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CH_4 Emission Model from *Bos Primigenius* Waste in Fish-Water: Implications for Integrated Livestock-Fish Farming Systems

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Abstract. This paper studies a methane (CH_4) emission model from the waste of cattle (*B. primigenius*) based on trends in integrated livestock-fish farming adoption by farmers in Nigeria. Dung of *B. primigenius* was employed as substrate in fish-water, obtained from a fish-rearing farm, as a matrix medium for simulating a low-oxygen wastewater environment of an agriculture-aquaculture system. A substrate to fish-water mass ratio of 1:3 was used, developed in a laboratory-size digesting reactor system. Volumetric readings, at ambient temperature conditions and with a retention time of thirty-two days, were then subjected to the logistic probability density function, and tested against correlation coefficient and Nash-Sutcliffe coefficient of efficiency criteria. The readings show that a volume of CH_4-containing gas as high as 65.3×10^{-3} dm^3 was produced on the 13th day from the *B. primigenius* substrate. Also, production of 234.59×10^{-3} dm^3/kg CH_4-containing gas, totaling 703.76×10^{-3} dm^3, was observed through the studied retention time. The 60% CH_4 constituent model of the measured gas generation showed a potency of 2.0664 kg emission per animal, which is equivalent to 43.3944 CO_2eq of global warming potential (GWP) annually per animal. This bears environmental and climate change implications, and therefore alternative sustainable practices for integrated livestock-fish farming adoption are suggested.

Keywords: *cattle dung; livestock-fish farming systems; logistic probability distribution function; methane emissions; waste management.*

1 Introduction

Livestock waste from the agricultural sector has been identified in studies as a major source of emissions such as CH_4, hydrogen sulphide (H_2S), nitrous oxide (N_2O), carbon dioxide (CO_2) and ammonia (NH_3) [1-3]. These emissions affect air quality and CH_4 is the major constituent. It can range from 60–70% of the emissions and is an anthropogenic greenhouse gas (GHG) that exhibits twenty-

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one times the global warming potential (GWP) of CO_2 [4-6]. This makes it worrisome that the prevalent behavioural pattern of livestock waste management among local farmers in developing countries [1-2,7-8] could be satisfying the conditions for the production of these GHG gases [4,9-10].

Studies have deliberated on the prevailing poor livestock waste management by local farmers, using Nigerian local farms as a case study [7-8], as well as the unhealthy emissions of local and global environmental effects that could result from such practices [11-14]. The practices whereby local farmers dispose of the inherently large turnout of waste from livestock rearing – usually not subjected to anaerobic pre-treatment before disposal – on their farms nearby bushes, pits, flowing streams and even stagnant wastewater pools, predisposes man and animals to various diseases and environmental hazards. Such environmental hazards include unpleasant odours from surrounding air pollution, surface water, runoff and groundwater contamination, pathogenic microbe growth, rodents and pest proliferation, infectious diseases, and fire outbreaks/explosion accidents caused by anaerobic CH_4 production [10,15-16].

Of particular concern are the recommendations in recent times concerning agriculture and aquaculture integration through the use of livestock manure as feed in fish ponds [7,15] to alleviate the poverty of farmers in developing countries [17]. While anything that would alleviate the poverty of these farmers is good, it is worth noting that, according to [15], application of fresh/untreated animal waste to fish ponds engenders oxygen depletion in the fish-water. The concern here is not only the fish deaths that could result from the inherent low-oxygen systems [15], but also that such oxygen depletion readily translates to anaerobic conditions that could also enhance CH_4 emissions.

