TESLA
Revista Científica
ISSN: 2796-9320
Vol. 2 Núm. 2 (Enero – Junio 2023), e132

Artículo de Investigación Original

Microbe-substrate and gas-microbe interaction factors in relation to liquid manure anaerobic digestion and crop productivity

Factores de interacción microbio-sustrato y gas-microbio en relación con la digestión anaeróbica del estiércol líquido y la productividad del cultivo

Abdulhalim Musa Abubakar[1][0000-0002-1304-3515], Aadil Khursheed[2][0000-0003-3068-2180],
Muhammad Tariq[3][0000-0001-5539-0454], Nasir Musa Haruna[4][0000-0002-5529-7169]
[1]Department of Chemical Engineering, Faculty of Engineering, Modibbo Adama University (MAU), P.M.B 2076, Yola, Adamawa State, Nigeria. [2]Department of Chemistry, Faculty of Science and IT, Madhyanchal Professional University, Bhopal, India. [3]Department of Zoology, Faculty of Biological Sciences, Cholistan University of Veterinary and Animal Sciences Bahawalpur, Pakistan. [4]Department of Animal Science and Range Management, Modibbo Adama University (MAU), P.M.B 2076, Yola, Adamawa State, Nigeria
[1]abdulhalim@mau.edu.ng, [2]aaddikhan12@gmail.com, [3]m.tariq.aziz.120120@gmail.com,
[4]nasirharuna@mau.edu.ng

CITA EN APA:
Musa Abubakar, A., Khursheed, A., Tariq, M., & Musa Haruna, N. (2022). Microbe-substrate and gas-microbe interaction factors in relation to liquid manure anaerobic digestion and crop productivity. *Tesla Revista Científica*, *2*(2), e132. https://doi.org/10.55204/trc.v3i1.e132

Recibido: 02 de oct 2022
Revisado: 08 oct -01 de nov 2022
Corregido: 11 de noviembre 2022
Aceptado: 16 de noviembre 2022
Publicado: 22 de noviembre 2022

TESLA
Revista Científica
ISSN: 2796-9320

Abstract. Chemical fertilizer's increasing cost is becoming a major bottleneck for small and large farmland cultivation, of which liquid manure (LM) offers a comparative advantage. LM is the end-product of anaerobic digestion (AD) of several organic matter and/or their compost mixed manually or mechanically in dugged trenches or bioreactor using water. Overall, the microorganisms present helps significantly in breaking down soil organic matter to useful nutrient for the plant's survival and growth, as moisture is essential for bacterial proliferation. In this work, interaction between the substrate and microbe (N) and microbe and gas being produced (K) in mesophilic AD system is examined using an existing model. Results shows that, N and K ranges from 0.00046-0.0016 and 0.1643-0.1987 respectively between 25-45℃ for LM digested for 120 days. Statistical parameters, R^2 and adjusted R^2 shows that, empirical biogas yield at different choice of mesophilic temperature adequately fits the correlated values for estimates of the interaction factors obtained. This study by implication, sought to improve on LM studies and exploration for both agricultural use and biogas production as a potential replacement of the costly chemical fertilizer.

Keywords: Liquid manure, Interaction factor, Biogas yield, Anaerobic digestion, Crop production

Resumen: El costo cada vez mayor de los fertilizantes químicos se está convirtiendo en un cuello de botella importante para el cultivo de tierras agrícolas pequeñas y grandes, de las cuales el estiércol líquido (LM) ofrece una ventaja comparativa. LM es el producto final de la digestión anaeróbica (AD) de varias materias orgánicas y/o su compost mezclado manual o mecánicamente en zanjas excavadas o biorreactores que utilizan agua. En general, los microorganismos presentes ayudan significativamente a descomponer la materia orgánica del suelo en nutrientes útiles para la supervivencia y el crecimiento de la planta, ya que la humedad es esencial para la proliferación bacteriana. En este trabajo, se examina la interacción entre el sustrato y el microbio (N) y el microbio y el gas que se produce (K) en el sistema AD mesófilo utilizando un modelo existente. Los resultados muestran que N y K oscilan entre 0,00046 y 0,0016 y 0,1643 y 0,1987, respectivamente, entre 25 y 45 ℃ para LM digerido durante 120 días. Los parámetros estadísticos, R^2 y R^2 ajustado muestran que el rendimiento empírico de biogás a diferentes opciones de temperatura mesófila se ajusta adecuadamente a los valores correlacionados para las estimaciones de los factores de interacción obtenidos. Este estudio, por implicación, buscó mejorar los estudios y la exploración de LM para uso agrícola y producción de biogás como un reemplazo potencial del costoso fertilizante químico

Palabras clave: Abono líquido, Factor de interacción, Rendimiento de biogás, Digestión anaeróbica, Producción de cultivos

INTRODUCTION

As significant basis for plant nutrition, liquid manure (LM) essentially adds organic matter to the soil. By so doing, it improves tilth, soil structure and amendments, cation exchange ability, plant growth and productivity, infiltration of water, and organic carbon content of the soil (that gives energy to soil microbes); prevents pest and disease attack; benefits socio-economically; and reduces runoff by acting as a mulch (BEL, 2005; Gajjela et al., 2018; Halder et al., 2018; Hoorman et al., 2009; Mahanta & Dhar, 2021; Maity et al., 2020; Msibi et al., 2014; Onduru et al., 1999; Supriya & Harish, 2019). LM are therefore, organic fertilizers formed by mixing and dissolving factory waste, crop residues, urine, green manures, sawdust, market waste, animal dung, household/kitchen waste, mushroom waste, agro-industrial wastes and farm residues, among others – by way of fermenting and/or decomposing them (Ansar et al., 2021; Elaiyaraju & Partha, 2016; Rana, n.d.; Supriya & Harish, 2019). In various farmlands, the efficiency of LM in growing certain types of crops compared to chemical fertilizers had been studied with near 100% success by many researchers (Alamene & Howells, 2022; Antoneli et al., 2019; Arunkumar et al., 2021; Byeon et al., 2021; Choi et al., 2017; Gajjela et al., 2018; Msibi et al., 2014). In whatever form (solid, semi-solid or liquid form), manures have the potential of polluting water bodies and the surrounding air, by causing GHG emissions, ground water pollution, leaching of pollutants, soil salinization and eutrophication of surface water (Ahlberg-Eliasson et al., 2021; Antoneli et al., 2019; Camilleri-Rumbau et al., 2021).

In essence, to apply LM on agricultural soils, certain guidelines and procedures needs to be followed. Also, their type (e.g. the 1000 years old ancient manures, including panchagavya, jeevanruth, sasyagavya, sanjivak, bijamrita, ampritpani, kunapajala, vermiwash, seaweed extract, bokashi tea and compost tea), method of preparation, method of soil application and the nutritional composition needs to be considered (Maity et al., 2020; Nene, 2018; Supriya & Harish, 2019). LM manufacturing processes depends naturally on the feedstock available and selected for its production (Alagesan, n.d.; Rana, n.d.). Method of application comprises of land surface spreading, spray irrigation and shallow subsurface injection using LM application device/machine or manual technique (Hoorman et al., 2009; Shapiro et al., 2005). Ess et al. (2012) presented different machines used to apply LM on site with means of generating real data from its embedded weighing systems, flow meters, speed sensors and GPS units in order to measure the discharge rate, width of application, travel speed and application rate. But studies have shown that foliar application by means of spray as opposed root application, supplies nutrients to higher plants 20 times faster (Gajjela et al., 2018; Hoorman et al., 2009; Masih et al., 2009; Pajak et al., 2001). The nutrient content depends on method of waste collection and storage, age and species of the animals (e.g. manures from cow, poultry, horse, dairy, pig, dog, cattle etc), their number per unit area, their diet/feed nutrient density, barn management, bedding material type and volume, method and time of land application, climate, type of crop the manure is applied to, characteristics of the soil and other management factors (Manitoba, 2015; Muvhiiwa et al., 2016; Ritz & Merka, 2013; Sutton et al., 1985). For instance, antibiotics are sometimes found in pig excreta which might not be suitable for plants if received as swine LM (Yang et al., 2020).

