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(RESEARCH ARTICLE)

Utilization of digestate from anaerobic co-digestion of water hyacinth and poultry waste as a sustainable source of organic fertilizer

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Abstract

Urbanization and population boom have resulted in increased crop production. However, the arable lands are not fertile enough to produce the required yield as a result of leaching and other anthropogenic activities, thus forcing farmers to resort to the use of inorganic (synthetic) fertilizers. These inorganic fertilizers though improve crop yield, have serious adverse effects on human health, the environment and soil fertility. Therefore, the need to look for traditional organic fertilizers cannot be emphasized enough. Water hyacinth (Eichornia Crassipes) is one of the world's most destructive, difficult to eradicate and noxious weed that has prolific growth rate of 17.5 metric tons of wet water hyacinth per hectare per day. However, it has high organic content which makes it a potential source for biogas and organic manure production. Also, poultry wastes which when disposed off on land pollutes groundwater and the environment, are also a very good source of organic manure and biogas. These poultry wastes contain high amounts of uric acid, which can damage burners or gasifiers, so mixing the waste with other biomass fuel is a necessity. This study was carried out by co-digesting water hyacinth and poultry droppings for biogas and organic fertilizer production was carried out in a digester. The digester was fed with 70% ground water hyacinth paste (3.5 kg) and 10% poultry droppings (0.5 kg). The digester was stirred gently to facilitate better aeration and porosity. Moisture content, pH, carbon content, nitrogen, phosphorus and potassium were analyzed for every 15 days. After 45 days the product had 30% moisture, 9.67% Carbon with pH 7.26 while the slurry nutrient value measured as nitrogen, phosphorus and potassium (NPK) values were 1.2%, 0.74% and 0.60% respectively. The NPK values are good forms of soil conditioners, but since different crops require varying concentrations of NPK, the specific requirements for each crop should be determined and the corresponding supplement values added. In this study the deficit of the NPK nutrients required for maize cultivation by a 25kg digestate was determined. The digestate was supplemented with 23kg poultry droppings for N, 23.77kg bone meal for P and 24kg wood ash.

Keywords: Digestate; Slurry; Water hyacinth; Poultry droppings; Organic fertilizer; NPK.

1. Introduction

The rapid growth of the global population has led to an increase in the demand for food production. However, conventional agricultural practices heavily rely on synthetic fertilizers, which have several negative environmental impacts (Ganiyu et al., 2019). In recent years, there has been growing interest in the utilization of organic waste materials as a sustainable source of nutrients for crop production that are healthier for consumption and safer for the environment and hence, the high demand for organic fertilizers over chemical fertilizers (Diaz et al., 2011). Unbalanced and prolonged use of chemical fertilizers lead to a decline in soil fertility (Prasertsak, et al., 2001). Anaerobic digestion of biomass offers a promising solution by converting these wastes into biogas and digestate. The digestate can be utilized as a nutrient-rich organic fertilizer. The digestate (slurry) is an organic fertilizer that supplies needed plant

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nutrients that contain major important quantities of nitrogen (N), phosphorus (P) and potassium (K) (Oviasogie et al., 2005). Organic fertilizers keep soil friable, promote beneficial soil life; increase crop yield, grow larger plants, benefit the environment by recycling and reducing waste, minimize greenhouse gas emission, protect certain crops from disease and are cheaper than chemical fertilizers as they can be locally prepared on farm at a low-cost using crop residues, animal dung and other plant material such as banana stems, leguminous leaves and green grasses (MapfumoandGiller, 2001). Anaerobic digestion (AD) is a process by which organic matter is broken down to simpler chemical components in the absence of oxygen and consists of four stages (hydrolysis, acidogenesis, acetogenesis and methanogenesis) in which each stage is carried out by a different group of anaerobic bacteria (Popoola, 2018; McCrum, 2011). Biogas systems in an agrarian community increases agricultural productivity as all the agricultural residue and dung within the community are available for anaerobic digestion, whereas previously, a portion would be combusted daily for fuel.

