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Biogas Production from Co-Digestion of Grass with Food Waste

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Abstract

Management of grasslands in Ghana has become so poor that most rural communities result in bushfires that cause a lot of environmental challenges. Grass could be used for biogas generation. This study investigated the effect of grass and food waste co-digestion on the biogas yield and clarified how the addition of grass enhances the AD performance. Grass (GR) mixed with the co-substrate food waste (FW) was then evaluated under anaerobic conditions for the production of biogas (methane). Five laboratory-scale reactors, R1 (100% FW, 0% GR), R2 (75% FW, 25% GR), R3 (50% FW, 50% GR), R4 (25% FW, 75% GR) and R5 (0% FW, 100% GR) were set up with different proportions of grass and food waste which had 8% total solid concentration. Digestion was carried out for twenty (20) days at room temperature, 35˚C ± 2˚C. The biogas yield in the R1, R2, R3, R4, R5 was 805, 840, 485, 243 and 418 mL respectively. Food waste only produced 805 mL and grass only produced 418 mL of biogas. Food waste only produced 50% more biogas than grass. However, co-digestion at 75% FW, 25% resulted in 6% more biogas than food waste only.

Keywords

Grass, Co-Substrate, Food Waste, Anaerobic Digestion, Biogas

1. Introduction

Grasslands play an important role in global agriculture covering around 26% of world's total land area [1]. In most developing countries, grasses are the main plant species in verges along roads, dams and on river dikes, for that reason, the hectares of grassland available are difficult to quantify. Besides its role as basic nutrient for herbivores and ruminants, grassland has a key role in the prevention of erosion, the immobilization of leaching minerals and carbon storage, helps in the regularization of water regimes and in the purification of pesticides and fertilizers. It also serves to furnish a habitat for wildlife, both flora and fauna and contributes to the attractiveness of the landscape [2] [3] [4].

In recent years, considerations on grassland use for bioenergy have increased considerably, mainly for biogas production and as solid fuel for combustion [5]. As well as for biogas production, grasses can be used in future for the production of lignocellulosic bioethanol, synthetic natural gas or synthetic biofuels. Previous studies have shown that grass represents a category of surplus lignocellulosic biomass, and it can also be used for biogas production [6]. The main benefits of using grass for bioenergy production are its lower water consumption for growth than other crops and the fact that it can be cultivated in non-arable lands, without competing with food crops [7] [8] [9].

At present, food waste (FW) regarded as municipal waste is sent to landfills and incineration plants as final disposal points. In some ways, these processes release some stress from garbage siege; at the same time, a series of problems are emerging including the rising cost of waste disposal, the lack of land space, groundwater pollution by leachate, and the emission of toxic and greenhouse gases [10]. Sometimes animals are fed with these wastes. FW is a desirable material to co-digest with grass because of its high biodegradability [11].

Anaerobic Digestion (AD) is a biochemical technology for the treatment of organic wastes and the production of biogas, which can be used as a fuel for heating or co-generation of electricity and heat. Anaerobic digestion of grass has been extensively researched and demonstrated. Previous studies [1] [6] have demonstrated that grass is a desirable material for biogas production. However, based on investment returns from energy production, the economics of grass are not favourable due to the relatively low biodegradability especially when no pre-treatment is done [1]. Biogas yield of grass, as compared to many other types of organic wastes such as food waste has been low. One of the approaches for improving the economics of grass is to increase their biogas production rate by co-digesting the grass with more degradable wastes.

Co-digestion of different materials may enhance the anaerobic digestion process due to better carbon and nutrient balance [12] [13] [14]. According to Mata-Alvarez *et al.* [14] [15], digestion of more than one substrate in the same digester can establish positive synergism and the added nutrients can support microbial growth. During mesophilic anaerobic co-digestion of cattle manure and fruit and vegetable wastes (FVW) in a continuous stirred tank reactor (CSTR) at 35˚C, Callaghan *et al.* [16] (2002) found that increasing the percentage of FVW from 20% to 50% increased the methane yield from 230 to 450 L/kg VS added. Misi and Forster [17] found that batch co-digestion, at 35˚C, of cattle manure with molasses (50% on dry weight basis) increased the biogas yield from 60 to 230 L/kg VS added.

