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Utilization of Co-digestion of Local Brewery Wastes and Cattle Dung as a Potential Source of Biogas and Organic Fertilizer

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A B S T R A C T

Biogas production from co-digestion of local brewery waste (BW) and cow dung (CD) was studied for value added to this solid waste. The objective of this research was to find the optimum condition for maximum biogas production rate and also examining the effectiveness of the process residue (liquor from anaerobic digestion process) as a nitrogen source for the production of okro. The experiments were performed in a laboratory scale through which 1.5 litter plastic bottles were used as digesters operated in batch mode and mesophilic conditions [35°C±0.5]. The feedstock were tested in the CD:BW ratios of 90:10, 80:20. 70:30, 60:40, 50:50, 40:60, 30:70. 20:80, and 10:90. The maximum biogas yield was attained with mixtures in the proportions of 70:30 CD:BW. The addition of BW increased the biogas production rate from 0.40 to 0.92lt/lt.day. It was found that CD: BW ratio of 70:30 is the optimum ratio from batch process. The gradual reduction of the VFA concentration clearly indicated the stability of the process. A micro (pot) experiment was conducted to study the comparative effects of biogas process residues and NPK fertilizers on growth and yield using okro as the test crop. Twelve experimental soil filled pots in a complete randomized block design were used comprising of Control T_1 (no NPK and no BR), T_2 100% NPK fertilizer, T_3 50% biogas process residues (BR) plus 50% NPK fertilizers and T_4 biogas residues (BR 100), all in triplicates. The parameters studied showed that plant height, root length, number of fruits per plant and fruit weight were affected by the addition of BR. A maximum 20.2% plant height increase over control T_1 was observed in T_3, 100% NPK yielded 10% height increase while T_4 has 8%. A maximum increase of 28.57% in number of fruits was recorded in treatment T_2 and T_3, while 14.29% increase was recorded in T_4 compared with the control. The 50% BR applied in combination with 50% NPK (T_3) resulted in 25.42% increase in fruit weight over control, T_4 had 20.34% weight increase and 16.95% was observed in T_2. Based on these results, it may be concluded that the application of approximately 50% of biogas process residue and 50% inorganic fertilizer improves the production of okro.

1. INTRODUCTION

Worldwide energy crisis directed the attention to the alternative sources of energy as a replacement for underground fossil fuel. Achieving way out to possible shortage in fossil fuels and environmental problems that the world is facing today, require long-term potential actions for sustainable development. In this regard, renewable energy sources appear to be an efficient and effective solution. Human activities both at the domestic front and in industrial operations are inevitably accompanied by waste generation. Even in compliance to the aspired or concept of cleaner production which entails that a higher percentage of raw materials are converted into products, solid waste generation is unavoidable. Recycling option may be considered as appropriate means of combating the menace of solid wastes. This involves the collection of the waste and reuse in the same or a different part of production or collection and treating wastes so that they can be sold to consumers or other companies. In line with this, biogas technology employs the use of anaerobic digestion of wastes to produce methane-rich gas known as biogas. Biogas usually refers to the gas that has been produced during the breakdown of organic materials without presence of oxygen, which consist of mainly methane and carbon dioxide. This process is known as anaerobic digestion and is performed by microorganisms present in the anaerobic digester. This phenomenon occurs also naturally in anaerobic environments like in ponds and marshes. This has been an emerging technology that has become a major focus of interest even in waste management throughout the world [1]. It is an identified