Alternatively, in lieu of mixing substrates to formulate LMs, anaerobic digestion (AD) provides a double benefit of realizing not just the LM obtained from the digestate but also, biogas. Because originally, organic liquid fertilizers are by-product of bio-waste compost and/or aerobic and anerobic degradation processes (Sanadi et al., 2019; Wilkie, 2005; Zeeman, 1991). In view of that, the driving force, in this case bacteria, has a proportional effect on the amount of gas produced and has direct link with the substrate itself – especially in anaerobic systems. Also, in respective of the feed phase that results in a digestate/liquid manure, addition of more bacteria into the system generates more biogas. Even as Zaeni et al. (2019) affirms in their findings that decomposing solid waste requires more retention period than liquid waste, the ultimate goal is to generate a nutrient-rich liquid organic fertilizer. Exploring ways to replace chemical fertilizers is attached to the fact that they are not economically beneficial for small and marginal farmers due to their increasing cost (Arunkumar et al., 2021). The LM or digestate obtained from AD is usually separated into solid and fluid fraction by gravity, mechanical systems (Figure 1) and chemical coagulants addition (Popluga et al., 2020; Rico et al., 2022). Advantage is the lowering of its environmental impact (e.g. odor, pollutant emission and disease spread), animal waste volume, transportation cost, storage cost, energy consumed, the possibility of using homogenizing systems and increase ease of introducing liquid fraction into soil (Byshov et al., 2020; Camilleri-Rumbau et al., 2021; Popluga et al., 2020; Tampio et al., 2022). Though solid-liquid separation refuses to guarantee the recovery of the enormous nutrients still present in the resulting liquid fraction, its primary benefit is the production of bi-fractions that are fundamentally easy to manage than the initial slurry and manufacture additional products while utilizing it (Camilleri-Rumbau et al., 2021; Popluga et al., 2020; Wilkie, 2005).

(a) Digestate Separation Machine

(b) Mobile Separation Unit

Figure 1: Separation of the Digestate (Popluga et al., 2020)

Microbes in AD systems are responsible for depleting the substrate and producing multiple gases. Water is an essential substance microbes need to grow in size and multiply in the system (Anonymous, 2001). Collectively, the gases produced are tagged “biogas” as they originates from convertible organic matter (viz., LM). These microbes are very active constituents of biofertilizer to promote plant growth even after AD (Vishwakarma et al., 2020). Previously, several equations where developed to compute the speed at which the substrate is degraded by microbes and the rate at which biogas is formed. Almost none (or lacking), is a basic model that relates the microbe to both gas generation and microorganisms. However, Nwoye et al. (2012) formulated a simple model that provides a dimensionless parameters to both microbe-substrate and gas-microbe interaction in a nonlinear equation in relation to biogas generation with time. The model deals only with microbe interaction with gases in a confined or anaerobic environment, even though it is known that some of the gaseous components can disappear into the atmosphere when exposed for too long.

The digestate LM releases hydrogen sulphide (H_2S) and ammonia (NH_3) to the air causing headaches, eye irritation to death, depending on concentration and length of exposure (Wallace, 2008). Obviously, agriculture is the largest source of NH_3 to the air, according to estimates (Sommer et al., 2022). Sutaryo (2012) mentioned acidification using sulphuric acid as a proven technique of reducing NH_3 emission from manure. This implies that not all plant nutrients (e.g. nitrogen, phosphorus, potassium, carbon, sulphur etc.) are available in LM during crop application (Adar, 2020; BEL, 2005; Halder et al., 2018; Manitoba, 2015; Rahmad et al., 2018). Nitrogen volatilization, potassium runoff, phosphorus leaching and sulphur in reduced form, reduces the amount of nutrient used by the crop (Halder et al., 2018; Manitoba, 2015). Nitrogen, either in organic and/or inorganic form, is hard to ascertain their presence in the soil (Lorimor, n.d.; Zebarth et al., 1996). It is necessary to know the amount of manure N available for crop utilization and so Agros Nova N meter is used to rapidly estimate the N content of LM in the field (Manitoba, 2015; Zebarth et al., 1996). Sommer et al. (2022) went ahead to develop a model for computing the amount of NH_3 emitted from stored animal LM. Though losses of nitrogen are caused by (Lorimor, n.d.): (a) % of it in the NH_3 found, (b) weather, (c) surface to which the manure is applied and (d) time. Basically, the higher the solids content, the lower the $\%NH_3$. Warm condition always led to significant losses of NH_3 as well as from crop residue. By reducing the period of manure exposure, losses can be reduced as this is largely during the initial 5-10 days. In AD systems, rise in free NH_3 content affects the microorganisms in the methanogenesis phase (Rajagopal, 2013) and escape during storage or crop application is a natural way of ensuring microbial survival and ability to aid plant's growth.

Literature results from LM anaerobic digestion depends naturally on its composition and reacting conditions. It can also be understood as a codigested feedstock of dissimilar plant-animal, plant-plant or animal-animal wastes products in slurrified form (mixed with water). In that case, most AD experiments carried out are indirectly of LMs, even if it is also referred to as the liquid fraction of the digestate separation after aerobic decomposition. Table 1 gives some literatura reacting conditions during AD of LM.

Table 1: Liquid Manure Digestion and Biogas Yield

Feedstock	RT	Feed/OLR	Digester Type	Reactor Condition	Biogas/Methane Yield	Reference
Liquid dairy manure	-	-	Plug & mixed 5low sequential reactor system	-	-	(Wen et al., 2007)
Cattle manure liquid fraction (CMLF)	30 days	-	250 ml BMP bottles	35℃; 120 rpm; 1.5 S/I ratio; 8.13 pH	465 mL	(Adar, 2020)
Liquid fraction of dairy manure	<1 day	26.4-34.8 $g[COD]\ l^{-1}d^{-1}$	1 litre UASB	25℃	8.4 $l[CH_4]l^{-1}d^{-1}$	(Rico et al., 2022)
Cow rumen liquid processing waste	84 days	900 ml	-	-	6.197 litres (98.86% CH_4)	(Zaeni et al., 2019)
Liquid dairy manure	10 days	2-4.5 kg VS/m^3 day	CSTR	-	0.66-1.47 m^3/m^3 d	(Rico et al., 2011)
Flushed dairy manure	-	-	-	-	-	(Wilkie, 2005)

CSTR = continuous stirred tank reactor, UASB = upflow anaerobic sludge blanket, OLR = organic loading rate, COD = chemical oxygen demand, BMP = biomethane potential bottle, VS = volatile solid.

There are different understanding of the term 'liquid manure' by scientist and bioengineers. A mixture of plant, animal wastes and water; manure in diluted form like slaughterhouse wastewater (e.g. cattle and poultry liquid processing waste); sludge from tanneries, beverage industries and water treatment plants and; sewage are in various fora considered as LMs. This work takes LM as an organic matter mixed with water before digestion in an oxygen-free vessel. It utilizes the biogas yield assay obtained after digesting LM in five reactors of varying temperature conditions to explain the interaction between both substrate and gas with microbes present. The effectiveness of the model in explaining the empirical biogas yield result is also demonstrated using analytical tools.

