Utilization of Co-Digested Poultry Droppings and Swine Dung for Biogas Production

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***Abstract*—Co-digestion of different mixtures of poultry manure, swine manure, and sawdust for biogas production was investigated. The substrate mixtures varying in their contents of carbon/nitrogen ratios (20:1, 25:1, and 30:1) were subjected to anaerobic digestion at ambient temperature for 42 days in a batch-type digestion experiment. The results showed that anaerobic digestion of the mixture of poultry manure and swine manure adjusted with sawdust and water to attain carbon-to-nitrogen ratio of 20:1 and 8% total solids at an average ambient temperature (30.4±1.52^{o}C), average digester temperature (39.9±5.90 ^{o}C), and average digester pH (6.75±0.180) yielded optimum biogas (266.9±294.26 cm^{3}/day). It was concluded that co-digestion of poultry manure and swine manure for biogas production provides a sustainable route for alleviating the environmental nuisance otherwise caused by non-disposal of the livestock waste.**

Keywords—Animal manure, Sawdust, Biogas, Anaerobic digestion, Carbon/Nitrogen ratio

1. Introduction

Improved agricultural production as a response to high food demand occasioned by the need to feed the teeming Nigerian population has led to increased agricultural waste generation in the country. The agricultural waste comprises, mainly of poultry and other livestock wastes, crop residues, agrochemical wastes, and packaging materials. The poor management of these wastes constitutes a nuisance to the environment through air pollution, soil degradation, and water contamination [1]. Of concern is the increased poultry and swine production for the supply of animal food protein to the vast majority of the undernourished, low-income earning, vulnerable Nigerians; and the associated problem of the waste generation from the farming activities. That is such wastes as animal manure, bedding, and litter, waste water, feedlot runoff, and even wasted feed [2], accumulates in a particular livestock farm environment without safe handling for productive re-use or disposal overtime [3].

Several proven wastes management methods are available. However, the choice of a suitable one depends on the nature, composition, and biodegradability of the waste quite apart from other factors including available technology, technical knowledge, and cost. Waste conversion and reuse are reportedly good management practices, with established studies on the efficacy of animal waste for compost manure and methane production [4]-[5]. This eco-friendly utilization of biodegradable agricultural waste by composting and anaerobic digestion is considered socioeconomically beneficial.

Anaerobic digestion mitigates envisaged environmental menace caused by the agricultural wastes through hydrolysis, acidification and methanization process under deoxygenated condition. Complex sugars in the digester are hydrolyzed into smaller and simpler ones by cellulolytic bacteria. Acid-forming bacteria further degrades the smaller sugars into methanogenic substrates. Finally, methane-forming bacteria converts these substrates (Fatty acid and glycerol) to methane and carbon (IV) oxide. However, methane formation occurs simultaneously in all the stages. Biogas and sludge are the dual products in anaerobic digestion. The former can be harnessed for domestic cooking. This reduces fossil fuel consumption and the destruction of the natural vegetation due to the use of lumbers for firewood. The latter product is suitable as manure for soil enrichment and amendment [6].

In this study, homogenized poultry and swine manure was co-digested with sawdust under anaerobic condition and mesophilic temperature for biogas production as a way of reusing of the livestock waste.

2. Materials and Methods

2.1. Experimental Treatments

Varying quantities of Poultry manure (PM), swine manure (SM), and sawdust (SD) were mixed to attain three different carbon/nitrogen ratios of 20:1, 25:1, and 30:1. Sawdust, a high dietetic value waste with a high carbon content coupled with insignificant nitrogen level, served the purpose of augmenting the C/N ratio of the mixtures of PM and SM for efficient biogas production. C/N ratios for PM (15.1 - 19.1) and for SM (10.1 – 17.9) reported by [7]- [8] are lower than the optimum C/N ratio (20.0 – 30.0) range required for proficient biogas production [9].