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veritable option in the integrated waste management of municipal solid waste and is involved in waste-to-energy transformation [2]. Biogas is about 20 % lighter than air and has an ignition temperature in the range of 650 to 750^{0}C. It is odourless and colorless gas that burns with clear blue flame similar to that of LPG gas. Its caloric value depends on methane content and burns with 60 % efficiency in a conventional biogas stove. Biogas refers to a gas made from anaerobic digestion of agricultural and animal waste. The gas is a mixture of methane (CH_4) 50-70 %, carbon dioxide 30-40 %, hydrogen 5-10 %, nitrogen 1-2 %, hydrogen sulphide (trace), water vapor 0.3 %. It is smokeless, hygienic and more convenient to use than other solid fuels [3]. Besides being a non-polluting, environmentally feasible and cost effective process, biogas generations have many applications such as for cooking, electricity generation and hatching of chickens [4]. The gas is useful as a fuel substitute for firewood, dung, agricultural residues, petrol, diesel, and electricity, depending on the nature of the task, and local supply conditions and constraints. Biogas systems also provide a residue organic waste, after anaerobic digestion that has superior nutrient qualities over the usual organic fertilizer, cattle dung, as it is in the form of ammonia. Anaerobic digesters also function as a waste disposal system, particularly for human waste, and can, therefore, prevent potential sources of environmental contamination and the spread of pathogens. The technology used for the biogas production also contributes to economic and social developments. Despite all benefits of biogas, biogas technology has not yet been accepted in many countries. One of the reasons for this is the high investment capital cost and the other reason is the unrealistic expectation of the users.

Local brewery is a common practice among many African countries, the brewery which produces beer (called burukutu in Northern Nigeria), and non-alcoholic beverages (called kunu in Northern Nigeria). The brewery wastes are accumulated everyday and its disposal creates environmental problems. To make use of the wastes efficiently and economically, the treatment of the brewery wastes using the anaerobic digestion method to produce biogas and bioferitlizers was considered. Brewery wastes contains spent grains, yeast biomass etc. Cow dung is also available in villages. The anaerobic fermentation of manure for biogas production does not reduce its value as a fertilizer supplement, as available nitrogen and other substances remain in the treated sludge [5]. The high water content, together with the high content in fibers, are the major reasons for the low methane yields when cattle manure is anaerobically digested, typically ranging between 10 and 20 m^3 CH_4 per tonne of manure treated [6]. Wei, [7] demonstrated that using co-substrates in anaerobic digestion system improves the biogas yields due to the positive synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates. Adelekan and Bamgboye [8] in a study carried out a research on the different mixing ratios of livestock waste with cassava peels. It was observed that the average cumulative biogas yield was increased to 21.3, 19.5, 15.8 and 11.2 L/kg TS, respectively, for 1:1, 2:1, 3:1 and 4:1 mixing ratios when cassava peel was mixed with livestock waste. In another report, Muyiiya and Kasisira, [9] employed co-digestion of cow dung with pig manure which increased biogas yield as compared to pure samples of either pig or cow dung. Comparing to samples of pure cow dung and pig manure, the maximum increase of almost seven and three fold was respectively achieved when mixed in proportions of 1:1. Co-digestion with other wastes, whether industrial (glycerin), agricultural (fruit and vegetable wastes) or domestic (municipal solid waste) is a suitable option for improving biogas production [10, 11, 12, 13].

Therefore, the present study aimed to assess the suitability of producing biogas from local brewery waste and utilization of the digest residue as fertilizer in okro cultivation by measuring plant height, root length, number of fruits per plant and weight of fruit.

2. MATERIALS AND METHODS

Feedstock The brewery wastes were collected from the house producing the local beer at Kamoru Dutse in Zangon Kataf Local Government Area of Kaduna State, Nigeria. Organic components in brewery effluent (expressed as COD) are generally easily biodegradable as they mainly consist of soluble starch, sugar, ethanol, volatile fatty acids etc. This is illustrated by the relatively high BOD/COD ratio of 0.72. The brewery solids consist mainly of spent grains, waste yeast etc. The cow dung was also collected from the same compound producing the beer. Both wastes were crushed separately into small particle sizes of 2mm after sun drying and were adjusted to 8% mass by diluting with water. Both the materials were stored at 0°C in a refrigerator before usage. Both substrates were mixed at a predetermined ratio before feeding into the batch reactor as shown in Table 1.