The recommendations of the Intergovernmental Panel on Climate Change (IPCC) [18] identify two methods for estimating CH_4 emissions from waste: the default, or Tier 1, method and the First Order Decay (FOD), or Tier 2, method. The FOD method, whose time-dependent emission profile has been employed in [11] because it reflects the degradation pattern over time better than the default method, cannot be employed for Nigeria, however, due to inadequacy of the historical data required for computation, when this approach is used. In accordance with the recommendations of good practice by the IPCC, a country-specific regional research would be required for a nation like Nigeria, where a dearth of CH_4 emission data from livestock waste remains prevalent. For this reason, the default Tier 1 method, which can be used for reasonably estimating actual emissions from waste, has always been employed for the local farm scenario of Nigeria. Usually, this takes the form of employing bio-digester reactor systems for studying gas production from waste [1-2,19]. However, while [19] has deliberated on biogas production from cattle dung (*Bos* *primigenius*) in ordinary water medium and other substrates, and [1] has studied CH_4 emission from pig dung (*Sus domesticus*) and poultry droppings (*Sus Gallus*) in oxygen-depleted medium, there has been no study on the emission potential of cattle dung (*B. primigenus*) in a low-oxygen medium, nor on the underlying implications of its use in integrated agriculture-aquaculture systems. This investigation, therefore, studies statistical modelling of the emission potential of CH_4 from the waste (dung) of cattle (*Bos primigenius*) in fish-water medium, in a bid to garner implications from this for integrated livestock-fish farming. In view of this objective, fish-water medium was used in such a way that it could simulate low oxygen medium obtained from integrated livestock-fish farming systems. It is opined that implications learnt from the results of this study can help raise awareness and promote the incorporation of sustainable waste management practice in integrated livestock-fish farming systems.

2 Materials and Methods

2.1 Livestock Waste Materials

The dung of *B. primigenus*, the waste material used as substrate in this work, was collected fresh from the Abule-Egba abattoir in Lagos State, Nigeria. The waste was collected as described in [19], using black polyethylene bags to avoid moisture loss in the dung content so as to maintain the density of the waste material. For the mixture matrix of the livestock waste substrate, one-day old fish-water was collected from the fish farm of the Centre for Entrepreneurial Development Studies (CEDS) of Covenant University, Ota, Nigeria, just before it was disposed, as part of the daily practice of changing fish livestock water. The measured pH value of the fish-water used to simulate a reduced oxygen environment was 6.5 [10]. By mass, 3 kg of substrate was thoroughly mixed with 9 kg of fish-water, giving a ratio 1:3 of substrate to fish-water.

2.2 Reactor Setup

A bio-digesting reactor model was assembled, as described in [1], Figure 1. The reactor comprised of an 18 L (0.018 m^3) distiller bottle to which the requisite fittings were attached. The T-connector at the top of the bottle was terminated with a ball valve at one of its outlets, while the other outlet was connected to another T-connector fitting. Piping leading to a vent-valve was connected to one end of the second T-connector. The vent-valve was used for flaring off the daily gas yield after the yield measurement had been taken, thus, simulating emission, preventing excessive pressure build up in the digester and avoiding gas leakage. The daily gas emission measurement was taken using a U-tube flexible and transparent piping assembly. As shown in Figure 1, the U-tube contained water and was connected to the second end of the second T-connector. The measurements of daily gas emission were obtained through millimetre-ruled tape that was attached to the open (i.e. upward water displacement) end of the U-tube in such a way that the rise in water height was used for computation of the gas volume produced. All the employed piping and fittings were of ¼ inch (6.35 mm) diameter size.

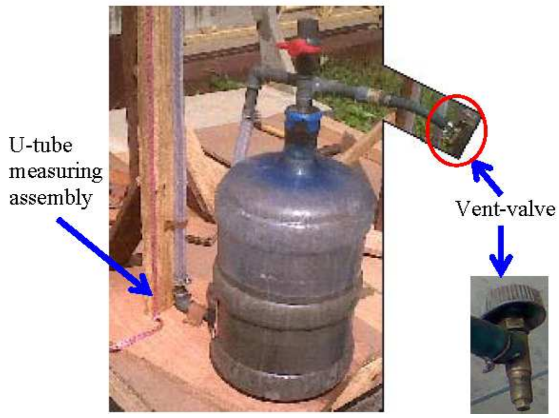

Figure 1 Experimental set-up for bio-digester reactor with vent-valve and measuring U-tube assembly.

2.3 Experimental Procedures

Three kilograms (3 kg) of *B. primigenius* substrate was thoroughly mixed with 9 kg of fish-water for a mix ratio of 1:3 [1,19]. The 12 kg mixture was then funnelled into the reactor. Air-tightness was ensured through the use of adhesives at the joints of the pipefittings in order to prevent leakage or unmeasured gas emission. To accelerate anaerobic conditions, the oxygen in the reactor assembly was burnt out by introduction of a burning splint into the reactor through the top ball valve. In this way, the splint burns until it was extinguished for lack of oxygen in the reactor. Subsequently, the splint was removed from the reactor and the top ball valve of the reactor was shut.