MATERIALS AND METHODS

Materials used include water, thermometer, weighing balance, decomposition vessel, organic matter consisting of animal dung and plant waste and Excel analytical softwares. After 30 days retention time, the temperatures and biogas yield in five bioreactors were recorded every five days. When there isn't much significant increase in gas generation, the measurement was stopped on the 120th day. Data Analytical Memory, 'C-NIKBRAN' developed in 2008 by Nwoye et al. (2012) was used throughout this work. It is an equation (Eqn. 1) introducing new parameters called interaction factors for the gas production and substrate depletion.

$$K \ln\gamma \cong \alpha + N \qquad (1)$$

Where, N = overall microbe-substrate interaction factor, K = Gas-microbe interaction factor, α = hydraulic retention time (days) and γ = methane and biogas yield (mL/gVS). Using a result of biogas yield with retention time earlier obtained over 120 days fermentation period, a plot of '$\ln \gamma$' against α was made. Parameters N and K were repeatedly guessed to find their appropriate estimates that would generate a new set of '$\ln\gamma$' that fits the '$\ln\gamma$' from empirical measurement. In the process, two statistical parameters, R^2 and adjusted R^2 were computed. The correlated or predicted '$\ln \gamma$' can therefore be determined by customizing Equation (1) and (2).

$$\gamma = \exp\left(\frac{\alpha+N}{K}\right) = e^{\left(\frac{1}{K}\right)\alpha + \frac{N}{K}} \quad (2)$$

The experimented and predicted '$\ln\gamma$' data were plotted together to illustrate their level of fit as evidenced in the respective R^2 and adjusted R^2 obtained at temperatures 25, 30, 35, 40 and 45℃. N and K values can also be harvested from the slopes ($^1/_K$) and intercepts ($^N/_K$) of '$\ln \gamma$' against α lines.

RESULTS DISCUSSION

Table 2 are values obtained by measuring the yield of biogas at equal intervals (5 days) in 19 occasions.

Table 2: Empirical Biogas Yield with Temperature and Retention Time

T(℃)	**25**	**30**	**35**	**40**	**45**
RT (DAYS)	γ	γ	γ	γ	γ
30	186.79	259.18	331.58	403.97	476.36
35	198.34	269.78	341.22	412.67	484.11
40	209.88	280.38	350.87	421.37	491.87
45	221.42	290.97	360.52	430.07	499.62
50	232.97	301.57	370.17	438.77	507.37
55	244.51	312.17	379.82	447.47	515.13
60	256.06	322.76	389.47	456.17	522.88
65	267.6	333.36	399.12	464.88	530.63
70	279.15	343.96	408.77	473.58	538.39

https://doi.org/10.55204/trc.v3i1.e132

75	290.69	354.55	418.42	482.28	546.14
80	302.24	365.15	428.06	490.98	553.89
85	313.78	375.75	437.71	499.68	561.65
90	325.32	386.34	447.36	508.38	569.4
95	336.87	396.94	457.01	517.08	577.15
100	348.41	407.54	466.66	525.78	584.91
105	359.96	418.13	476.31	534.48	592.66
110	371.5	428.73	485.96	543.18	600.41
115	383.05	439.33	495.61	551.89	608.16
120	394.59	449.92	505.25	560.59	615.92

Abubakar et al. (2022) carried out a similar study using a ready-made Excel Calculator that returns the biogas yield of LM at constant temperature and varying time. Temperature shows a proportional trend in the behavior of the yield with time, which agrees with Eronmosele et al. (2020) and Tian et al. (2018) studies.

Gas-microbe and microbe-substrate interaction factors are new set of parameters introduced in AD system. Nwoye et al. (2012) did not explain vividly, how important these factors are in microbial or biogas yield analysis as with other kinetic equations. Also, appropriate ranges for N and K are not given, but can be estimated for a set of γ and α. But from Table 3, N and K estimates shows that activities of microbes are the main agents those parameters aim to explain. N and K happens to decrease with increasing temperature. At a particular retention time, gas yield skyrockets with increasing temperature, which is opposite the trends shown by N and K. A high N (at 25°C) implies that the activity of microorganism or their conversion of the LM substrate to biogas is low. Because temperature increases reaction rate, a low N (at 45°C) by indication, shows that around the mesophilic temperature (Gaby et al., 2017; Murillo-Roos et al., 2022; Zeeman, 1991), the environment is most favorable for microorganisms to proliferate and generate more gases. Since both N and K have identical decreasing trends with temperature, high K is illustrative of the fact that gas production is limited due to either low microbial presence, insufficient nutrient or a near psychrophilic temperature regime which is not quite favorable in this experiment. While low K, would give better yield, of which intuitively, it can be presumed that the microorganisms present are mesophilic.

Table 3: Interaction Factors of Liquid Manure AD and Statistical Parameter

	Temperature				
	25°C	30°C	35°C	40°C	45°C
Factors:					
N =	0.001629	0.001129	0.000828	0.00061	0.00046
K =	0.198653	0.185137	0.176084	0.169451	0.164309
Statistical Parameter:					
R^2 =	0.999982	0.999995	0.999998	0.999999	0.999999
adj. R^2 =	0.999981	0.999995	0.999998	0.999999	0.999999

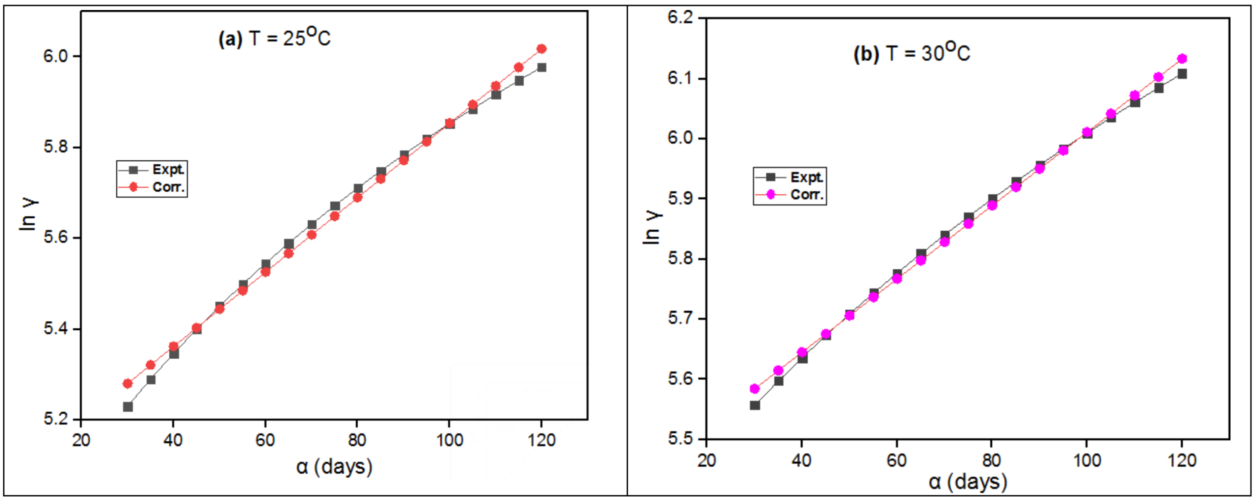
Microbes in the AD system are responsible for converting the nutrients in the LM to biogas. At any temperature, the longer the α, the less the nutrient remnants inside the LM after digestion, due to increased consumption rate by the microbes leading to increased biogas yield. Therefore, there would be less available nutrient for plant growth in the digestate; a situation that is identical with the high N scenario. However, non-metallic nutrients such as NH_3 and H_2S are products of bacteria degradation of the LM and contains sulphur and nitrogen also needed for plant growth. So within the digestate, there would still be elements of sulphur, nitrogen, potassium and phosphorus after digestion which are most atimes enough for crop production.