2.1. Laboratory set-up

One and half litre plastic bottles were used as digesters operating in batch mode and mesophilic conditions [35°C±0.5] as used by [8]. This was a modification of a compact system digester that digests small volumes of feedstock to produce biogas. The pH of the mixtures was measured with a digital pH meter while weighing was done using a digital weighing scale. A crusher was used for crushing and it helps to produce a homogenized feed stock. Biogas formed was measured by liquid displacement method as being used by Muyiiya and Kasisira [9], Yetilmezsoy and Sakar [14] and [15]. The composition of biogas was also continuously monitored by gas chromatography.

A rapid and stable process was achieved by optimal increase of the brewery wastes and at the same time, decrease in biogas for very high brewery waste addition was as a result of clogging. The digesters were operated with 3.5gVS per litre as an average value and retention time of 40 days.

Figure 1. Experimental set up.

2.2 Experimental set-up for investigating the effect of biogas residue on growth and yield of crop

A micro (pot) experiment was conducted to study the comparative effects of biogas process residues, and NPK fertilizers on growth and yield using okro as the test crop. Soil was collected from farmland, sieved and the pots were filled with 10 kg of soil. Four seeds were sown in each pot which was thinned to one plant 12 days after germination. Pots were placed outside under natural conditions. Ground water was used for irrigations. Twelve pots experimentally filled by soil in a complete randomized block design were used comprising of three each for Control, biogas residues (BR), 50% BR plus 50% NPK and NPK fertilizers as follows:

T1 = Control (No fertilizer + No BR),

T2 = Full NPK

T3 = 50% NPK and 50% BR)

T4 = Full biogas residues (BR

Plants were harvested at maturity and the following parameters were studied: plant height, root length, number of fruits per plant and fruit fresh weight.

3. RESULTS AND DISCUSSION

Table 1 shows the average composition of the feedstock. The higher values of VS, COD and the value of C/N ratio as 17 are favourable for anaerobic digestion. The pH was slightly acidic but it was neutralized easily by the addition of the CD. The experiments were carried out with batch process of the brewery wastes and the cattle dung on different ratios. Initially the reactor was filled only with CD and it was left to reach a steady-state biogas yield. The average biogas production was 0.40 L/L.d. After the start-up has been achieved, a co-digestion was started with a feed of CD and BW. Different ratios of cow dung and brewery wastes were taken in different digesters as follows.

Cow dung: brewery wastes = 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80, and 10:90.Although, variations in reactor performance were observed in the early period of digestion, a variation of 6.65 - 7.8 pH was observed during the entire operations. This implies average buffering capacity of the mixed substrate. Several researches on anaerobic digestion of waste, have shown that pH of digestate has strong influence on the rate of production and yield of biogas by the substrate. The methanogenic bacteria are known to be very sensitive to pH. The most favourable pH values given by researchers vary. Yadvika, et al. [17] reported a favourable pH range of 6.8-7.2 for anaerobic digestion, while Nwabanne, et al. [18] reported a value of 6.6 and 7.8. This value of the pH of substrates determined in this research falls within the range values which are in agreement with the values reported by these researchers.

TABLE 1. Average composition of the Feedstock

Parameters	BW	CD
TS,%	8.5	8.0
VS,%	93	83
pH	5.2	7.3
COD[mg/lt]	6100-8100	6100
BOD[mg/lt]	2800–6100	4290
Nitrogen[N] in mg/L	40 – 60	30 – 38
Phosphorous[P] mg/L	30 - 40	10 – 12

The results of biogas composition presented in Table 2 revealed that the CH_4 increases with increase in BW concentration up to 30% (CD:BW 70:30 ratios). The average biogas composition was 70% CH_4 and 28.5% CO_2. The biogas compositions obtained in this study are comparable to those obtained by Wang et al. [19] who studied the anaerobic batch digestion at 35°C of food waste using laboratory and pilot-scale hybrid solid–liquid anaerobic digesters. Their results showed that the methane contents of the produced biogas were 71 and 72%, respectively. The methane yield obtained in this work is lower than the values reported by Cho and Park [20], who obtained 472mL/g VS at 37°C and 25 days and Heo et al. [21], who obtained 489 mL/g VS at 35°C and 40 days. It should be pointed out that the VS/TS of the food waste tested by Cho and Park [20] was 95%, which is higher than the VS/TS of substrates tested in this study. During the process, the concentration of VFA in the soluble fraction indicated an increase from the initial average value of 0.5g/L to the average value of 3.6g/lt on the digestion start and then a gradual decrease in concentration of VFA was obtained as shown in the