The above discussions highlight that biogas is considered to be an important component of the future renewable energy mix. Given its nature it has great flexibility to be converted to electricity, stored as a pressured gas or cleaned and used in a gas grid or as transport fuel. Many options exist for its production and of these grassland show significant promise. This study was initiated to investigate the feasibility of adding food waste into grass to enhance the biogas production. The work is also aimed to add knowledge to the anaerobic digestion of grass and food waste degradation. This study aims to: 1) Investigate the effect of grass and food waste co-digestion on the biogas yield; 2) clarify how the addition of grass enhances the AD performance.

2. Materials and Methods

2.1. Inoculum and Substrates

Microbial inoculum (sludge) was collected from a mesophilic operating anaerobic bioreactor from the bio-methanation plant at TERI GRAM, India. Food waste and grass were the substrates used. Mechanical pre-treatment (Chipping) was carried out to reduce the size of grass for better digestion [18] [19]. After chipping the final particle size of grass was usually between 10 - 30 mm [19]. Grass was collected in a polythene bag and transferred to the laboratory. The pre-treatment used for the food waste was grinding [20]-[24]. Substrate ratio for food waste and grass was varied to maintain the C/N ratio. No chemical treatment was carried out on the materials before use.

2.2. Experimental Design

Batch experiments were carried out in the laboratory. The digestion test was carried out using 300 mL glass bottles with a working volume of 225 mL. The experiment was operated at 37˚C ± 2˚C for twenty (20) days. The experimental conditions are given in **Table 1**. The experimental conditions were carried out to examine the influence of co-digestion ratio (R1 to R5) on biogas yield. The concentrations of the substrate were based on organic loading mass [25]. The amount of volatile solids (VS) of the inoculum and the substrate were calculated based on the predetermined co-digestion ratio. For all experiments, fresh water

Table 1. Experimental conditions of the batch tests.

Experimental Design					
	Co-digestion Ratio, Food waste (FW): Grass (GR) (%)		Quantity, FW: GR (g)		Pre-treatment
	FW	GR	FW	GR	
Experiment					
R1	100	0	75.00	0.00	Grinding
R2	75	25	56.25	18.75	
R3	50	50	37.50	37.50	
R4	25	75	18.75	56.25	
R5	0	100	0.00	75.00	Chipping

was added, and no additional nutrients/trace elements were added to the reactors as it was assumed that they are provided by the inoculum (anaerobic sludge).

Studing the reactors (R1, R2, R3, R4, and R5), the influence of the different co-digestion of food waste and grass on biogas production, food waste was used as the sole substrate and inoculum was added for R1, while grass was the sole substrate in R5 and the inoculum was added. The experimental conditions of the batch test were chosen based on trail preliminary experiments in the laboratory. The designed percentages (see experimental set-ups) of waste were put in the digester and water was added at a ratio of 1:2. This was placed in a BOD incubator for six (6) days without the addition of culture. This acidification stage was carried out for 6 days. The pH was adjusted with Sodium Hydroxide (NaOH). The methanogenic culture was added after the sixth day. Biogas production started the next day and the monitoring of the gas was done for twenty (20) days. The daily gas production was recorded as Daily Gas Yields (DGY) by measurement of displaced water every morning. This is done by noting the quantity of water displaced by the gas collected in the measuring cylinder.

2.3. Analytical Techniques

2.3.1. Organic Carbon

Organic carbon was determined by the method of Datta *et al.* (1962) [26]. A known quantity (1.0 g) of completely dried and powdered waste was taken in a 250 ml conical flask, then 10 ml of 1N potassium dichromate ($K_2Cr_2O_7$) was added and mixed thoroughly. After mixing, 20 ml of the concentrated sulphuric acid (H_2SO_4) was added and kept for 4 - 5 hours. The mixture was diluted by adding 100 ml distilled water and kept for 1 hour for waste particles to settle. The optical density of clear solution was measured at 645 nm. The organic carbon was calculated using sucrose as standard.