The estimates of the interaction factors can be plugged into Equation (2) as shown in Equation 3-7 to give their respective model equations.

$$25°\text{C:} \quad \gamma = e^{0.0082\alpha + 5.0339} \tag{3}$$
$$30°\text{C:} \quad \gamma = e^{0.0061\alpha + 5.4014} \tag{4}$$
$$35°\text{C:} \quad \gamma = e^{0.0047\alpha + 5.6791} \tag{5}$$
$$40°\text{C:} \quad \gamma = e^{0.0036\alpha + 5.9014} \tag{6}$$
$$45°\text{C:} \quad \gamma = e^{0.0028\alpha + 6.0861} \tag{7}$$

The derived model equations excludes kinetic parameters found in biogas kinetic models (e.g. modified Gompertz, Cone, Transfert, First-order models etc.) previously analyzed for the same feedstock by Abubakar et al. (2022) and microbial growth kinetic models (e.g. Monod, Contois etc.). However, N and K can be compared with biomethane potential, lag phase, shape factors, maximum specific growth rate and half-saturation constants in those models.

Figures 2 demonstrates a fitted line of experimental logarithm of the bioyas yield and that of the predicted values. They equally shows a proportionate rise in biogas with time and temperature.



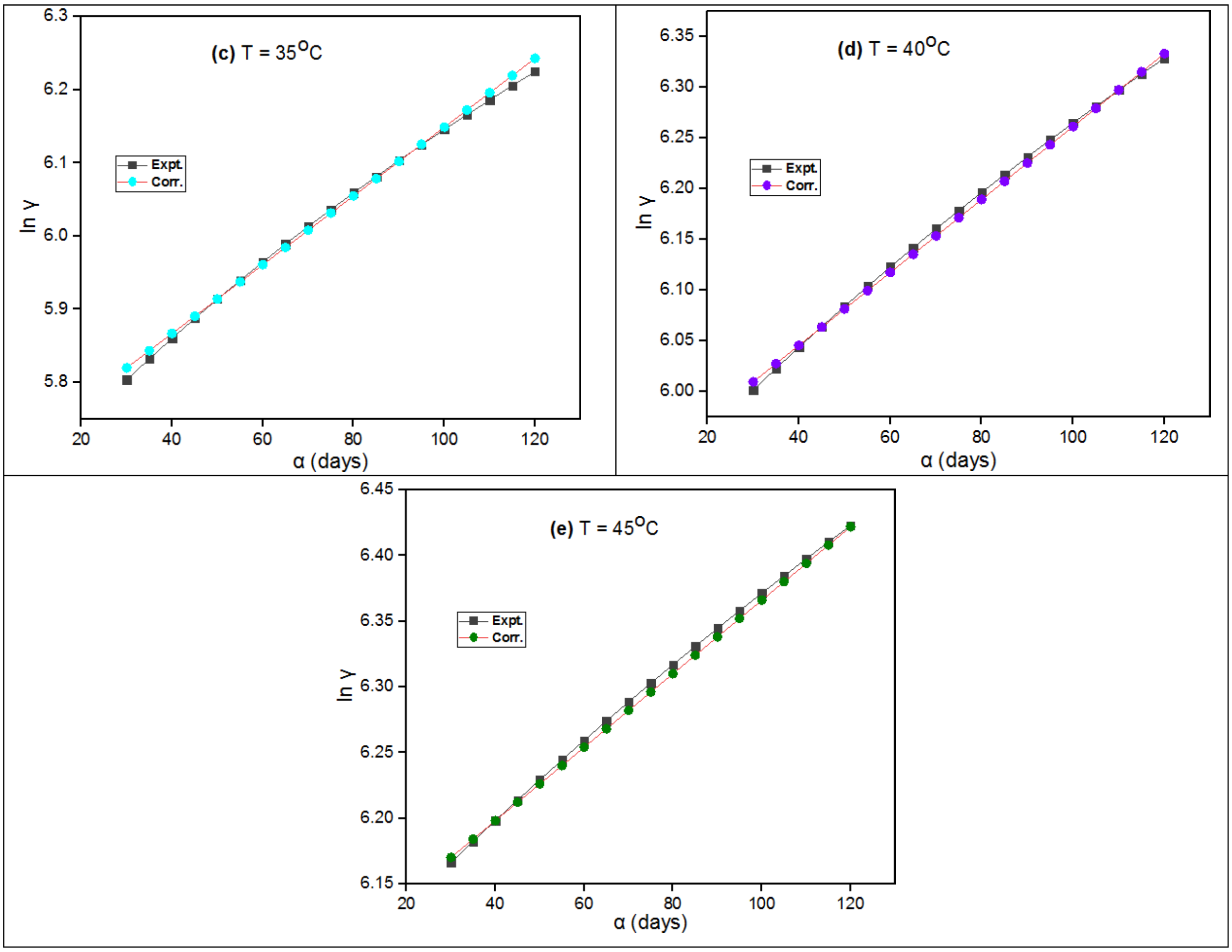
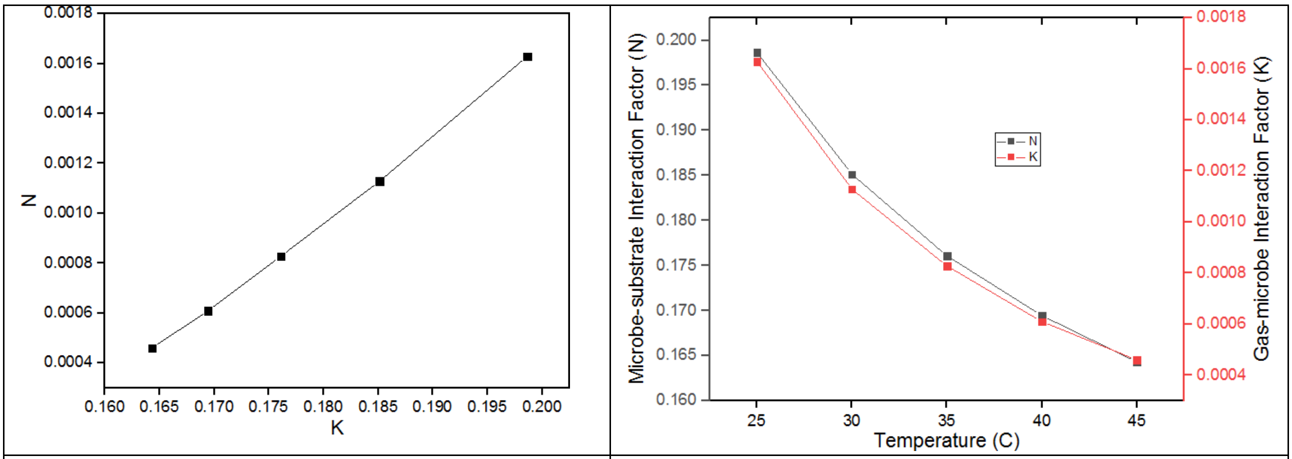


Figure 2: Demosntrating C-NIKBRAN Model Effectiveness in Predicting N and K of Fitted γ

As obtained in this work and stated by Muvhiiwa et al. (2016), high temperature leads to more biogas production than low temperatures. That is, of the three temperature regimes (namely, cryophilic/psychrophilic, mesophilic and thermophilic regime), as proved by Sichilalu et al. (2017), Ukpai et al. (2015) and Singh et al. (2017), bacteria continues to multiply with upward rise in temperature from 20-40℃ (around the mesophilic range) thereby increasing biogas generation. Above 40℃, bacteria reduces or stop multiplication, according to Sichilalu et al. (2017), who compared the biodigester with the stomach. But, Pandey & Soupir (2012) works shows that biogas produced during dairy manure digestion was highest at 52.5℃ while Sultan et al. (2019) and Zahoor et al. (2021) obtained more at 55℃. By implication, 45℃ is not an optimum temperature at which biogas generation is maximum for LM-AD.