Table 2. On increase of BW concentration above 30%, a decrease in CH_4 with increase in CO_2 concentration was also observed. There was no significant change in pH of the reactor as it ranged from 7.1 to 7.5. A similar trend of increasing up to 30% BW composition and subsequently decreasing was observed in biogas production in L/d, Biogas yield in m^3/kg VS_{added} and Methane yield in m^3CH_4/kg VS_{added} as shown in Table 3. The VS and COD transformed into biogas was 75.2% and 54%, respectively. After 10 days from the beginning of the process the composition ratio was changed to the different ratios in different digesters. As shown in Table 3, it is clear that the biogas production increased with increase of BW in the influent and the maximum value was 0.92lt/day for the ratio of 70:30.

The extent of biodegradation of TS% and extent of biodegradation of COD% also shows a similar trend as observed in Table 4 with both increasing with increase in BW composition up to 30% and gradually decreases as the BW composition increases. The trend is an indication that 70:30 CD:BW ratio is the optimal ratio. The four ratios of 40:60, 30:70, 20:80, and 10:90 did not give appreciable biogas production rate due to the clogging of the batch digester. Methane content and production was stable and appreciable on 70:30 ratio. From Table 4 it can be seen that the averaged TS and COD removal efficiency for 30% BW was 67.5 and 46.3%, respectively, which is higher than 52 and 40.6% obtained by Singhal et al. [22], respectively. The result is, however, comparatively lower than COD removal obtained from cattle manure of between 51 and 79% by Castrillon et al. [23]

TABLE 2. Average biogas composition on steady state biogas yield

Ratios CD:BW	CH_4%	CO_2%	Average VFA concentration during start of the experiment (g/L)	Average VFA concentration at the end of the experiment (g/L)
90:10	66.0	30.5	3.1	1.9
80:20	67.5	30.0	3.3	1.6
70:30	70.0	28.5	3.6	1.4
60:40	66.0	31.5	3.4	1.7
50:50	64.5	32.2	3.3	1.8
40:60	63.2	32.8	2.9	2.0
30:70	62.1	33.1	2.8	2.0
20:80	59.6	33.9	2.7	2.1
10:90	58.3	34.4	2.6	2.2

TABLE 3. Results obtained with different mixtures of CD and BW

Ratios CD:BW	TS %	Biogas production, lt/day	Biogas yield, m^3/kg VS_{added}	Methane yield, m^3CH^4/kg VS_{added}
90:10	8	0.58	0.22	0.140
80:20	8	0.76	0.29	0.182
70:30	8	0.92	0.41	0.287
60:40	8	0.61	0.36	0.190
50:50	8	0.53	0.34	0.190
40:60	8	0.48	0.32	0.189
30:70	8	0.41	0.30	0.179
20:80	8	0.30	0.28	0.170
10:90	8	0.21	0.25	0.162

TABLE 4. Characteristic changes of the materials due to biodegradation

Ratios CD:BW	TS_{in},%	$TS_{eff.}$,%	Extent of biodegradation of TS%	$VS_{eff.}$, %	$COD_{in.}$ g/lt	$COD_{eff.}$ g/lt	Extent of biodegradation of COD, %
90:10	8	3.2	60.0	70	106	78	26.4
80:20	8	3.0	62.5	64	91	55	39.5
70:30	8	2.6	67.5	55	82	44	46.3
60:40	8	3.8	52.5	67	75	58	22.7
50:50	8	3.9	50.1	68	72	58	20.3
40:60	8	4.2	47.5	73	69	56	18.8
30:70	8	4.6	43.3	76	70	55	18.1
20:80	8	5.0	37.5	80	63	52	17.4
10:90	8	5.2	35.2	83	67	51	16.9