A thirty-two day retention time was employed for the experimental setup. Daily readings were taken in the afternoon, at about 3.00 pm local time in Nigeria, and the ambient temperature recorded during this period was between 29−34°C. Several days after the experimental period and when no emission was observable from the reactor, the stabilised substrate/fish-water mixture from the biogas reactor was dewatered in a hot-air stream oven maintained at 45°C for five weeks. Also, a control sample of 3 kg fresh *B. primigenius* substrate was dried in a separate container in a hot-air stream oven for correcting the water content in the mixed experimental substrate. The dried weights of these substrates was then measured, in kg, using Adam equipment (Model PW 254, 250g × 0.0001g) and the net weight obtained through the formula:

$$W_{dried,net} = W_{dried,control} - W_{dried,experimental} \tag{1}$$

2.4 Statistical Data Analysis

The daily measured data of gas production from the waste of *B. primigenius* was analysed using the logistic probability density function (PDF) [20], which bears similarity with and can be used instead of the normal distribution function. The PDF of the logistic distribution is given by the equation

$$f(x) = \frac{1}{k} \cdot \frac{\exp\left[-\left(\frac{x-a}{k}\right)\right]}{\left\{1+\exp\left[-\left(\frac{x-a}{k}\right)\right]\right\}^2} \tag{2}$$

where x is the variable of daily gas production (dm^3), a is the location parameter, which also gives the mean and the most probable or modal gas emission (all in dm^3), while k is the shape parameter and is dimensionless.

The cumulative density function (CDF) for this Logistic fitting of the data was obtained using [20]:

$$F(x) = \frac{1}{\left\{1+\exp\left[-\left(\frac{x-a}{k}\right)\right]\right\}} \tag{3}$$

2.5 Performance of the Logistic Fitting Model

The performance of the logistic PDF model for fitting the gas emission data from the waste of *B. primigenius* was studied using the correlation coefficient R, coefficient of determination R^2, and the Nash-Sutcliffe coefficient of efficiency (CoE) [21-22]. The obtained values of R were compared with those from the table of values of the correlation coefficient [23] to test for significance at a 95% confidence interval for number of variables (x, y) = 2 and degrees of freedom $\nu = n - 2 \equiv 30 - 2 = 28$ for n number of observations. The computed R from the experiment will be significant at the confidence interval if

$$\left|R_{Computed}\right| > \left|R_{Tabulated}\right| \tag{4}$$

3 Results and Discussions

Measured quantities of daily gas production from the *B. primigenius* substrate reactor over the whole retention period of 32 days are presented in Figure 2. This figure shows that daily gas production from the substrate of *B. primigenius* dung started on the 5th day, with the bulk of it suspected to be CO_2. Actual methane (flare gas) production was noticed on the 7th day. Although the time for the substrate of *B. primigenus* to initiate gas production was longer than that of *S. domesticus* and *S. Gallus* reported in [1], it was shorter compared to that of the substrate of cattle (*B. primigenius*) in ordinary water reported by [19]. This affirms that earlier gas production is possible in a low-oxygen medium, as suggested by [1].