N < K for all temperature conditions in Table 3 points to better conversion of substrate to gas by the microorganism even at low quality condition of the feed/nutrient present for the microbe to interact with, which is arguably wrong. Figure 3a obviously shows that N an K are proportional, where a low K corresponds with a low N and a high K corresponds with a high N in this experiment.



(a) N-K Relationship | (b) Temperature-Interaction Factor Relationship

Figure 3: N, K and Temperature Relationship

Notice that two sets of N and K that lies between the maximum and minimum values obtained in this work and as shown in Figure 3(a) can be plugged into Equation 1 and solved simultaneously for γ and α. That is, if the two equations are written in form of “$(\ln \gamma).\ K - N = \alpha$”, which can be solved using the Appendix D C++ codes. Alternatively, N and K at any temperature between 25 and 45℃ can be determined from Figure 3b by drawing a vertical line from the temperature to intersect the N and K curves. Other graphical illustrations that clearly explains some relationships are presented in the Appendix.

CONCLUSIONS

Perfect interaction between microbes and both substrates and gas will ensure an efficient AD process. The interaction is favoured by good reacting condition to enable microbial survival so that they continue to perform effectively to generate the desired feedstock-biogas conversion. High temperature around the terminal value of the mesophilic microbe temperature range (e.g. 45℃) provides 476.36-615.92 mL/gVS of biogas which is compared highest to lower temperatures. However, the temperature-effect is not incorporated in model used in this study, but is significant in explaining both N and K values obtained, which in turn gives clue on nutrient availability in the LM for plant growth. The C-NIKBRAN analytical memory model needs further examination in other biogas source. It also needs to be tested and compared with biogas kinetic models and microbial growth kinetic models in the literature for same and diverse feedstock combinations. Questions like, ‘how growth parameters in those models relates with N and K?’ should be answered in future combined examination of the models with selected feedstock.

FUNDING

The authors received no funding for the development of this research.

CONFLICT OF INTERESTS

The authors declare that there is not in existence any conflict of interest.

AUTHORSHIP CONTRIBUTION

In accordance with the internationally established taxonomy for the assignment of credits to authors of scientific articles (https://credit.niso.org/), the authors declare their contributions in the following matrix:

	Abdulhalim MA..	Aadil K	Muhammad T	Nasir MH
Participar activamente en:				
Conceptualización	X			
Análisis formal	X			
Adquisición de fondos				X
Investigación	X			
Metodología			X	
Administración del proyecto		X		
Recursos				X
Redacción –borrador original		X		
Redacción –revisión y edición				X
La discusión de los resultados	X			
Revisión y aprobación de la versión final del trabajo.			X	

ACKNOWLEDGMENT TO REVIEWERS

The journal acknowledges the time and effort of the editor / section editor PhD. Maricel Caputo and anonymous reviewers who dedicated their time and effort to the evaluation and improvement of this article.

REFERENCES

Abubakar, A. M., Umdagas, L. B., Waziri, A. Y., & Itamah, E. I. (2022). Estimation of biogas potential of liquid manure from kinetic models at different temperature. *International Journal of Scientific Research in Computer Science and Engineering (IJSRCSE)*, *10*(2), 46–63. www.isroset.org

Adar, E. (2020). Optimization of cattle manure liquid fraction anaerobic digestion at different temperatures: Modelling by Taguchi method. *Sigma Journal of Engineering and Natural Sciences*, *1753–1766*(4), 38.

Ahlberg-Eliasson, K., Westerholm, M., Isaksson, S., & Schnurer, A. (2021). Anaerobic digestion of animal manure and influence of organic loading rate and temperature on process performance, microbiology, and methane emission from digestates. *Frontiers in Energy Research*, *9*(740314), 1–16. https://doi.org/10.3389/fenrg.2021.740314

Alagesan, P. (n.d.). Simple liquid manure production technique. *The Hindu*, 1–2.

Alamene, A., & Howells, P. A. (2022). Evaluation of sustainable bio-liquid fertilizer (Supergro) on the production of fluted pumpkin (Telfairia occidentalis). *European Journal of Food Science and Technology*, *10*(1), 20–42. https://www.eajournals.org

Anonymous. (2001). Factors that influence microbial growth. In *Evaluation and definition of potentially hazardous foods* (pp. 1–36).

Ansar, M., Bahrudin, Fathurrahman, Darman, S., Thaha, A. R., Angka, A. W., & Rahmadanih. (2021). Application of bokashi goat manure and organic liquid fertilizer to improve the growth and yield of Lembah Palu shallot variety. *The 1st International Conference on Environmental Ecology of Food Security*, *681*(012047), 1–7. https://doi.org/10.1088/1755-1315/681/1/012047

Antoneli, V., Mosele, A. C., Bednarz, J. A., Pulido-Fernandez, M., Lozano-Parra, J., Keesstra, S. D., & Rodrigo-Comino, J. (2019). Effects of applying liquid swine manure on soil quality and yield production in tropical soybean crops (Parana, Brazil). *Sustainabilitylity*, *11*(3898), 1–11. https://doi.org/10.3390/su11143898

Arunkumar, S., Srinivasappa, K. N., & Reddy, M. V. (2021). Effect of bio-digester liquid manure on growth, yield and quality of Capsicum under open field condition. *International Journal of Current Microbiology and Applied Sciences*, *10*(02), 2857–2864. https://doi.org/https://doi.org/10.20546/ijcmas.2021.1002.317

BEL. (2005). Liquid and solid manure application. In *Building Environmental Leaders* (pp. 1–2). University of Wisconsin-Extension Publication.

Byeon, J.-E., Lee, H.-J., Ryoo, J.-W., & Hwang, S.-G. (2021). Effect of different liquid manure anaerobic digestates on the growth and yield of rice and the optimum application concentration. *Korean Journal of Crop Science*, *66*(1), 97–104. https://doi.org/https://doi.org/10.7740/kjcs.2021.66.1.097

Byshov, N. V, Uspenskiy, I. A., Yukhin, I. A., & Limarenko, N. V. (2020). Ecological and technological criteria for the efficient utilization of liquid manure. *6th International Conference on Agriproducts Processing and Farming: Earth and Environmental Science*, *422*(012069), 1–4. https://doi.org/10.1088/1755-1315/422/1/012069

Camilleri-Rumbau, M. S., Briceno, K., Sotoft, L. F., Christensen, K. V., Roda-Serrat, M. C., Errico, M., & Norddahl, B. (2021). Treatment of manure and digestate liquid fractions using membranes: Opportunities and challenges. *International Journal of Environmental Research and Public Health*, *18*(3107). https://doi.org/https://doi.org/10.3390/ijerph18063107

Choi, S.-T., Ahn, G.-H., Kim, S.-C., & Kim, E.-S. (2017). Effect of liquid manure and chemical fertilizers on shoot growth and nitrogen status of young “Fuyu” persimmon trees. *Journal of Agricultural Chemistry and Environment*, *6*, 144–151. https://doi.org/https://doi.org/10.4236/jacen/2017.63009

Elaiyaraju, P., & Partha, N. (2016). Studies on biogas production by anaerobic process using agroindustrial wastes. *Res. Agr. Eng.*, *62*(2), 73–82. https://doi.org/10.17221/65/2013-RAE

Eronmosele, P., Thelma, A. E., & Essienubong, A. I. (2020). Comparative study of the kinetics of biogas yield from the codigestion of poultry droppings with waterleaf and poultry droppings with elephant grass. *Engineering Sciences (NWSAENS)*, *15*(3), 139–150. https://doi.org/http://dx.doi.org/10.12739/NWSA.2020.15.3.1A0457

Ess, D. R., Hawkins, S. E., & Morris, D. K. (2012). *Implementing site-specific management: Liquid manure application*. Knowledge to Go: Purdue Extension. http://www.agcom.purdue.edu/AgCom/Pubs/menu.htm