2.3.2. Total Nitrogen

Total nitrogen was estimated by the method of Jackson (1967) [27]. One gram of waste was heated with 5 ml concentrated sulphric acid slowly until the solution was clear. The contents were made up to 50 ml. 5 ml aliquote of the solution was transferred to Kjeldahl distillation apparatus and heated. The distillate was collected in 5 ml of 4% boric acid and then titrated with standard 0.01 NHCl. The nitrogen content was calculated using the titre value.

2.3.3. COD Estimation

Total and soluble COD of the waste slurry was monitored during the course of the digestion to check the digestion level of the slurry. A homogenised paste of the waste was used for total COD determination. For soluble COD estimation, slurry was centrifuged at 8000 rpm for 20 minutes and then supernatant was analysed for COD according to standard methods (APHA) [28].

2.3.4 Total Solids, Volatile Solids and Fixed Solids Estimation

For TS, a known amount of sample was transferred into a previously weighed crucible and dried at 110˚C for 24 hours. For volatile solids (VS) estimation, dried sample obtained after TS estimation was ignited in a muffle furnace at 550˚C for 4 hours and for fixed solids, the residue left in the vessel after a sample is ignited (heated to dryness at 550˚C) was estimated [28].

3. Results and Discussions

3.1. Chemical Composition of Raw Substrate

Table 2 shows the composition of raw substrate used in the digestion process. It is clear from the table that grass has a low pH which can be attributed to the high concentration of volatile fatty acids (VFAs) in the waste of above 800 mg/l which was also reported by Abu-Dahrieh J. K. *et al.* [29]. The increased VFA content could be as a result of the fermentation of the grass. The VFAs in the waste are then used directly in the acetogenesis stage to produce acetic acid, which is then used by the methanogens to produce methane.

3.2. Daily Biogas Production Rate

All the experiments were carried out under daily mean temperature range of 37˚C ± 2˚C throughout the period of biogas production. The results of the experiment carried out for the twenty (20) days indicated that blending of field grass with the food waste affected the total biogas yield and onset of gas flammability for each of the biogas systems. Biogas production from all the rectors commenced within 24 hours after the acidification process of six (6) days. During the acidification process, pH dropped to 5 on the third day and it was reset to 7. This could be due to the fact that Volatile Fatty Acid (VFA) is possibly high. If the VFAs are not utilized at the rate they are produced, then it can kill the methanogenic activity due to lower pH. Feng *et al.* [30] reported that the possible acidogenic biological pathways that lead to a varied distribution of the VFAs, mainly is a function of pH. Maximum biogas was produced on the first day in all rectors. Daily biogas production from the grass and food waste is graphically shown in **Figure 1**.

Table 2. Characterization of raw materials used in the biogas digester.

S/N	Parameters	Food Waste (FW) %	Grass (GR) %
1	Moisture (%)	74.79	62.32
2	TS (%)	25.21	38.1
3	VS (%)	92.87	77.04
4	Fixed Solids (%)	7.13	22.96
5	Organic Carbon (%)	82.35	71.20
6	Nitrogen, N (%)	2.15	1.98
7	C:N Ratio	38:1	35:1
8	pH	3.80	3.40
9.	COD (mL/g of O_2)	18,557.82	13,768.71

