Influence of Digestate Recirculation and Recirculation Percentage on Biogas Production from Lawn Grass via Anaerobic Digestion

Noxolo T Sibiya, Habtom B. Tesfagiorgis and Edison Muzenda

***Abstract*—Recirculation of digestate either in the form of liquid or solids has proven to enhance biogas production from energy crops including lawn grass. The explanation to this is that digestate contains suitable bacteria and trace elements (nutrients) needed by methanogens. Influence of digestate recirculation and recirculation percentage in biogas production from lawn grass via anaerobic digestion was studied in laboratory scale digester (1L plastic bottles) at mesophilic condition. Three scenarios were used: digester without recycle digestate (control) (WRD), digesters with recycled liquid digestate (RLD) and digesters with recycled solid digestate (RSD). Liquid recycled digestate was added in percentages variation ranging from 10%-60%, solid recycle digestate was added in percentages variation ranging from 10%-50%. The maximum biogas production with methane content of 55% was obtained in the digester with 60% RLD on the 8th day. During the study of recirculation of solids, highest biogas yield with methane content of 53% was observed in a digester with RSD of 40% on the 5th day. Retention time for both digesters with recycled digestate was reduced and biogas production rate was increased compared to the digester with no recycled digestate**

***Index Terms*— Biogas, Digestate, Recirculation, Retention time**

I. Introduction

BIOGAS production via anaerobic digestion (AD) is of great importance in the present world's energy situation due to its renewability [1]. Additional benefit of this technique is that the end product (biogas) can be used as vehicle fuel, or for co-generation of electricity and heat, and thus reducing the environmental challenges which result from greenhouse gases (GHG) emissions [2].

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In South Africa, grass is one of the most abundant agricultural residues, covering approximately 28.4% of the country's land [3]. Thus, making use of grass waste for biogas generation can be quite significant. However, grass waste cannot be effectively degradable due to an imbalance in nutrients for microorganism and lack of buffering capacity for chemical reaction [4]. In addition, grass belongs to the lignocelluloses biomass group containing about 30% of lignin, 50% hemicelluloses and 40% cellulose [5]. These characteristics make it even more difficult to be broken down. Previous researchers reported that biodegradability of grass can be improved by pre-treatment such as chemical, mechanical, explosion as well as co-digestion [6]. It was also suggested that the imbalance of nutrients and vitamins can be ameliorated by re-introducing liquid digestate or / and solid digestate into the digester [6],[7]. According to Gerin *et al.* [8] recycled digestate contains bacteria, responsible for the whole AD process, and a range of nutrients and vitamins needed by these micro-organisms.

Preceding researchers have focused more on studying the effect of liquid/ leachate recirculation other than the recirculation of solid digestate. As a result, there is a limited literature on the effect of recirculation of solid digestate on the anaerobic process. Peng *et al.* [9] investigated the impact of recycling different digestate fractions during anaerobic digestion of wheat straw in single-stage continuous stirred tank processes. They compared three scenarios: one without recycling of digestate serving as a reference control while in the other two, the supernatant after centrifugation and after filtration were recycled to the reactors. Their results showed that the methane content in reactors with recycle leachate was above 50% while for the reactor without recycling was below 50% after 50days of process operation. Murphy *et al.*[10] further reported an increase by 21% of methane yield in the digester with recycled nutrients. In addition, process with recycled nutrients showed stability indicated by minimal VFA accumulation (<0.5g/L).

Though recirculation of liquid digestate optimizes the anaerobic digestion, excessive re-use may results in process inhibition due to the accumulation of microbial waste products, recalcitrant component as well as intermediate breakdown components such as ammonia in the liquid digestate [11].

This study was carried out for the purpose of investigating the influence of digestate recirculation in a digester during anaerobic digestion of lawn grass. The objective was to give a clear understanding on the importance of using recycled digestate, determining the digestate phase and ratio that gives the optimal biogas and methane production.

II. Material and Procedure

A. Material

The lawn grass was collected in summer, at University of Johannesburg, South Africa. Cow dung, used in this study as a source of inoculum, was collected from Johannesburg Zoo. Both substrates were stored in $4^{o}C$ until used in the experiment. The recycled liquid and solid digestate were obtained by filtering the effluent from the mesophilic digester treating lawn grass through a sieve (112 µm pore diameter). Both extracted solids digested and liquid were sufficient to run the experiment at different percentage ratios.