Gaby, J. C., Zamanzadeh, M., & Horn, S. J. (2017). The effect of temperature and retention time on methane production and microbial community composition in staged anaerobic digesters fed with food waste. *Biotechnology for Biofuels*, *10*(302), 1–13. https://doi.org/https://doi.org/10.1186/s13068-017-0989-4

Gajjela, S., Chatterjee, R., Subba, S., & Sen, A. (2018). Prospect of liquid organic manure on organic bitter gourd cultivation. *Journal of Pharmacognosy and Phytochemistry*, *7*(6), 189–193. www.phytojournal.com

Halder, J. N., Kang, T.-W., Kim, S.-R., Yabe, M., & Lee, M.-G. (2018). The application of liquid fertilizer quality certification (LFQC) for liquid manure fertilizers and probability of implementation as a quality specification for business purposes in South Korea. *J. Fac. Agr.*, *63*(2), 443–449. https://doi.org/https://doi.org/10.5109/1955667

Hoorman, J. J., Rausch, J. N., & Brown, L. C. (2009). Guidelines for applying liquid animal manure to cropland with subsurface and surface drains. In H. Keener, T. H. Harrigan, W. G. Bickert, M. J. Monnin, F. E. Gibbs, S. R. Reamer, & M. I. Gangwar (Eds.), *Agriculture and Natural Resources (ANR-21)*. CFAES Publications. https://ohioline.osu.edu

Lorimor, J. (n.d.). Ammonia losses from broadcast liquid manure. *Management/Economics*, 1–2.

Mahanta, D., & Dhar, S. (2021). Liquid organic manures: A boon to organic farmers. In *Indian Farming*. Indian Council of Agricultural Research. epubs.icar.org.in

Maity, P., Rijal, R., & Kumar, A. (2020). Application of liquid manures on growth of various crops: A review. *International Journal of Current Microbiology and Applied Sciences, 11*, 1601–1611. http://www.ijcmas.com

Manitoba. (2015). *Properties of manure*. manitoba.ca/agriculture

Masih, M. R., Choudhary, R. L., Banani, S., & Singh, B. (2009). Liquid organic manure is a boon for organic cultivation of crops. *International Journal of Agricultural Sciences*, *5*(1), 8–10.

Msibi, B. M., Mukabwe, W. O., Manyatsi, A. M., Mhazo, N., & Masarirambi, M. T. (2014). Effects of liquid manure on growth and yield of spinach (Beta vulgaris Var Cicla) in a sub-tropical environment in Swaziland. *Asian Journal of Agricultural Sciences*, *6*(2), 40–47. https://doi.org/10.19026/ajas.6.5301

Murillo-Roos, M., Uribe-Lorio, L., Fuentes-Schweizer, P., Vidaurre-Barahona, D., Brenes-Guillen, L., Jimenez, I., Arguedas, T., Liao, W., & Uribe, L. (2022). Biogas production and microbial communities of mesophilic and thermophilic anaerobic co-digestion of animal manures and food wastes in Costa Rica. *Energies*, *15*(3252), 1–16. https://doi.org/https://doi.org/10.3390/en15093252

Muvhiiwa, R. F., Chafa, P. M., Chikowore, N., Chitsiga, T., Matambo, T. S., & Low, M. (2016). Effect of temperature and pH on biogas production from cow dung and dog faeces. *African Journals Online (AJOL)*, *45*(4).

Nene, Y. L. (2018). The concept and formulation of Kunapajala, the world's oldest fermentated liquid ornanic manure. *Asian Agri-History*, *22*(1), 8–14. https://doi.org/10.17485/aah/2018/v22i1/18292

Nwoye, C., Ferdinand, A., Agatha, I., & Samuelmary, O. (2012). Model for assessment evaluation of methane gas yield based on hydraulic retention time during fruit wastes biodigestion. *Journal of Minerals and Materials Characterization and Engineering (JMMCE)*, *11*, 947–952. http://www.scirp.org/journal/jmmce

Onduru, D., Gachini, G. N., Jager, A. de, & Diop, J. M. (1999). Participatory research on compost and liquid manure in Kenya. *Managing Africa's Soils*, 1–31.

Pajak, J. J., Zebrowska, T., Dabowski, P., Dlugolecka, Z., & Kowalik, B. (2001). The influence of fertilization with liquid cattle manure on the nutritive value of lucerne forage for ruminants. *Journal of Animal and Feed Sciences*, *10*(2), 351–355. https://doi.org/https://doi.org/10.22358/jafs/70120/2001

Pandey, P., & Soupir, M. (2012). Impacts of temperatures on biogas production in dairy manure anaerobic digestion. *International Journal of Engineering and Technology*. https://doi.org/10.7763/IJET.2012.V4.448

Popluga, D., Kreismane, D., & Cīrulis, J. (2020). *Separation of liquid manure and digestate: Climate-friendly agricultural practice in Latvia*.

Rahmad, Karim, A., Nafie, N. La, & Jayadi, M. (2018). Synthesis of liquid organic fertilizer based on chicken manure using Biosca and Fungus bioactivator Trichoderma harzianum. *Indonesia Chimica Acta*, *11*(2), 28–44.

Rajagopal, R. (2013). Inhibiting factors in the anaerobic digestion process for biogas production. *Bioresource Technology*, *143*, 632–641.

Rana, L. (n.d.). Liquid manure. In J. Bahadur & D. Gharti (Eds.), *The Farmers' Handbook* (p. 11). Grihasthi Communications.

Rico, C., Rico, J. L., & Lasa, C. (2022). *Anaerobic digestion of the liquid fraction of dairy manure separated by screw-pressing and centrifugation in a UASB reactor at 25C* (pp. 1–16).

Rico, C., Rico, J. L., Tejero, I., Munoz, N., & Gomez, B. (2011). Anaerobic digestion of the liquid fraction of dairy manure in pilot plant for biogas production: Residual methane yield of digestate. *Waste Management*, *31*(9–10), 2167–2173. https://doi.org/https://doi.org/10.1016/j.wasman.2011.04.018

Ritz, C. W., & Merka, W. C. (2013). Maximizing poultry manure use through nutrient management planning. In *Bulletin 1245* (pp. 1–6). UGA Extension-University of Georgia Cooperative Extension.

Sanadi, N. F. A., Lee, C. T., Sarmidi, M. R., Klemes, J. J., & Zhang, Z. (2019). Characterisation of liquid fertilizer from different types pf bio-waste compost and its correlation with the compost nutrients. *Chemical Engineering Transaction*, *72*, 253–258. https://doi.org/10.3303/CET1972043

Shapiro, C. A., Kranz, W. L., & Wortmann, C. S. (2005). Salt thresholds for liquid manure applied to corn and soybean. *Transactions of the ASAE*, *48*(3), 1005–1013.

Sichilalu, S., Ngoyi, L., Mathaba, T., Wanjiru, E., & Xia, X. (2017). Experimental determination of a critical temperature for maximum anaerobic digester biogas production. *Multi-Disciplinary Conference*, 1–6. www.manzivalley.com

Singh, G., Jain, V. K., & Singh, A. (2017). Effect of temperature and other factors on anaerobic digestion process, responsible for bio gas production. *International Journal of Theoretical and Applied Mechanics (IJTAM)*, *12*(3), 637–657. http://www.ripublication.com

Sommer, S. G., Hafner, S. D., Laubach, J., van der Weerden, T. J., Leytem, A. B., & Pacholski, A. (2022). Model for calculating ammonia emission from stored animal liquid manure. *Biosystems Engineering*, *223*, 41–55. https://doi.org/https://doi.org/10.1016/j.biosystemseng.2022.08.007

Sultan, S. M., Wadullah, H. M., Mohammed, A. G., & Ahmed, O. K. (2019). Improve biogas production by using bacteria. *1st Al-Noor International Conference for Science and Technology (NICST 2019)*, 73–78.