Fig. 2 shows the height of okro in response to different treatments. It can be seen from the figure that the maximum plant height of 60.1 cm with standard deviation of 1.3 cm was observed in treatment T_3

(20.2% increase over control T_1) where 50% of BR and 50% NPK combination was applied. The 100% NPK was the second which shows a 10% increase in plant height over the control though comparable with T_4 which has 8% increase over the control. This result is in agreement with the findings of the Islam et al. [24] who also reported that maize plant height and stem circumference were significantly ($p< 0.01$) influenced by the application of 50% N from biogas slurry. Okwuagwu et al. [25] also reported that mean plant height was the highest with the application of NPK along with cattle manure treatment. The increase in plant height associated with T_3 is due to nitrogen fertilizers. Nitrogen fertilizer, either organic or inorganic, always affects vegetative growth of the fodder plants [26].

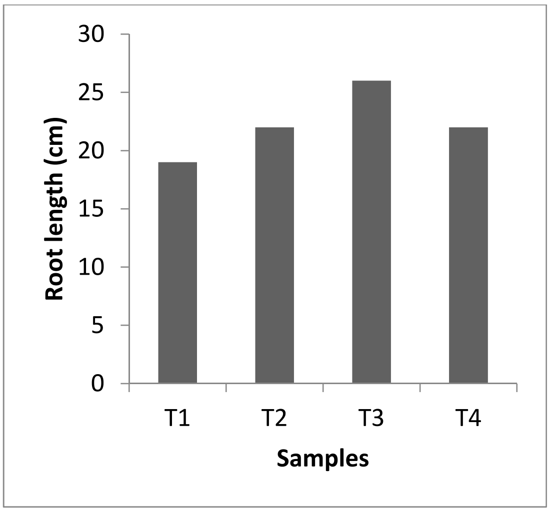

Figure 2. Effect of treatment on root height

Similar root length was observed in T_2 and T_4 with 15.79% increase over the control treatments (T_1). A significant increase in root length was, however, observed with combined application of biogas residue and chemical fertilizer as shown in Fig. 3.

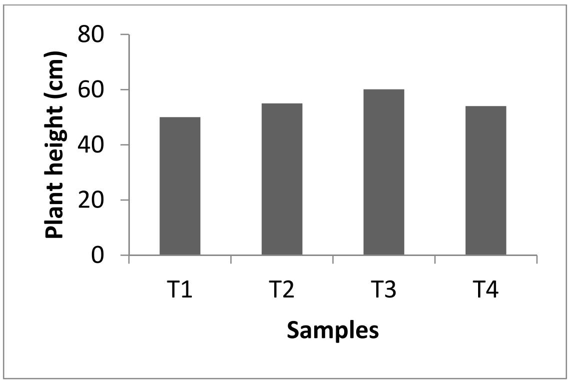

Figure 3. Effect of treatment on plant length of plant

The maximum root length (26 cm) was observed with the application of 50% chemical fertilizer in combination with 50% biogas residue (T6) and this increase was 36.84 % over control. This work is also in agreement with Baldi et al. [27] research in which it was reported that the application of compost increased the production of new roots compared with the treatment in which alone chemical fertilizers were applied.

From Fig. 4, a maximum increase of 28.57% number of fruits was recorded in treatment T_2 and T_3, while 14.29% increase was recorded in T_4 treatment compared with control. From Fig. 4 treatment where 50% of BR was applied in combination with 50% NPK (T_3) resulted in 25.42% increase in fruit weight over control. It was followed by T_4 with 20.34% increase in fruit weight. A minimum increase of 16.95% in fruit weight was observed in treatment T_2 compared to the control T_1 as shown in Fig. 5.