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B. Experimental Procedure

Ten 1litre batch scale anaerobic digesters (plastic bottles) with the working volume of 800mL were used in this study. All digesters were operated on a 14 day retention time at $45^{o}C$. Fig.1. shows the schematic diagram of experiment laboratory set up conducted during anaerobic digestion of lawn grass. Each digester was started with seeding fresh lawn grass with 10g of cow dung and then fed according to the table 1 and 2 at the loading rate of 60g/L in total. Digesters were then sealed and purged with nitrogen to create anaerobic condition. The control was used without recirculation for comparison. Mixing of content of the digester was achieved by shaking the digester twice a day.

A. Analysis methods

To determine the moisture content (MC) and Total solids (TS) fresh substrate was weighed and then dried in an oven at 105 ^{o}C. After 24 h, the dried substrate was weighed. The MC was calculated by the expression MC (%) = 100- (Original weight- dry weight)/ original weight and $TS = (m(dry)/m(wet)) \times 100\%$. To determine the total volatile solid (TVS), dried samples were combusted at 550 ^{o}C for 2 h and the mass of ash (m(ash)) was measured. The volatile solid content (VS) was calculated by the expression $((m(dry) - m(ash))/m(dry)) \times 100$. Where m (dry) referred to dry mass, m (ash).

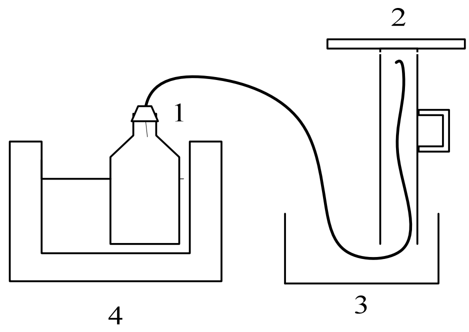

Fig. 1 Schematic showing the lab-set up for anaerobic digestion of lawn grass. Where: 1 = digester, 2 = the measuring cylinder, 3= trough with water and 4 = water bath or incubator.

Chemical composition of lawn grass and cow dung is shown in TABLE I. The digester pH was measured by pH meter (Thermo Electron, USA). Biogas production was measured daily by means of water displacement. Methane content in biogas analysis was carried out in a gas chromatograph (GC, claurus 8610) equipment with a thermal conductivity detector (TCD) and matrix molecular sieve 5A column (Sigma–Aldrich, USA). There were three replicates for each experiment. The standard deviations and statistics differences were analyzed by Microsoft excel 2010. Graphs were drawn using Microsoft excel 2010. TABLE II and TABLE III shows the ratios at which recycled digestates were fed in the digester for both studies.

TABLE I

CHEMICAL COMPOSITION OF LAWN GRASS AND COW DUNG

	Lawn grass	Inoculum(cow dung)
MC (%)	8.44	83
TS (%)	79.12	19
TVS (%)	84.2	72
pH	7.12	6.5
C:N	42	24

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TABLE II

DIFFERENT RECYCLED LIQUID DIGESTATE PERCENTANGE INPUT

Number of digester	Total liquid recovered (ml)	Recycled liquid digestate		New fresh water Fed	
		ml	percentage	ml	percentage
1	-	0	0%	680	100%
2	680	68	10%	612	90%
3	680	136	20%	544	80%
4	680	204	30%	476	70%
5	680	272	40%	408	60%
6	680	340	50%	340	50%
7	680	408	60%	272	40%

TABLE III

DIFFERENT RECYCLED SOLID DIGESTATE PERCENTAGES INPUT

Number of digester	Total solid recovered (g)	Recycled solid digestate water		Fresh lawn grass fed	
		g	percentage	g	percentage
1	-	0	0%	50	100%
2	50	5	10%	44	90%
3	50	10	20%	40	80%
4	50	15	30%	35	70%
5	50	20	40%	30	60%
6	50	25	50%	25	50%
7	50	30	60%	15	40%

III. Results and discussion

A. *Influence of recirculation of liquid digestate in anaerobic digestion of grass*

As shown in TABLE I, grass had the highest TS content (79.21%) and TVS (84.2%) than While cow dung (inoculum) had 19% of TS and 72% of TVS. In this study, the C: N of grass was found to be 42. A report by Oleszek et al., [12] showed similar results for reed canary grass.