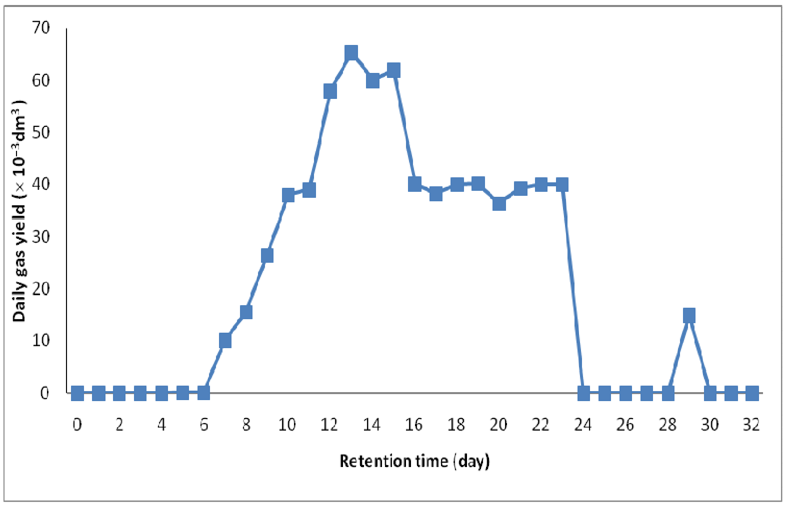

Figure 2 Daily yield of gas production from the substrate of *B. primigenius* for 32 days retention time.

A further notable increase in gas production volume per day continued up to the 13th day, where the biogas production peak was observed at 65.3×10^{-3} dm^3. A slight decrease was observed between the 13th and 15th day, followed by a more visible decrease in the daily gas yield of the cattle substrate. This was followed by a period of relatively constant daily gas yield from the 16th to 23rd day, with a mean gas production of about 39×10^{-3} dm^3 per day. From the 24th day, the production from the *B. primigenius* substrate ceased. Although trace gas production was noticed on the 29th day, there was none thereafter.

The plot of the logistic cumulative distribution function (CDF) for the measured daily emissions of methane containing gas of *B. primigenius* substrate is shown in Figure 3, and the real-time cumulative gas emission of the substrate is shown in Figure 4. Also, the estimated parameters of the logistic fittings and the real-time computations from the daily measurements of the methane containing gas emissions from the substrate are presented in Table 1; these include the statistical estimates of the mean and standard deviation for the substrate per day and the fitting performance of the daily emissions by the logistic PDF using correlation coefficient R, coefficient of determination R^2, and the Nash-Sutcliffe coefficient of efficiency (CoE).

From Table 1, the fitting of the logistic PDF and the measured daily gas emissions from the *B. primigenius* substrate finds a very strong but negative correlation (R = –0.91). With reference to Eq. (4), for v = 28, number of variable = 2, table of correlation coefficient at a 95% confidence interval [23] gives the value of R to be 0.361. The comparison of this value to the absolute value of the computed R in Table 1 shows that the $|R_{\text{Computed}}|$ is greater than 0.361, thus, the computed value of R is significant. This also suggests the existence of a correlated relationship between the logistic probability density function and the measured daily gas emissions. From the computed correlation coefficient, the coefficient of determination is R^2 = 0.84. The Nash-Sutcliffe coefficient of efficiency equals 0.80. From this CoE result, it can be deduced that the logistic model describes the gas production better than the measured emission data in accordance with the Nash-Sutcliffe CoE criteria.

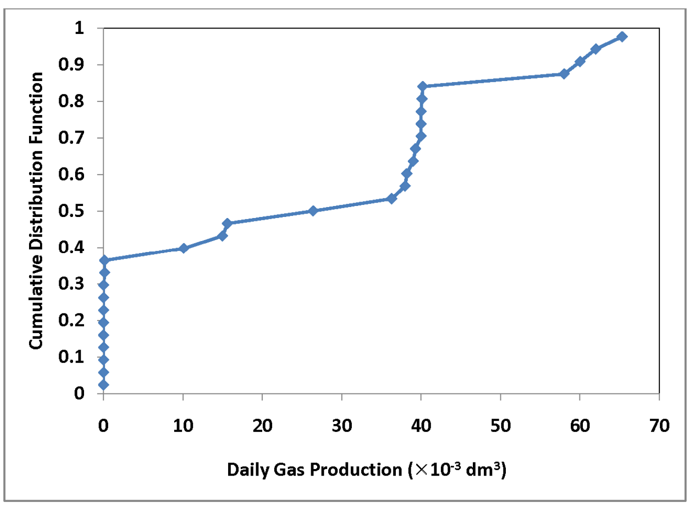

Figure 3 Plot of the cumulative distribution function of the logistic fittings of daily gas production from substrate of *B. Primigenius.*