Each mixture was adjusted to 8% total solid with tap water and homogenized prior feeding into three different cylindrical stainless steel digesters for anaerobic digestion and biogas production. Equal loading rates were administered to each digester. Overfeeding was avoided to ensure thorough mixing of the digests during stirring, and to avoid acid accumulation in the reactor. Digestion was allowed for 42 days at ambient temperature during which bio-digesters (feedstock) were agitated daily, and daily records of ambient and feedstock temperatures and daily and cumulative gas production were kept. Also, the pH of the feedstock was measured and recorded weekly. The batch-type digestion experiment was replicated twice.

2.2. Analytical Procedures

Poultry manure, swine manure, and sawdust were analyzed for total nitrogen by the micro-Kjeldahl method [10]. Total organic matter (TOM) was determined by ignition loss, and total organic carbon (TOC) was deduced from prediction equation (TOM = 1.135 + 1.803TOC, r = 0.968, n = 67) established by [11].

2.3. Statistical Analyses

Data obtained in the study were subjected to statistical analysis, including ANOVA, and regression and correlation analyses. Duncan Multiple Range Test was used to separate significantly different treatment means. Statistical analysis was performed by the use of the StatPlus Pro on a MacBook Pro personal computer.

3. Results & Discussion

The results of carbon and nitrogen determinations and the C/N ratios of PM, SM, and SD used in the present study are presented in Table 1. While both PM and SM contained significantly higher nitrogen than SD, the reverse was the case with carbon contents. SD is essentially cellulosic with characteristically high carbon content but low in nitrogen [12]. The high C/N ratio (202.37) observed in the present study justified its use as a bulking agent and its suitability for raising the C/N ratios of the mixtures of PM and SM up to 30 used in the study. References [9], [13] had earlier observed that C/N ratio of between 20:1 and 30:1 was optimum for anaerobic digestion of agricultural wastes.

The C/N ratios of 3.84 and 5.15 obtained in the present study for PM and SM are lower than those established by [7]-[8]. Remarkable variability in the composition of poultry droppings and swine dung is expected because of the variability in feed composition and nature, feed digestibility and utilization, and age and physiological state of animals among others.

Reference [14] observed that the rate of biogas production depended on the substrate’s organic matter content and biodegradability. Also, references [15], [8], [16] reported that C/N ratio, temperature, pH, mixing, and hydraulic retention time affected the balance of different groups of microorganisms implicated in methane production and thus affected the yield of biogas from anaerobic digestion of a substrate. Consequently, the ambient temperature, the feedstock temperature, and feedstock pH were monitored throughout the period of anaerobic digestion and their effects on daily and cumulative biogas production were observed in the present study. The results are presented in Tables 2 and 3.

Table 1. Carbon, Nitrogen and C/N Ratios of the Animal Manure and Sawdust

Feedstock material	Carbon (%)	Nitrogen (%)	C/N ratio
Poultry droppings	4.03b*	1.05a	3.84b
Swine dung	4.89b	0.95a	5.15b
Sawdust	54.64a	0.27b	202.37a

*Mean values denoted by different subscripts differ significantly (P>0.05)

Table 2. Effect of retention time, ambient temperature and feedstock temperature on Biogas Production