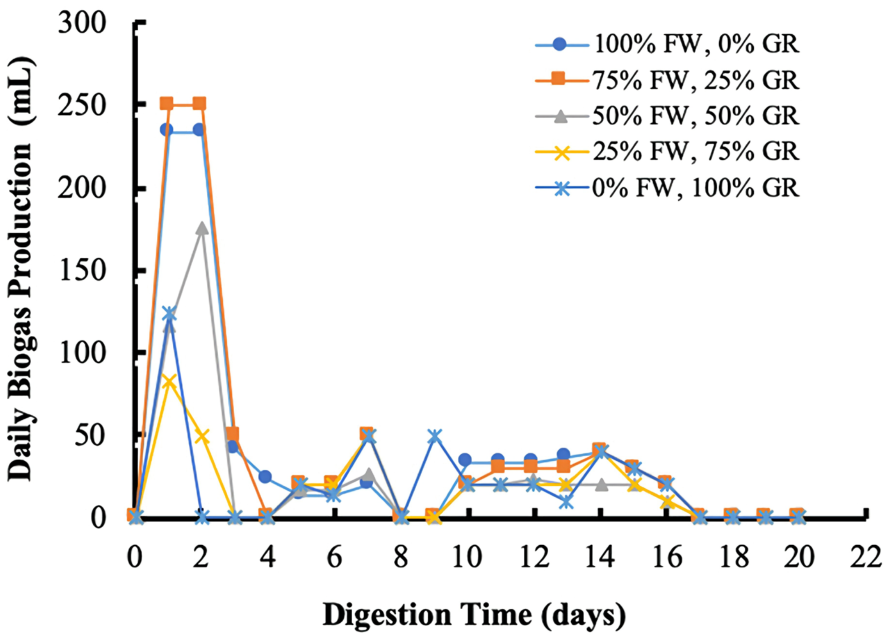

Figure 1. Daily biogas production of co-digestion of food waste and grass in different percentages.

It is observed in **Figure 1** that the reactor 1 (R1) *i.e.* 100% FW produced the highest daily biogas yield of 233 mL. Grass only (R5) produced the lowest daily biogas yield of 125 mL. Food waste produced 50% more than grass only (R5). This is probably due to the lignocellulose structure of grass. Cellulose and hemicellulose are polysaccharides that can be hydrolyzed into simple sugars. Lignin which acts as a support to the cell structure, embedding cellulose and hemicellulose, hinders the susceptibility to microbial attack during hydrolysis process [31]. The main aim of the pretreatment is to break the lignin layer that protects the cellulose and hemicellulose, in order to make the biomass more accessible for digestion [31]. Co-digestion at 75% FW and 25% GR (R2) resulted in 6% more than food waste only. **Figure 1** illustrates daily biogas production for all reactors over a period of twenty (20) days. For all of the reactors, there is a sharp increase in the amount of biogas produced during the first 1 - 2 days of the experiment. This is then followed by a sharp decrease following the near-complete consumption of the different substrates in the reactors. This was due to the increased availability of the biomass during the initial stages, leading to subsequent growth of the anaerobic organisms. After 3 days the rate of biogas production began to decrease due to a reduction in nutrient content. The samples show that there was a decrease in pH from pH 7.0 - 5.0 over the course of the experiment for all reactors. The dropped pH was reset to 7.

At the beginning of gas production, the anaerobes present in the organic material became active and began increasing in population [31]. When gas production began to rise, they were fully established and were acting on more substrate. At the peak of production, they were acting on the maximum amount of organic matter possible. After this point, gas production began to drop because the excess substrates were being converted to methane. At this point also, there is a steady decline in the amount of substrate available to the bacteria to act on [31]. There is also a decrease in either carbon or nitrogen available for use. When one becomes exhausted, the process slows gradually to a stop. This decline continues until gas production gradually comes to an end. While the process progresses, the condition becomes more appropriate for the methane forming bacteria. This led to an increase in the percentage composition of methane in the biogas produced until the maximum level is reached. Thus as fermentation approaches the end, the burning characteristics of the biogas improve [32].

3.3. Results of Different Experiments (Ratios) for Optimum Production

Figure 2 shows the commutative biogas yield for the experimental setup R1 to R5. Cumulative Biogas Yield for R4 made up of 25% food waste and 75% grass recorded 243 mL. This may be due to the high cellulose content of the grass. The small amount of anaerobic bacteria present will take more time to establish itself and begin biogas production. The sample made of 50% grass and 50% food waste (R3), and those made up of 25% grass and 75% food waste (R2), 100% food waste (R1) and 100% grass (R5) recorded 485, 840, 805 and 418 mL of biogas yield respectively.