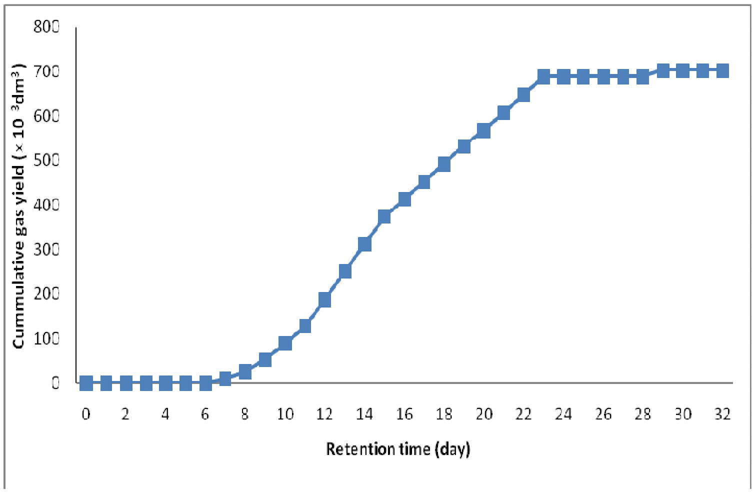

Figure 4 Real-time cumulative gas production of *B. primigenius* substrate in fish-water medium.

Table 1 Logistic/Real-time Parameter Estimates For CH_4-containing Gas Emissions from *Bos Primigenius* Reactor.

Estimated parameter	Logistic model	Real-time computation
Correlation coefficient (R)	–0.91	–
Coefficent of determination (R^2)	0.84	–
Nash-Sutcliffe CoE	0.80	–
Location parameter (a)	24.27	–
Scale parameter (b)	14.80	–
Average gas emission (μ) for 32 days ($\times 10^{-3}$ dm^3/day)	24.27	24.27
Standard deviation (σ)	26.85	22.81
Residual dried net weight of substrate, $W_{dried,net,}$ $\times 10^{-3}$ kg	–	0.5713
Total gas produced $\times 10^{-3}$ dm^3	–	703.76
Gas emission per unit mass of substrate ($\times 10^{-3}$ dm^3/kg)	–	234.59
60% – 70% Methane emission potential per unit mass of substrate ($\times 10^{-3}$ dm^3/kg)	–	140.75 – 164.21

In Table 1 it can be observed that the estimation of the location parameter *a* of the logistic fitting of the daily gas emission from the dung of *B. primigenius* was valued the same as the logistic PDF modelled average gas emission per day, μ_{Logostic}; i.e. $a = \mu_{\text{Logostic}} = 24.27 \times 10^{-3}$ dm^3/day. Also, this value is equal to the value of the modal gas production from this experimental setup. The estimated value of the scale parameter of the logistic PDF model, *b*, equals 14.80×10^{-3} dm^3, from which the logistic model of standard deviation can be computed to obtain $\sigma_{\text{Logistic}} = 26.85 \times 10^{-3}$ dm^3. While this logistic modelled value of standard deviation represents an over-estimate compared to the real-time computation of the standard deviation of 22.81×10^{-3} dm^3, the logistic modelled estimate of mean given above is the same as the real-time average daily gas production from the measured gas emissions.

In this experimental model, a unit mass of *B. primigenius* substrate in fish-water produced 234.59×10^{-3} dm^3, such that the 3 kg substrate in the reactor produced a total of 703.76×10^{-3} dm^3 in the 32 days of retention time. The total gas production obtained in this work just surpassed that obtained for the same mass of cattle dung studied in [19], valued at 690×10^{-3} dm^3/day, just as average gas emission per day of 24.27×10^{-3} dm^3/day from this study was greater than their 23.8×10^{-3} dm^3/day. The gas production from *B. primigenus* dung in this work was also produced earlier within 32-day retention time, and all gas had been produced on the 29th day, compared to the 40-day retention time in [19], where gas production from the substrate extended beyond the 30th day. These differences may not be considered to be significant; however, they bear suggestions of improved gas production, which would not be unconnected to use of low-oxygen medium for the substrate in this work. This notion is similar to what was proposed in [1], in which pig dung and poultry droppings were used as substrates. Also, it is worth noting that the residual net weight of *B. primigenus* substrate equals 0.4713×10^{-3} kg from Eq. (1). Given the density of CH_4 = 0.66 kg/m^3, the 703.76×10^{-3} dm^3 total gas production translates to 0.4655×10^{-3} kg CH_4 in the emission model, whereas 0.5713×10^{-3} kg from the net dried weight model translates to 865.61×10^{-3} dm^3. This yields a percentage difference of 23% between the experimental gas emission model and the net dried weight analysis.