Supriya, M. E., & Harish, J. (2019). *Preparation of liquid manures and their quality and its use in* *organic farming* (S. T. Bhairappanavar, R. Jayaramaiah, G. Pramod, & B. T. Naveenkumar (eds.)). https://www.slideshare.net/HarishReddy280/preparation-of-liquid-manures-and-their-quality-and-its-use-in-organic-farming

Sutaryo. (2012). Optimization and inhibition of anaerobic digestion of livestock manure [Aarhus University: Technical Report BCE-TR-3]. In J. Rintala, H. W. Uellendahl, P. Kristensen, H. B. Moller, & A. J. Ward (Eds.), *Biological and Chemical Engineering*. http://www.eng.au.dk

Sutton, A. L., Nelson, D. W., & Jones, D. D. (1985). Utilization of animal manure as fertilizer. In *Soil Fertility* (pp. 1–12). Purdue University.

Tampio, E., Marttinen, S., & Rintala, J. (2022). *Liquid fertilizer products from anaerobic digestion of food waste: Mass, nutrient and energy balance of four digestate liquid treatment systems* (pp. 1–55).

Tian, G., Yang, B., Dong, M., Zhu, R., Yin, F., Zhao, X., Wang, Y., Wang, Q., Zhang, W., & Cui, X. (2018). The effect of temperature on the microbial communities of peak biogas production in batch biogas reactors. *Renewable Energy*, *123*, 15–25. https://doi.org/https://doi.org/10.1016/j.renene.2018.01.119

Ukpai, P. A., Agbo, P. E., & Nnabuchi, M. N. (2015). The effect of temperature on the rate of digestion and biogas production using cow dung, cow pea, cassava peeling. *International Journal of Scientific & Engineering Research*, *6*(1).

Vishwakarma, K., Kumar, N., Shandilya, C., Mohapatra, S., Bhayana, S., & Varma, A. (2020). Revisiting plant-microbe interactions and microbial consortia application for enhancing sustainable agriculture: A review. *Frontiers in Microbiology*, *11*, 1–21. https://doi.org/10.3389/fmicb.2020.560406

Wallace, T. (2008). *Sampling liquid manure for analysis* (pp. 1–6). Agri-Facts: Practical Information for Alberta’s Agriculture Industry.

Wen, Z., Frear, C., & Chen, S. (2007). Anaerobic digestion of liquid dairy manure using a sequential continuous-stirred tank reactor system. *Journal of Chemical Technology and Biotechnology*, *82*(8), 758–766. https://doi.org/https://doi.org/10.1002/jctb.1736

Wilkie, A. C. (2005). Anaerobic digestion of dairy manure: Design and process considerations. In N. Y. Ithaca (Ed.), *Dairy Manure Management Conference: Natural Resource, Agriculture, and Engineering Science (NRAES-176)* (pp. 301–312). Cornell University.

Yang, F., Han, B., Gu, Y., & Zhang, K. (2020). Swine liquid manure: A hotspot of mobile genetic elements and antibiotic resistance genes. *Scientific Reports*, *10*(15037), 1–10. https://doi.org/https://doi.org/10.1038/s41598-020-72149-6

Zaeni, A., Susilowati, P. E., Harlia, & Rasmin, N. (2019). Anaerobic digestion of solid and liquid organic waste with microorganism from manure. *The 5th International Seminar on Sciences: Earth and Environmental Sciences 299*, *299*(012063), 1–9. https://doi.org/10.1088/1755-1315/299/1/012063

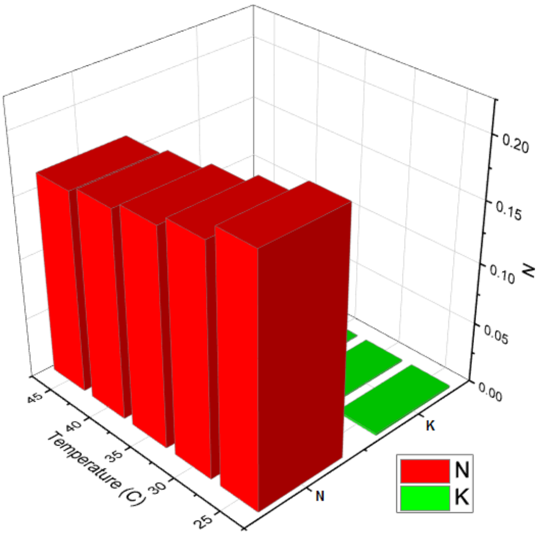
Zahoor, A., Arslan, C., Sattar, A., Tahir, M. A., Farooqi, Z. U. R., Shoaib, M., Saqlain, M., Safdar, M., & Ahmad, N. (2021). Effect of temperature on biogas production potential of banana peels co digested with biogas slurry in anaerobic bioreactor. *Engineering Heritage Journal (GWK)*, *5*(2), 49–52. https://doi.org/https://doi.org/10.26480/gwk.02.2021.49.52

Zebarth, B. J., Paul, J. W., Schmidt, O., & McDougall, R. (1996). Influence of the time and rate of liquid-manure application on yield and nitrogen utilization of silage corn in South Coastal British Columbia. *Canadian Journal of Soil Science*, *76*, 153–164.

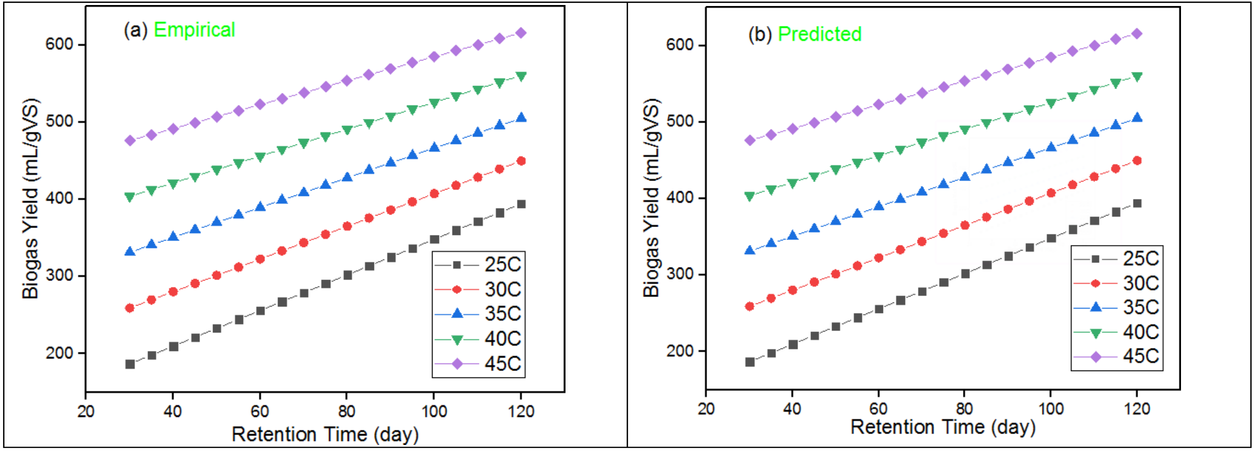
Zeeman, G. (1991). *Mesophilic and psychrophilic digestion of liquid manure*.