Co-digestion of 25% grass and 75% food waste (R2) produced the maximum biogas. This is similar to the study of Okonkwo *et al.* [33]. They reported that a maximum volume of biogas, 809 cm^3 was produced by the sample containing 50% poultry dropping and 50% weeds. This indicates that this sample possesses the best C/N ratio of all the samples prepared. Different materials have their C/N

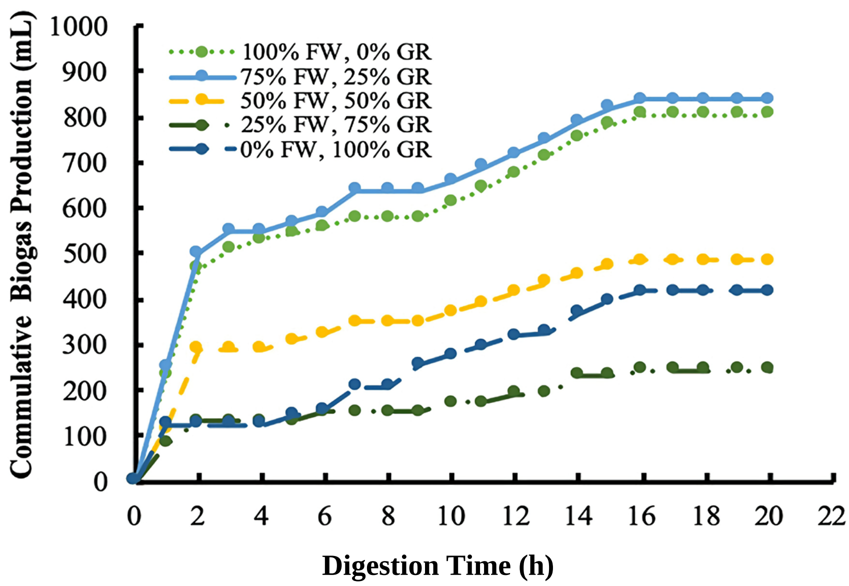

Figure 2. Commulative biogas production of co-digestion of food waste and grass in diffrent percentages.

ratio, but mixture of different materials can alter the overall C/N ratio of the total feedstock. The result shows that this sample contains the C/N ratio which approaches the optimum C/N ratio of 30:1. R4 produced the least of the biogas which is similar to the studies by Okonkwo *et al.* [33]. They reported that the sample containing 25% poultry dropping and 75% groundnut shell had the least desirable value of C/N ratio. The bacteria responsible for the anaerobic process required both elements, as do all living organisms, but they consume carbon roughly 30 times faster than nitrogen. Assuming all other conditions are favourable for biogas production, a carbon-nitrogen ratio of about 30:1 is ideal for the raw material fed into a biogas plant. A higher ratio will leave carbon still available after the nitrogen has been consumed, starving some of the bacteria of this element. These will in turn die, returning nitrogen to the mixture, but slowing the process. Too much nitrogen will cause this to be left over at the end of digestion (which stops when the carbon has been consumed). The correct ratio of carbon to nitrogen will prevent the loss of methane content [33].

4. Conclusion

Biogas is produced by the anaerobic digestion of grass and food waste. Over a period of twenty (20) days, 840 mL of biogas was produced from a mixture of food waste and grass. A mixture of 25% grass and 75% food waste produced the largest volume of biogas. It is suggested that a ratio of 25% grass and 75% food waste should be used for co-digestion of food waste and grass. The digester after acidogenesis stage took only one day to begin biogas production and produced a higher volume of the total, hence it is suggested that the first two days should be the peak days for biogas collection. Further studies would be carried out in bigger volume reactors (5 L AND 10 L) and also on a pilot scale.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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