Retention Time (days)	Daily Biogas Production (cm^3)			Cumulative Biogas Production (cm^3)			Temperature (°C)			
							Ambient	Feedstock		
	20:1	25:1	30:1	20:1	25:1	30:1		20:1	25:1	30:1
0	0.0	0.0	0.0	0.0	0.0	0.0	32.4	32.4	32.4	32.4
1	173.5	94.0	32.0	173.5	94.0	32.0	32.4	33.2	33.5	33.3
2	301.5	64.5	75.0	475.0	158.5	107.0	31.2	34.5	33.7	34.8
3	42.0	16.1	48.0	517.0	174.6	155.0	29.3	34.9	34.3	32.6
4	57.0	27.3	5.3	574.0	201.8	160.3	29.5	35.4	35.7	30.5
5	32.5	63.5	25.0	606.5	265.4	185.2	28.7	37.2	35.2	31.4
6	137.0	71.5	112.0	743.5	336.8	297.3	29.3	38.3	34.4	31.2
7	485.0	590.0	13.1	1228.5	926.9	310.3	32.0	37.5	36.3	32.6
8	0.0	121.0	27.5	1228.5	1047.8	337.9	30.3	36.7	35.5	33.4
9	287.5	56.0	71.0	1516.0	1103.9	408.9	28.1	37.3	36.8	35.7
10	537.7	908.0	610.0	2053.7	2011.8	1018.9	30.5	40.1	38.6	34.3
11	845.0	595.5	541.0	2898.8	2607.4	1559.9	31.5	44.7	40.5	35.9
12	1220.0	7.0	567.5	4118.8	2614.3	2127.4	34.2	45.3	43.6	36.6
13	1052.5	174.5	342.5	5171.2	2788.9	2469.9	33.8	47.5	44.2	39.4
14	181.2	1116.5	147.5	5352.4	3905.3	2617.4	31.4	46.2	46.9	38.1
15	550.0	0.0	0.0	5902.4	3905.4	2617.4	30.2	47.8	45.3	40.3
16	192.5	11.5	52.5	6094.9	3916.8	2669.9	30.7	48.6	46.7	41.8
17	643.3	6.0	230.0	6738.2	3922.9	2899.9	28.6	48.2	45.7	40.5
18	257.5	985.5	150.0	6995.6	4908.3	3049.9	30.5	47.9	44.8	39.6
19	330.0	19.0	197.5	7325.7	4927.4	3247.4	31.8	48.3	45.7	40.2
20	180.0	6.5	173.0	7505.6	4933.8	3420.4	31.7	46.1	44.9	39.8
21	229.5	0.0	227.5	7735.2	4933.9	3647.9	31.4	48.3	45.8	41.3
22	106.5	0.0	162.5	7841.6	4933.8	3810.4	30.9	47.8	43.1	39.5
23	61.0	1052.5	222.5	7902.7	5986.4	4032.9	30.4	45.8	45.4	38.6
24	858.7	353.0	475.0	8761.4	6339.3	4507.9	30.8	44.9	45.3	39.4
25	282.8	0.0	357.5	9044.1	6339.4	4865.4	29.6	45.3	44.7	36.6
26	312.5	120.5	170.0	9356.7	6459.8	5035.4	30.5	43.2	42.6	37.1
27	179.8	88.5	4.8	9536.4	6548.4	5040.2	29.3	42.1	41.3	36.4
28	242.5	215.0	232.0	9778.9	6763.3	5272.2	28.9	43.6	39.5	34.6
29	5.5	42.5	30.5	9784.4	6805.8	5302.6	29.4	40.4	38.3	35.6
30	152.5	150.0	67.5	9936.9	6955.9	5370.2	30.2	37.9	35.8	34.2
31	2.0	122.5	90.0	9938.9	7078.3	5460.2	29.7	35.6	33.5	35.2
32	425.0	147.5	52.5	10363.9	7225.8	5512.6	29.4	34.2	36.7	34.3
33	31.5	89.5	1.5	10395.4	7315.3	5514.2	28.1	33.5	35.3	33.7
34	3.0	37.0	0.0	10398.4	7352.4	5514.1	27.9	32.6	32.6	30.6
35	218.5	168.5	7.0	10616.9	7520.8	5521.1	29.7	33.7	34.8	31.2
36	27.5	79.0	45.0	10644.4	7599.8	5566.1	28.1	32.1	33.6	29.4
37	146.0	100.0	12.0	10790.4	7699.9	5578.2	30.9	33.3	34.5	28.8
38	13.5	33.0	0.0	10803.9	7732.8	5578.2	30.2	34.6	33.7	29.4
39	29.0	89.0	90.0	10832.9	7821.9	5668.1	28.7	33.6	32.8	27.6
40	8.5	1.5	1.0	10841.4	7823.3	5669.1	33.2	32.1	32.6	28.5
41	367.5	138.0	80.0	11208.9	7961.4	5749.1	30.1	32.6	32.4	28.1
$\bar{x} \pm$ SD	266.9a* ±294.26	189.6b ±302.51	136.9c ±164.62				30.4 ±1.52	39.9a ±5.90	38.8a ±5.06	34.9b ±3.97

*Mean values for a parameter denoted by different subscripts differ significantly (P>0.05)