However, from the emission model obtained in this study, an assumed 60-70% methane constituent of the gas production translates to $140.75 – 164.21 \times 10^{-3}$ dm^3/kg of substrate. According to [24], cattle can produce an amount of manure between 23.5 kg/animal/day to 62.5 kg/animal/day, depending on lactating or weight status. Such cattle, by assuming the lower value from the emission models, could be potent to generate CH_4 emissions ranging from 3307.625×10^{-3} $dm^3 \cdot day^{-1}$ to 8796.875×10^{-3} $dm^3 \cdot day^{-1}$ per animal, in a low oxygen aquaculture medium, where anaerobic conditions can be satisfied. This would imply an annual CH_4 generation that ranges from 1207.28 dm^3 to 3210.85 dm^3 or about 0.7769 kg to 2.0664 kg per animal at an STP (standard temperature and pressure) of 30°C [1]. Since CH_4 has a GWP 21 times higher than CO_2, this emission model could then be as potent as between 16.3149 kg to 43.3944 kg CO_2eq at trapping heat in the atmosphere and affecting climate change.

These results, from the experimental model in this study, bear implications for integrated livestock-fish farming as propagated by some developing countries. Many farmers from these countries that could benefit from an integrated farming system do not usually subject their livestock waste to pre-treatment. Also, many of the proposed designs of integrated agriculture-aquaculture for these poor farmers are such that the dung of livestock falls directly into an underlying fish-water for fish feeding tank. The study in this paper shows that accelerated GHG emissions can be initiated within 5 days in a stagnant fish-water pool on an integrated farm in a way that the modelled anaerobic conditions in this study could be satisfied. For this reason, the act of prolonged use of untreated wastewater pools in such integrated farming practices should be dissuaded. This could be done through relevant policies, punitive and rewarding schemes that will both enforce and encourage sustainable waste management practices in livestock-fish farming systems. Also, awareness raising and relevant technological support for generating domestic energy from these potent emissions from integrated livestock-fish farming wastewater should be provided to farmers by the government, environmental institutions and other stakeholders of environmental sustainability.

4 Conclusions and Recommendations

A CH_4 emission model from the waste of *B. primigenius* that could result from integrated livestock-fish farming systems in local farms in developing countries has been studied in this work. From this, the following conclusions can be drawn:

1. The fish-water matrix medium employed to simulate low-oxygen medium resulted in quick initiation of gas emission in the livestock substrate studied.
2. The daily measured data of gas emission, modelled using the logistic PDF method, exhibited a strong but negative correlation coefficient, $R = -0.91$, coefficient of determination, $R^2 = 0.84$ and a Nash-Sutcliffe coefficient of efficiency (CoE) of 0.80, thus indicating a good fitting of the (modelled) data with the logistic PDF using these criteria.
3. The dung studied emitted CH_4-containing gas; 24.27×10^{-3} dm^3/day, as high as 65.3×10^{-3} dm^3 on the 13th day, 703.76×10^{-3} dm^3 cumulative emission, and 234.59×10^{-3} dm^3/kg emission per unit mass.
4. According to the 60% methane-constituent model of measured gas emission, up to 140.75×10^{-3} dm^3/kg was emitted by the cattle substrate studied. This can be scaled-up, based on manure production per day and per head of cattle, to obtain a CH_4 emission of 3210.85 dm^3 or 2.0664 kg per animal annually that can be as potent as 43.3994 kg CO_2 eq.

Environmental implications of this emission potential from the adoption of integrated livestock-fish farming by local farmers in developing countries portend the dire need to establish sustainable waste and wastewater treatment for this farming system. This could be initiated through:

1. Policy development and raising awareness concerning domestic energy utilization that is possible from the CH_4 producing waste system;
2. A legislative measure/reward system to enforce/encourage livestock waste pre-treatment and post-treatment to be incorporated as important procedures in integrated livestock-fish farming systems.

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