APPENDIX

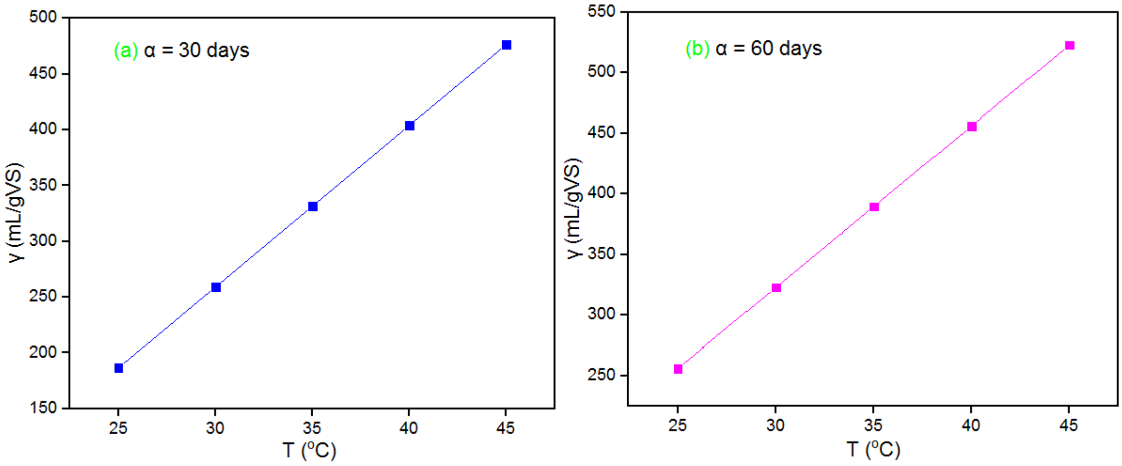
A. Alternative Illustration of the N, K and Temperature Relationships

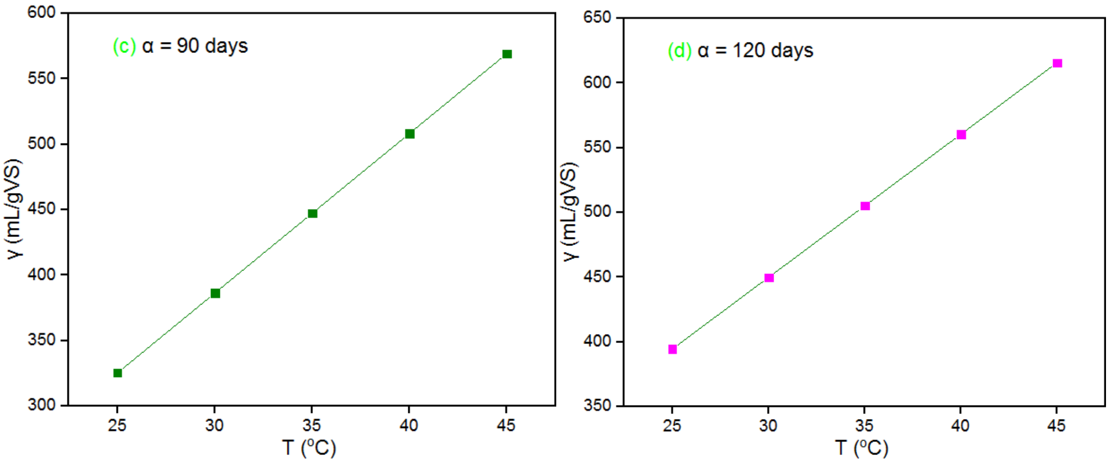


B. Depiction of Measured and Correlated γ with α

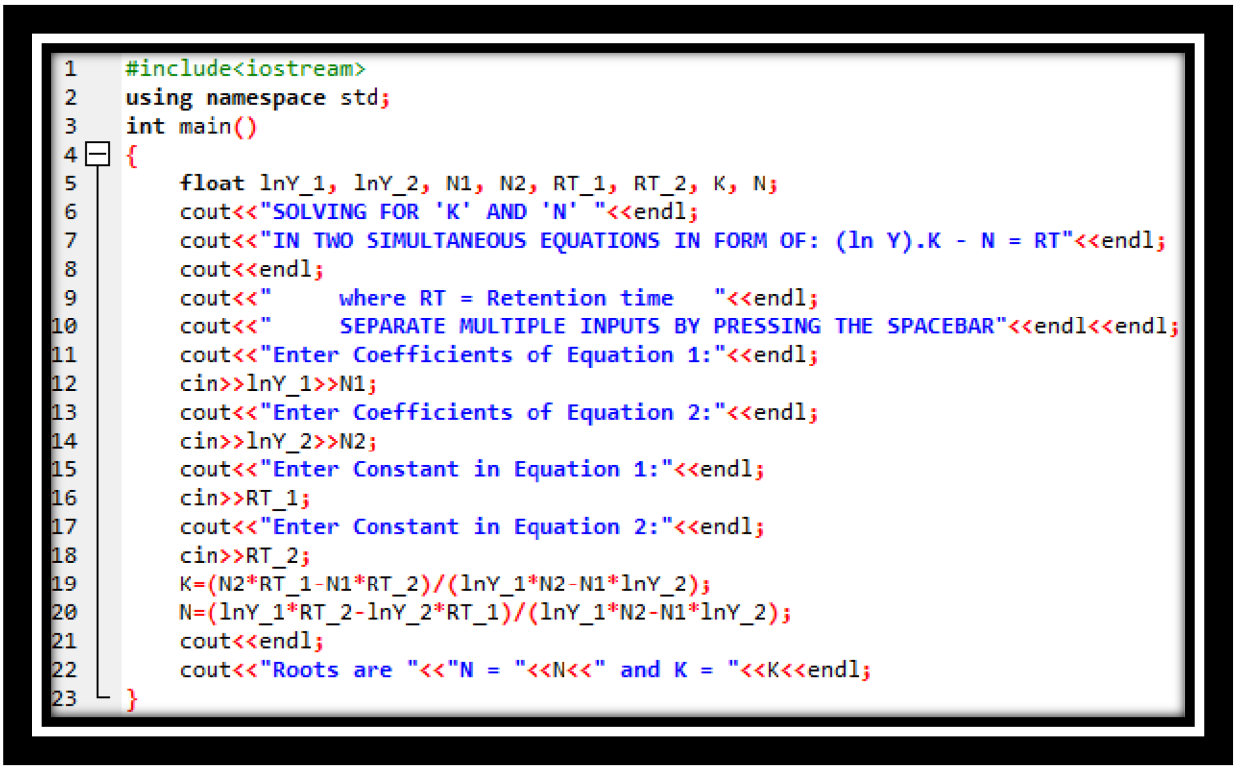


C. Gas Yield versus Temperature at Specific Retention Time





D. C++ Codes to Find ‘N’ and ‘K’ for Biogas Yield at two Retention Periods



```
#include<iostream>
using namespace std;
int main()
{
    float lnY_1, lnY_2, N1, N2, RT_1, RT_2, K, N;
    cout<<"SOLVING FOR 'K' AND 'N' "<<endl;
    cout<<"IN TWO SIMULTANEOUS EQUATIONS IN FORM OF: (ln Y).K - N = RT"<<endl;
    cout<<endl;
    cout<<"     where RT = Retention time    "<<endl;
    cout<<"     SEPARATE MULTIPLE INPUTS BY PRESSING THE SPACEBAR"<<endl<<endl;
    cout<<"Enter Coefficients of Equation 1:"<<endl;
    cin>>lnY_1>>N1;
    cout<<"Enter Coefficients of Equation 2:"<<endl;
    cin>>lnY_2>>N2;
    cout<<"Enter Constant in Equation 1:"<<endl;
    cin>>RT_1;
    cout<<"Enter Constant in Equation 2:"<<endl;
    cin>>RT_2;
    K=(N2*RT_1-N1*RT_2)/(lnY_1*N2-N1*lnY_2);
    N=(lnY_1*RT_2-lnY_2*RT_1)/(lnY_1*N2-N1*lnY_2);
    cout<<endl;
    cout<<"Roots are "<<"N = "<<N<<" and K = "<<K<<endl;
}
```

https://doi.org/10.55204/trc.v3i1.e132