Table 3. Weekly biogas production and digest pH in feedstock of different C/N ratios

Retention time (Weeks)	Biogas production (cm^3/week)			Bio-digester pH		
	C/N (20:1)	C/N (25:1)	C/N (30:1)	C/N (20:1)	C/N (25:1)	C/N (30:1)
	Mean	Mean	Mean	Mean	Mean	Mean
1	1228.5	926.85	310.35	7.5	7.4	7.2
2	4123.9	2978.5	2307.05	6.9	7.0	7.0
3	1028.5	1030.5	1030.5	6.6	6.9	6.8
4	2043.75	1829.5	1624.25	6.8	7.1	6.9
5	838.0	757.5	249.0	6.5	6.6	6.5
6	592.0	440.5	228.0	6.2	6.3	6.1
Mean ± SEM*	1642.44a** ± 535.957	1327.23b ±380.272	958.19c ±352.331	6.75 ± 0.180	6.88 ± 0.158	6.75 ± 0.161

*SEM, standard error of the treatment means.
**Mean values of a parameter denoted by different subscripts in row differ significantly (P>0.05)

C/N ratio in the mixture of animal wastes significantly (P>0.05) affected mean daily biogas production. Daily biogas production was negatively correlated with C/N ratio of the bio-digest (R = -0.20; R Standard Error = 0.0077). Biogas production decreased significantly with the widening of the C/N ratio. It was highest (266.9±294.26 cm^3/day) in mixture with the lowest C/N ratio (20:1) and was least (136.9±164.62 cm^3/day) in the mixture with the highest C/N ratio (30:1). This observation is in agreement with the earlier findings that C/N ratio significantly affected biogas production [9]. Also, references [17]-[19] noted that C/N ratio of 16:1-25:1 and 7-9% solids concentration in the substrate was optimum for biogas production. Waste mixtures (feedstock) used for biogas production in the current study contained 8% total solids.

Significantly poor biogas yield from feedstock with the widest C/N ratio (30:1) was suspected to be due to poor utilization of the high carbon content contributed by sawdust, the bulking agent. Indeed, references [20]-[22] attributed low biogas yield from pure sawdust to its high lignin content. Also, reference [23] affirmed that substrate with high lignin content inhibited anaerobic bacteria digestibility unless the feedstock was pretreated. Reference [24] noted that sawdust contained about 27 % lignin and concluded that it was high enough to lessen biogas production. Consequently, reference [16] recommended pretreatment of cellulosic materials prior incorporation as a feedstock for biogas production. The pretreatment was necessary because of the inability of the microorganisms to secrete enzymes that will free cellulose from lignocellulose, the form in which it is present in sawdust. The findings from the present study tended to support earlier assertions that the nature of substrate is a dominant factor in biogas production.

The pattern of daily and cumulative biogas production from the anaerobic digestion of the mixtures of PM, SM, and SD in the current study are depicted in Figs. 1 and 2, respectively. Retention time significantly (P>0.05) affected daily biogas production. Both variables had a weak but positive correlation (R = 0.16; R Standard Error = 0.0079; R^2 = 0.03). The regression equation describing the relationship between both variables is shown in Table 4. Also, the results revealed that irrespective of the C/N ratio, cumulative biogas production increased progressively and remarkably, too throughout the anaerobic digestion period. However, cumulative biogas produced reduced significantly with increasing C/N ratio.