Water hyacinth (Eichhornia crassipes) is a fast-growing aquatic plant that can be used as a feedstock for anaerobic digestion. It contains moderate levels of nutrients, including nitrogen, phosphorus, and potassium. The nitrogen content in water hyacinth can range from 1% to 2.%, phosphorus from 0.2% to 0.5%, and potassium from 0.8% to 1.5% (Gao et al., 2021). However, these values can vary depending on the growth stage of the plant and environmental conditions. On the other hand, poultry droppings, such as those from chickens or turkeys, are rich in nutrients due to the diet of the birds. The nutrient content of poultry droppings can depend on factors such as bird species, diet, and management practices. Generally, poultry droppings are known to have high nitrogen content, typically ranging from 2% to 4%. The phosphorus content can range from 1% to 3%, and potassium content can range from 1% to 3% as well. However, these values can vary depending on specific conditions.

However, the co-digestion of biomass in varying proportions improves the biogas yield and digestate due to positive synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates (Alvarez and Liden, 2008). When water hyacinth and poultry droppings are co-digested, the nutrient content and ratios of the resulting digestate will depend on the proportions of the feedstocks used, the digestion process, and other factors. There are basically two outputs from a biogas system namely biogas and digestate (effluent/slurry).The digestate from an anaerobic digestion process can be used as organic fertilizer as it is very rich in N-P-K. (Adekunle and Okolie, 2015).

1.1. Anaerobic co-digestion process

Anaerobic co-digestion is a biological process carried out by a consortium of microorganisms that involves the decomposition of organic materials in the absence of oxygen resulting in the production of biogas and a nutrient-rich residue called digestate. When water hyacinth, a highly invasive aquatic weed, and poultry waste, such as manure and bedding materials, are blended together and subjected to anaerobic digestion. The process not only helps in the efficient decomposition of the waste materials but also enhances the biogas production (Scarlat et al., 2018). A simple schematic diagram of the anaerobic digestion process is presented in Figure 1.

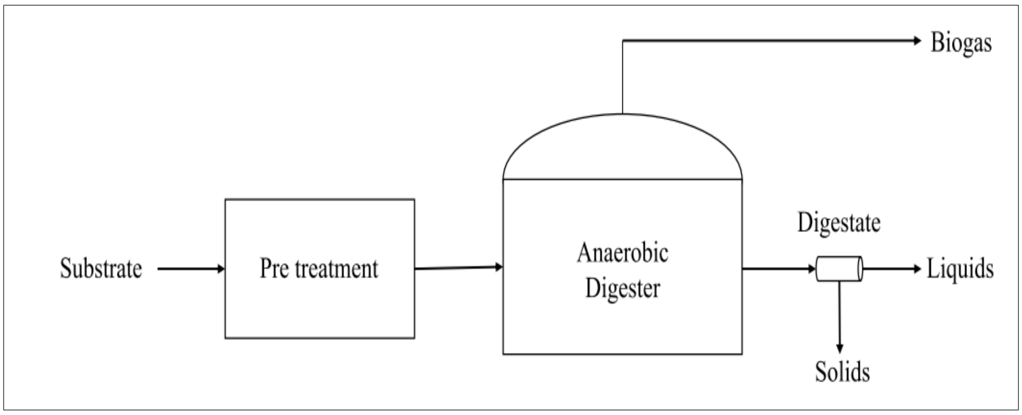

Figure 1 Schematic diagram of anaerobic digestion

1.1.1. Biogas production

The anaerobic co-digestion of water hyacinth and poultry waste results in the production of biogas, which is primarily composed of methane (CH_4) and carbon dioxide (CO_2). Biogas can be utilized as a renewable energy source for various applications, including electricity generation, cooking, and heating. The utilization of biogas as a replacement for fossil fuels contributes to a significant reduction in greenhouse gas emissions and helps combat climate change.Finally, after biodegradation of the dung in the digester, the remnant could still be use as manure (Möllerand Müller, 2012).

1.1.2. Digestate (fertilizer) production

Digestate is produced as a byproduct during the anaerobic digestion process by micro organisms. It consists of the undigested or partially digested matter, liquid, and solids. After extraction of biogas (energy), the slurry (also known as digestate/effluent) comes out of digester as by-product of the anaerobic digestion system. The slurry is found in different forms inside the digester either as:

- A light rather solid fraction, mainly fibrous material, which floats on the top forming the scum;
- A very liquid and watery fraction remaining in the middle layer of the digester;
- A viscous fraction below which is the real slurry or sludge; and heavy solids, mainly sand and soils that deposit at the bottom.