Total biogas production, methane content and methane content with respect to time during anaerobic digestion of grass with 0%, 10% , 20%, 30%, 40%,50% and 60% recycled liquid digestate are shown in Fig. 2. As shown in Fig. 2 A, the percentage of recycled liquid digested had significant effect on total biogas production, hence biogas production increased with an increased in recycled liquid digestate percentage. The highest total biogas of approximately 6962.3 mL was obtained in the digester with 60% recycled liquid digestate, followed by the digester with 50% recycled liquid digestate. These observations may be associated with the presence of suitable bacteria from recycled liquid digestate in the digester. The total biogas volume on the 14th day for digester with 10%, 20%, 30%, and 40% were 2600mL, 3840mL, 6350mL, and 6550 mL respectively. All the digesters with recycled liquid digestate had high methane content in comparison to the digester without recycled liquid digestate.

The methane content followed the same pattern like the biogas production (Fig. 2 B) and increased with an increase in recycled liquid digestate. An increase in methane content by approximately 10% was obtained when recycled liquid digestate of 60% was added into the digester. This was assumed to be due to the exponential growth of methane producing bacteria in the digester. These results are in agreement with results reported by Nges *et al.* [13] who investigated wheat as a substrate. The effect of retention time on methane content is represented in Fig. 2 C**.**

In this study, the biogas production was produced straight from day 1 of the experiment in all digesters, and increased with time. The highest total biogas production peak was observed on the 9th day. From this finding it can be concluded that optimal retention for this study was 8 days.

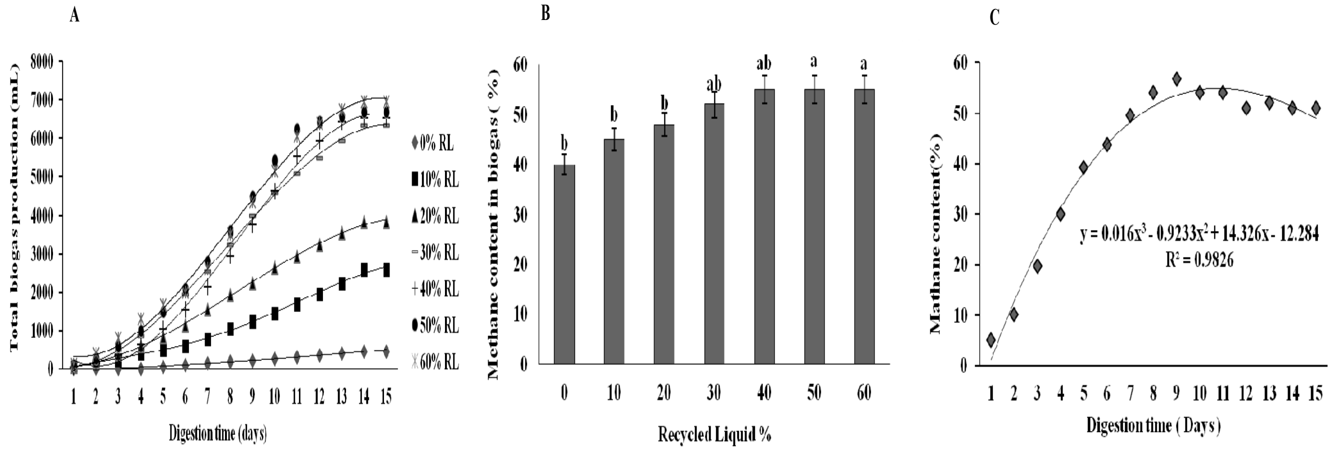

Fig. 2 Total biogas production (A), methane content (B) , methane content with respect to time (C) obtained during anaerobic digestion of lawn grass with recycled liquid digestate. b is methange content range from 40-45%,