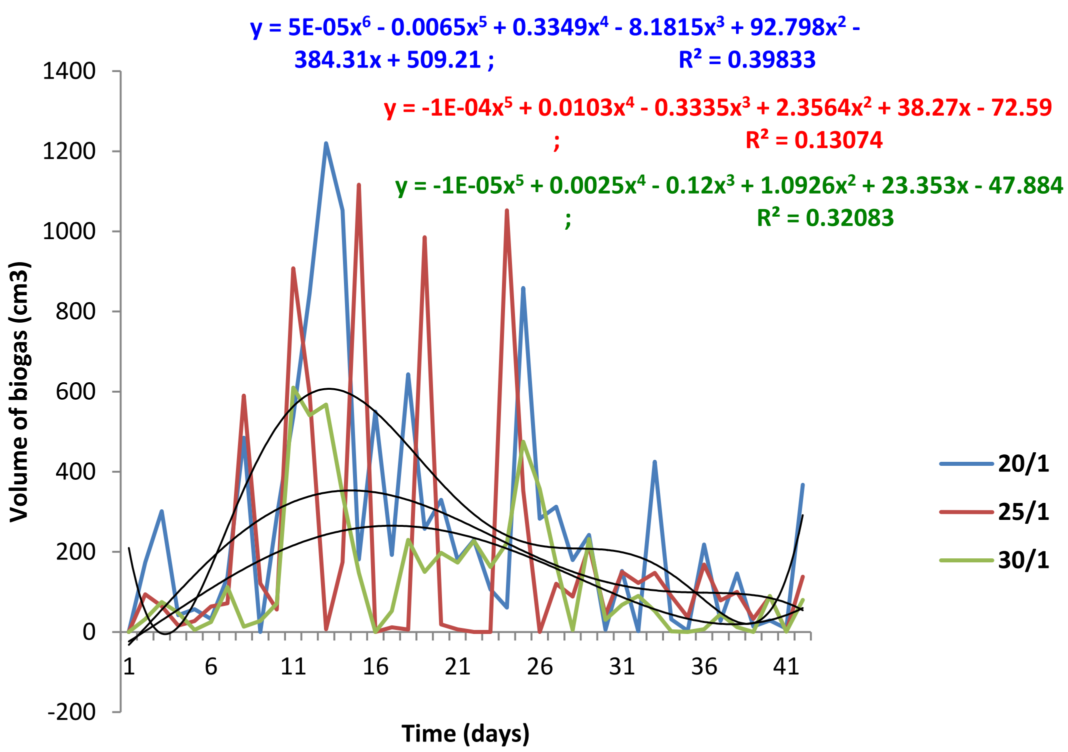

Fig 1. Mean daily production of biogas from mixtures of PM, SM and SD at different C/N ratios

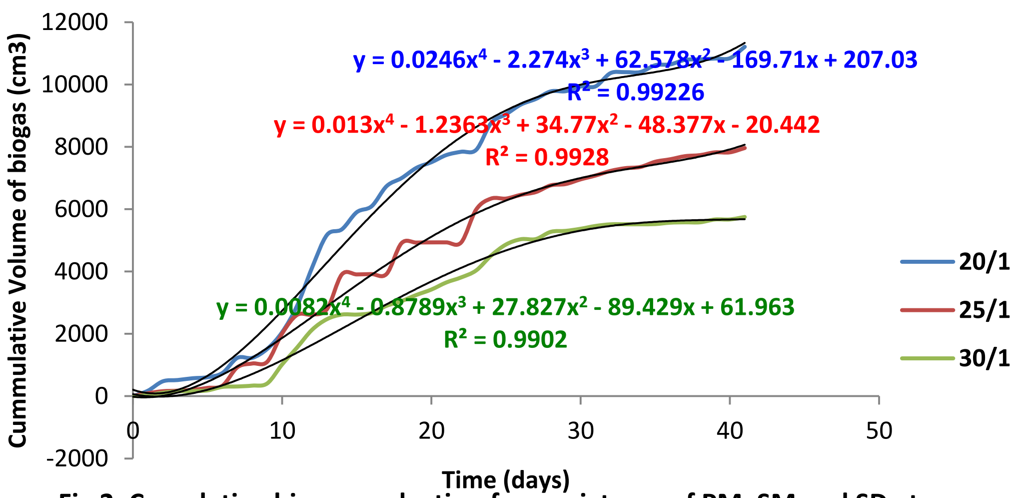

Fig 2. Cumulative biogas poduction from mixtures of PM, SM and SD at different C/N ratios

