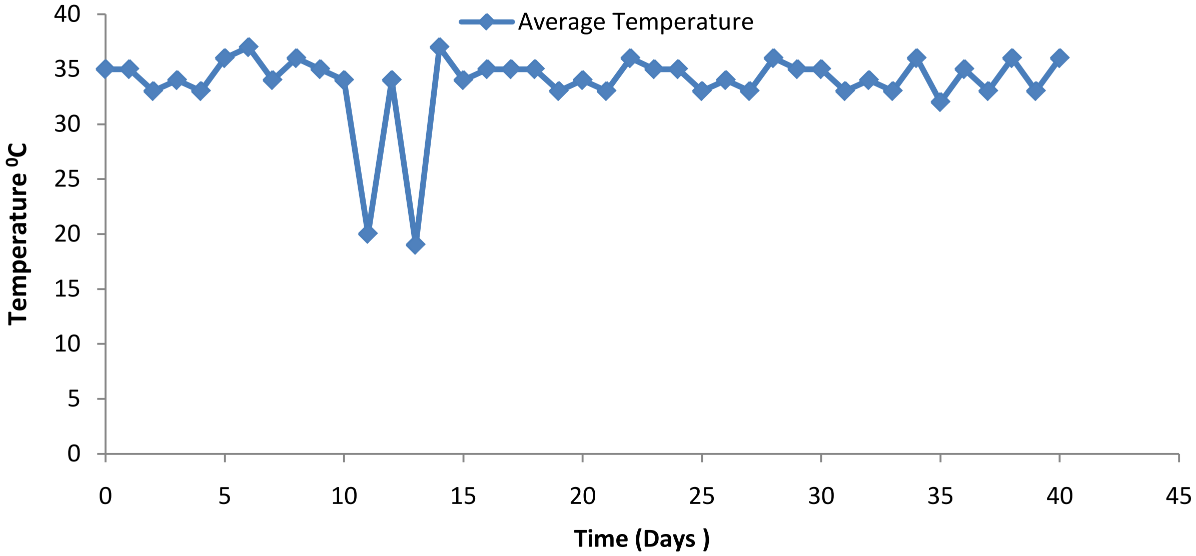

Figure 5: Progress curve showing the average ambient during the co-digestion of Rice Straw (RS) with Cow Dung (CD) at different mixing ratios for 40 days

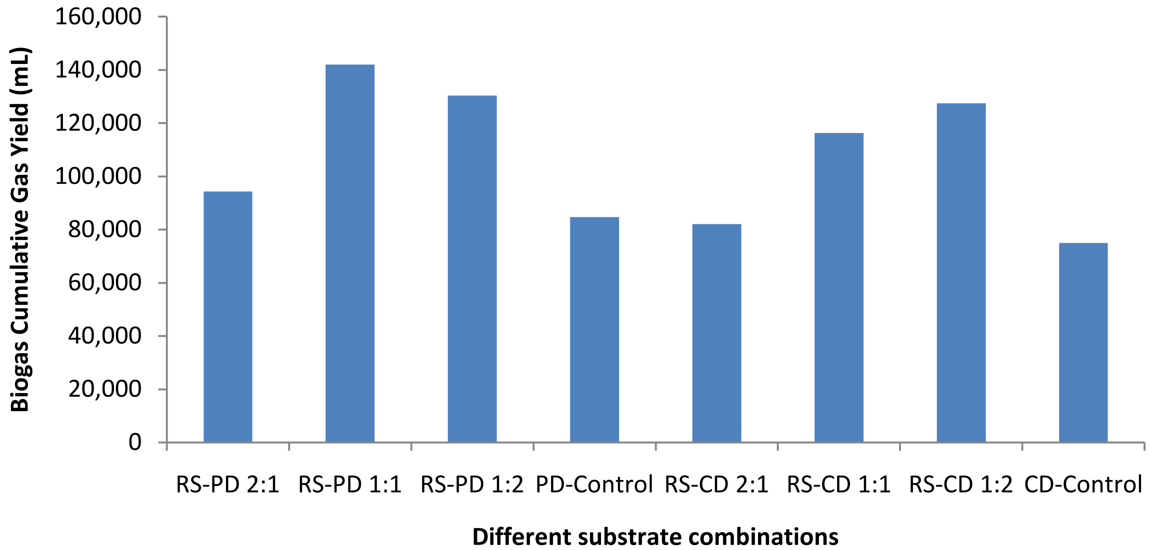

Figure 6: Comparison of the final Cumulative Gas Yield (CGY) from the co-digestion of rice straw with cow dung and piggery dung with a retention time of 40 days

CONCLUSION

This paper shows that a co-digestion of RS with either PS or CD provides viable alternative raw materials for biogas production. The final cumulative biogas yields observed for all combinations of rice straw with cow dung and piggery shows that combining these agricultural residues offers higher biogas yields when compared to mono-digestions with only cow dung or piggery dung. Although previous studies in literature have shown much higher biogas yields greater than 400L/kg of co-digestion experiments carried out at in laboratory shake flasks with maximum volume of less the 1L, It must be considered that these laboratory experiments are usually carried out with agitation, constant temperature and lower volume. The study also showed a marginally higher biogas yield with a co-digestion of rice straw with piggery dung when compared to a co-digestion of rice straw with cow dung. This difference in yield could be attributed to piggery dung providing better C/N ratio when combined with rice straw. It can also be concluded that mono-digestion by either piggery dung or cow dung produced lower biogas yields when compared to co-digestion with piggery dung and cow dung.

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