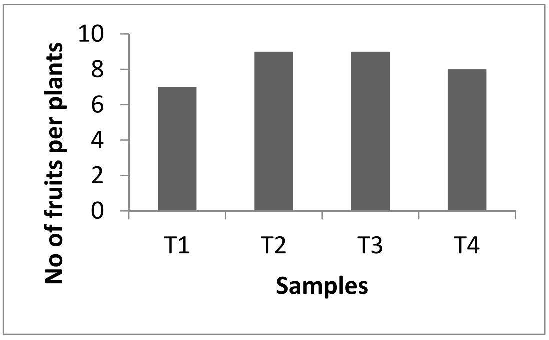

Figure 4. Effect of treatment on numbers of fresh fruits per plant

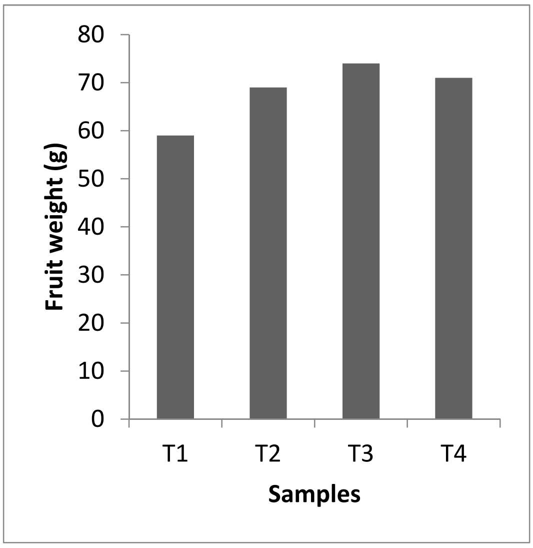

Figure 5. Effect of treatment on weight of fresh fruits

This result was also in agreement with the findings of Parvathy and Vaishnavy [28] who also reported the significant effect of biogas slurry supplemented with chemical fertilizers on number of fruits per plant. Dhussa [29] compiled the results of some of the experiments conducted on the effects of biogas effluent on the yield of rice, wheat, maize, cotton, cucumber, tomato, mung bean, and sunflower. They also concluded that wheat and cotton yield was increased by 15 and 16%, whereas the yield of maize and rice was increased by 9 and 7%, respectively.

The increase in yield is due to the application of fresh biogas slurry because the wet biogas slurry had higher mammal value than that of the dry slurry. The wet slurry is reported to contain around 1.6% of the nitrogen in form of readily available ammonia [30]. The higher weight recorded by T_4 treatment over T_2 is due to mineralization of organic nitrogen in liquid form. The nitrogen in liquid slurry is also reported to be superior to that in sun-dried slurry and farmyard manure [31, 32, 33, 34]. Olaniyi and Akanbi [31] and Pandey et al. [35] also reported that the integrated use of organic and inorganic N fertilizer enhance the yield of crops.

4. CONCLUSIONS

The maximum biogas yield was attained with mixtures in the proportions of 70:30 CD:BW. At these proportions, there was a biogas yield increase as compared to that of the other ratios. Co-digestion of cow dung and local brewery waste is therefore, one way of addressing the problem of deforestation which has aided desertification.

It will also help to reduce the time which is needed by women in the rural areas to search for firewood for cooking. It was evidently observed that a stable anaerobic co-digestion can be achieved by using a mixture of local brewery wastes and cattle dung in various proportions. The addition of BW increased the biogas yield from 0.40 to 0.92 L.L.d.

It was found that CD:BW of 70:30 is the optimum ratio from batch process. The gradual reduction of the VFA concentration clearly indicated the stability of the process. Physical growth characteristics in okro, i.e. plant height, root length, number of fruits per plant and weight of fruit as a result of biogas digest residue affected the characteristics studied.

It might be concluded that approximately 50% of biogas residue and 50% of inorganic fertilizer is an optimum level for okro production. Excessively high biogas residue decrease okro yield and nutritional quality, perhaps due to the presence of some inhibiting agents in the residue.

Further research is necessary to identify the cause of the observed decrease in yield and quality at that higher residue level.

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