1.2. The mass balance for anaerobic digestion

The mass balance for anaerobic digestion is shown in Figure 2.

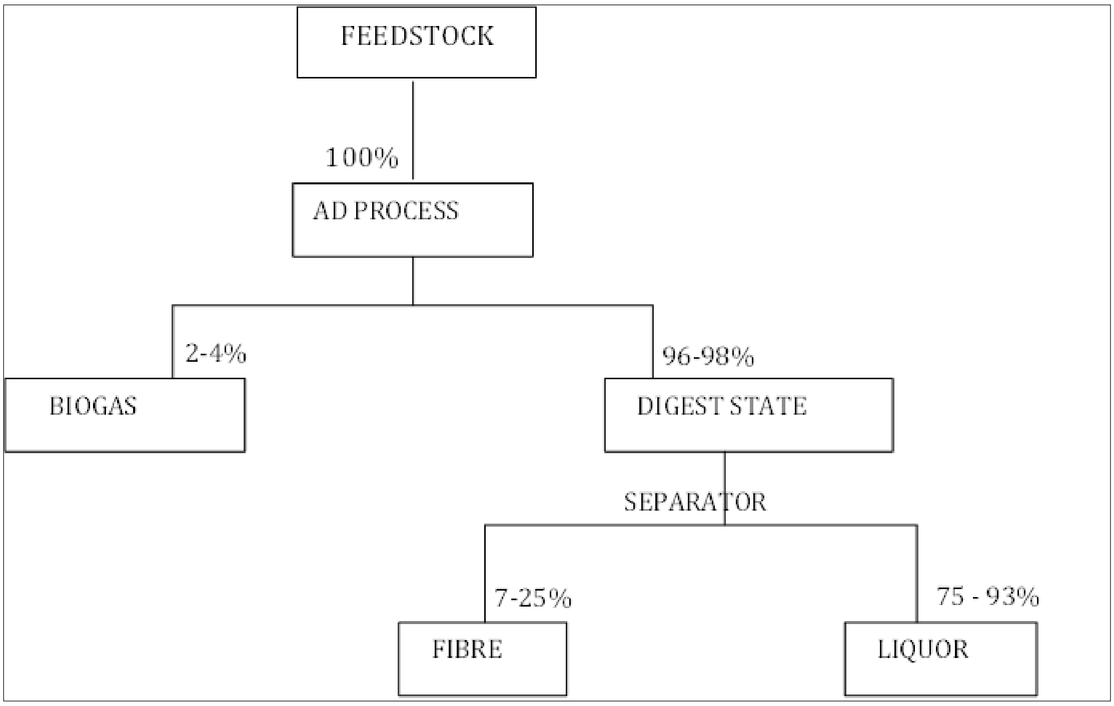

Figure 2 Mass balance for anaerobic digestion

The effluent from biogas unit is both a soil conditioner and organic manure. The digestate is a nutrient-rich fertilizer that contains essential plant nutrients, including nitrogen (N), phosphorus (P), and potassium (K), along with trace elements, organic matter, and beneficial microorganisms in varying proportions depending on the mix ratio of the feedstock (Gao et al., 2021), Table. 1.

Table 1 Components of various types of manure

Manure Type	Nitrogen (N) %	Phosphorus (P) %	Potassium (K) %
Farmyard Manure	0.5 – 1	0.5 – 1.0	0.5 – 0.8
Digested Slurry (Liquid)	1.5 – 2.0	1.0	1.0
Digested Slurry (dried)	1.3 – 1.7	0.85	0.85

The nutrient content of digestate varies depending on the feedstock composition and the digestion process. However, studies have shown that digestate from the co-digestion of water hyacinth and poultry waste has a balanced nutrient profile, making it a valuable fertilizer for various crops. The organic matter in digestate improves soil structure, water-holding capacity, and nutrient retention, thus reducing the need for chemical fertilizers (Ganiyu et al., 2019). Furthermore, digestate provides a slow-release source of nutrients, ensuring a steady supply of essential elements to plants throughout their growth cycle. Its application has been shown to enhance crop yield, improve crop quality, and increase soil microbial activity. Additionally, the use of digestate as a fertilizer promotes circular economy principles by recycling organic waste materials and reducing reliance on synthetic fertilizers.