The positive correlation between retention time and biogas production is in agreement with the findings of [25]-[26]. The authors concluded that although the longer the substrate was kept under appropriate digestion conditions, the more complete its degradation would be. However, it was necessary for economic biogas production to determine the optimum retention time for which the substrate is retained in the digester. While reviewing factors affecting digestion, reference [27] noted that methane-forming microorganisms grow slowly with a doubling period of about 5-16 days and then concluded that hydraulic retention time should be at least 10-15 days unless the bacteria was entrapped. Mean daily biogas production shown in Figure 1 tended to suggest that there was no lag time as biogas productions were noticed in all the digestions within 24 hours from commencement of the experiment. This might be due to the fact that the biodegradation microorganisms were already acting on the livestock waste (PM and SM) from point of source since such wastes do not require inoculants to enhance influent digest start. The lines of best fits for the plots revealed that there were sharp rises in biogas production from day three of digestion to the peak on the day fifteen, and then crashing to low levels on day thirty-eight. However, the bulk of biogas production was observed in the second and third week of anaerobic digestion. The patterns of biogas productions were the same in all the tested feedstock irrespective of the varying C/N ratios. The results showed that biogas productions were highest in the second week (that is, 4123.9 cm^3 of C/N ratio of 20:1, 2978.5 cm^3 for C/N 25:1, and 2307.05 cm^3 for C/N ratio of 30:1). Thereafter, production dropped steadily in all cases until the 6^{th} week of anaerobic digestion when the least values were obtained. Therefore, it appeared that most biogas production was within 4 weeks of digestion irrespective of the C/N ratio in the substrates.

Ambient temperature ranged from 27.9 to 34.2°C and averaging 30.4±1.52°C during the experimentation. It affected daily biogas production significantly (P>0.05). However, both variables had weak positive correlation (R = 0.29; R Standard Error = 0.0074; R^2 = 0.09). The regression equation describing the relationship between daily biogas production and the ambient temperature is shown in Table 4. On the other hand, bio-digest temperatures were higher ranging from 26.7 to 48.6°C with an average of 37.9±5.51°C. Biogas production had a stronger positive relationship with bio-digest temperature (R = 0.43) than with ambient temperature (R = 0.29). Also, duration of digestion was negatively correlated with the bio-digest temperature (R = -0.19; R Standard Error = 0.0078). The range of bio-digest temperature recorded in the present study was considered to be mesophilic and was similar to those reported by [28] as suitable for biogas production during digestion. Methanogens are active within the bio-digest temperature range.

The results further revealed that bio-digest temperatures varied significantly (P>0.05) among the digest with different C/N ratios. Mean digest temperature decreased significantly with increasing C/N ratio. Bio-digest with the least C/N ratio of 20:1 had the highest temperature (39.9±5.90°C), while digest with the highest C/N ratio of 30:1 recorded the least (34.9±3.98°C). However, there was no significant difference between the temperatures recorded for digests with 20:1 and 25:1 (38.8±5.06°C) C/N ratios.

The positive correlation between Bio-digest temperature and daily biogas production (R = 0.43; R Standard Error = 0.0066; R^2 = 0.18) tended to suggest that the observed increase in bio-digest temperature was positively associated with the increased microbial activity and biochemical reactions leading to biogas production. Consequently, significantly higher bio-digest temperatures recorded in the waste mixtures containing C/N ratios of 20:1 and 25:1 were due to remarkably higher daily biogas production than the mixture having C/N ratio of 30:1. The regression equation describing the relationship between daily biogas production and the ambient temperature is shown in Table 4.

Relationship	**R**	**R^2**	**Linear regression equation**
Daily biogas production Vs Retention Time	0.16335	0.02668	Daily biogas prod (cm^3) = 270.66859 – 3.55588*Time (days)
Daily biogas production Vs Ambient Temperature	0.29405	0.08647	Daily biogas prod (cm^3) = -1374.67792 + 51.77808*Ambient Temperature (°C)
Daily biogas production Vs Digest Temperature	0.42717	0.18248	Daily biogas prod (cm^3) = -580.17729 + 20.5548*Digest Temperature (°C)
Weekly biogas production Vs Weekly Digest pH	0.37209	0.13845	Weekly biogas prod (cm3) = -5398.31652 + 987.2187*Weekly digest pH
Weekly digest pH Vs Retention time	-0.8997	0.80953	Digest pH = 7.49111 – 0.19905*Time (weeks)

Methane-forming bacteria are sensitive to acidity condition of the environment and hence their growth and biogas production are impaired at low pH below 5 [29]. However, it has been established that most methanogens thrive well at a pH range of 6.5 – 7.5, and thus yield biogas optimally at the same pH range [30], [19]. Reference [30] attributed the occurrence of acidity in the anaerobic digestion medium to combined effects of acidogenesis and acetogenesis resulting in the production of volatile fatty acids, ammonia, hydrogen, and carbon (IV) oxide.