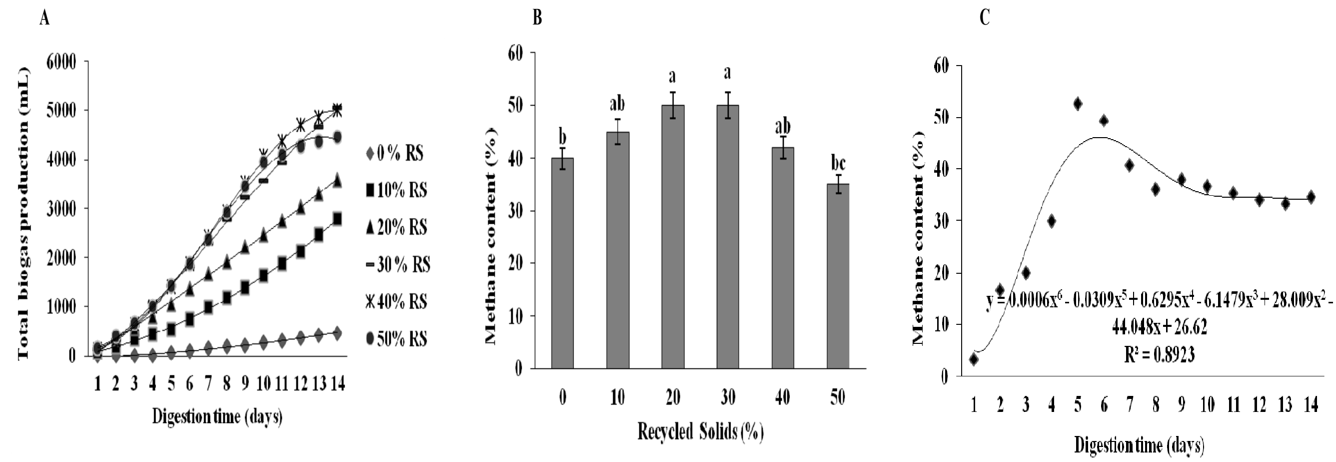

Fig. 3 Total biogas production (A), methane content (B), methane content with respect to time (C) obtained during anaerobic digestion of lawn grass with recycled solids digestate. a is methane content range between (50-55), b is (45-50), c is (35-40)

B. Influence of recirculation of solid digestate in anaerobic digestion of grass

Fig. 3 demonstrates the total biogas production, methane content and methane content with respect to time in the digester treating lawn grass with 0%, 10%, 20%, 30%, 40% and 50% recycled solid digestate. Though it was observed that recirculation of solid digestate resulted in an increase in biogas production, excessive addition of recycled solid digestate resulted in a biogas production decrement (Fig. 3A). This is due to inhibition of micro-organisms and delay of hydrolysis, which ultimately resulted in delay of the whole anaerobic digestion of lawn grass. The maximum total biogas production which was 87% higher than that of the digester with no recycled solid digestate was achieved in a digester with 40% recycled solid digestate. Total biogas production of digesters with 0%, 10%, 20%, 30%, 40%, 50% recycled solid digestate were recorded to be 460mL, 2420mL, 2840mL, 3170mL, 3280mL, and 2180m,L respectively.

The methane content from the biogas generated from the anaerobic digestion of grass is shown in Fig. 3 B. Again a drastic decrease in methane content was observed when excessive recycled solid digested was added in the digester. Nevertheless, methane content ranged between 35-53%. The highest methane content of 53% was observed in the digestion system with 20% and 30% recycled solid digestate. Higher than 30% recycled solid digestate resulted in reduction of methane content. This inverse relation might be due to low methanogenic activity and/ or over population of anaerobic bacteria in the digesters, which could result in the accumulation of the volatile fatty acids (VFA) produced during the acidogenic step.

The effects of retention time on methane content are shown in Fig. 3 C. It was noted that methane content increased with time. The highest peak was observed on the 5th day with methane content of 53%. After day 5, the methane content drastically decreased, indicating that acidogenic bacteria, which suppress the activities of methanogenic bacteria, were predominant in the digester after day 5. Recirculation of liquid digestate resulted in higher enhanced biogas production and methane content in comparison to when solid digestate were recycled. This is attributed to the fact that a lot of trace elements (nutrients) that might be present in the digestate are soluble. Therefore, they remain in the effluent (liquid digestate) of the digestate [8].

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IV. CONCLUSION

The present study shows that recirculation of digestate either in the form of solid or liquid may enhance biogas production and methane content when treating lawn grass at mesophilic condition. Maximum total biogas production and methane content where observed when 60% of liquid digestate was recycled in the digester. This was attributed to the availability of methanogens bacteria and trace element (nutrients) in the digestate. The recirculation of solid digestate also showed an improvement of biogas production. However, at excessive percentage of recycled digestate methane content was inhibited. High methane content was obtained in a digester with 30% recycled solid digestate. In conclusion, recirculation of liquid digestate resulted in higher enhanced biogas production and methane content in comparison to when solid digestate were recycled. This is attributed to that lot of trace elements (nutrients) that might be present in the digestate are soluble. Therefore, they remain in the effluent (liquid digestate) of the digestate.

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