Results presented in Table 3 showed that the weekly bio-digest pH ranged from 6.1 to 7.5 and averaging 6.79 ± 0.389 during the experimentation. Also, the pH range was close to the specified optimum range (6.5 – 7.5) for maximal biogas production [30], [19]. However, retention time affected bio-digest pH significantly (P>0.05), and both parameters were negatively correlated (R = -0.89; R Standard Error = 0.01190; R^2 = 0.80953). Regression equation describing the relationship is given in Table 4. The anaerobic digestion commenced with digest pH at almost neutrality and progressed towards acidity in the last week of experimentation. This observation is in agreement with earlier findings that hydrolysis and acidogenesis stages, which constitute the start-up phase in the anaerobic degradation of fresh waste required constant near neutral pH to proceed. This phase preceded methane formation that lowered the pH [31].

Furthermore, the results (Table 3) showed that the C/N ratio of digestion mixture did not significantly (P<0.05) affect the pH of the digest, whereas retention time did remarkably (P>0.05). Mean weekly bio-digest pH values of the mixtures were 6.75±0.401, 6.88±0.387, and 6.75±0.394 for mixtures having C/N ratios of 20:1, 25:1, and 30:1, respectively. The non-significant effect of C/N ratio on digest pH was contrary to expectation because nitrogen is the source of ammonium-nitrogen and hence ammonia formation in the anaerobic digestion reaction process [32]. Ammonia, being alkaline will raise the pH of the digesting substrate. Therefore, anaerobic digestion of the waste mixture with the narrowest C/N ratio (20:1) is expected to produce more ammonia and hence more alkalinity while the substrate with the widest C/N ratio (30:1) would be more acidic. The results obtained in the present study seemed to suggest that the balance of carbon to nitrogen in all the three C/N ratios tested substrates was about adequate for biogas production from such substrates in the anaerobic digestion.

Weekly biogas production significantly (P>0.05) influenced the bio-digest pH irrespective of the C/N ratio. Also, both variables were positively correlated (R = 0.37; R Standard Error = 0.1385; R^2 = 0.09). The regression equation describing the relationship between weekly biogas production and bio-digest pH is shown in Table 4. At the onset of the biochemical reactions leading to the production of biogas, simple sugars, fatty acids and amino acids, which are products of hydrolysis will be converted to carbonic acids, alcohols, hydrogen, carbon (IV) oxide and ammonia during acidogenesis. Products of the latter biochemical reaction excepting ammonia will be converted to hydrogen, acetic acid, and carbon (IV) oxide during acetogenesis. Finally, hydrogen and acetic acid are converted to methane and carbon (IV) oxide [28]. Consequently, ammonia accumulates and thus causing a rise in pH of the anaerobic digester. If the rise in pH continued, the growth, population, and biogas producing capacity of the methanogenic bacteria would be impeded [29]. However, the rise in digest pH from 6.1 to 7.5 in the current study was within the optimal pH range for growth and methane-forming activities of the methanogenic bacteria [30].

4. Conclusion

From the foregoing, it may be concluded that anaerobic digestion of the mixture of poultry droppings and swine dung adjusted with sawdust and water to attain carbon-to-nitrogen ratio of 20:1 and 8% total solids at an average ambient temperature (30.4±1.52^{o}C), digester temperature (39.9±5.90 ^{o}C), and average digester pH (6.75 ± 0.180) yielded optimum biogas (266.9±294.26 cm^3/day). Therefore, co-digestion of poultry droppings and swine dung and sawdust for biogas production provides a sustainable route for alleviating the environmental nuisance otherwise caused by non-disposal of the livestock waste.

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