Its application to agricultural fields improves soil fertility, enhances nutrient cycling, and promotes sustainable crop production. In order to ensure that the loss of nutrient is kept at a minimum, measures are taken to collect the leachate water and avoid the effluent from drying in the sun. As the biomass is mixed with water to ensure an efficient fermentation process, the effluent that comes out of the digester will hold quite a low dry solid content (about 8% TS) with the liquid part having much of the nitrogen (Pognani et al., 2012). Loss of nitrogen will be the result if the effluent is not taken care of properly. If it is dried in the sun, the heat will cause the nitrogen to diffuse with the air as ammonia and bacteria can cause denitrification in the presence of air. Almost all the nitrogen in the effluent can evaporate to the atmosphere through these processes (Logan and Visvanathan, 2019). The liquid part, containing much of the nitrogen, might also run off as leachates into the ground. A useful way of handling the effluent is to apply the effluent to a compost pit together with other biomass and wastes. The digestate is almost pathogen-free stabilized manure that can be used to maintain soil fertility and enhance crop production.

There is less separation in the slurry if the feed materials are homogenous. Appropriate ratio of urine, water and excrement and intensive mixing before feeding the digester leads to homogeneous slurry. The slurry that is returned after methanogenesis is superior in terms of its nutrient content. The process of methane production serves to narrow the Carbon:Nitrogen ratio (C:N), while a fraction of the organic nitrogen is mineralized to ammonium (NH_4^+) and nitrate (NO_3^-), the form which is immediately available to plants. According to Frischmann (2012), the resulting slurry has double the short-term fertilizer effect of dung, while long-term fertilizer effects are cut by half. However, in the tropics, the short-term effects are the most critical, as even the slow degrading manure fraction is quickly degraded due to rapid biological activity. An increase in land fertilizer then can result in an increase in agricultural production. The knock-on benefits may include improve subsistence, increased local food security, or income generation from a higher output. In the wastewater treatment industry, anaerobic digestion has long been used as a means of reducing the amount of organic matter, which must be treated. Since anaerobic digestion reduces the amount of organic waste and produces methane (a valuable fuel) and organic fertilizer, it is becoming more and more attractive as a waste treatment alternative. Anaerobic digestion also improves manure manageability. These benefits are at national, regional, local and individual levels.

The digestate contains much water and there is need to dewater it. Dewatering and drying of the digestate in agricultural operations can also eliminate the need for spraying completely, leading to a reduction in application costs and permitting better ”targeting” of land nutrient deficiencies. Dewatering has a significant positive economic impact in larger operations. Storage requirements are reduced and transportation cost is significantly lower. Dewatering is achieved by combined mechanical separation- vacuum cascade evaporation technology. The digestate contains solids in suspension as well as nutrients primarily in solution. Mechanical separation splits these into a solution with typically less than 1% solids and a paste, which contains approximately 60 – 70 % moisture, 80% of all nutrients will remain in solution. The easiest way of removing water from a solution is by evaporating it. Unfortunately, this requires large amount of energy. Using multiple stages – in cascade can evaporate four times the amount of water with the same amount of energy (Massaccesi, 2013). In other term, a four-stage continuous flow vacuum cascade requires ¼ of the amount of energy to evaporate one ton of water that would be require under ambient conditions. The water should have the following characteristics: pH: 6 – 7, Conductivity: 3000 to 800, COD: 100 to 300 mg/l and Total N: 30 to 100 mg/l. Land application of digestate does not require complex technology. That is, high pressure “honey wagons” used in application of raw manure leading to significant cost savings. Waste treatment costs are reduced, since biogas plants generate revenues.

2. Materials and Methods

To produce digestate from the co-digestion of water hyacinth and poultry waste, the following materials and methods were employed.

2.1. Materials

Fresh water hyacinth biomass, poultry waste (poultry manure and bedding materials) and a suitable anaerobic digester system capable of handling the feedstock quantity.

2.2. Methods

2.2.1. Samples collection and feedstock preparation

Water hyacinth was collected from River Forcados, Patani and poultry wastes from a poultry farm in Patani. The water hyacinth was chopped into small particles to increase the surface area and facilitate digestion. The water hyacinth and poultry droppings were mixed in a ratio suitable for efficient co-digestion and dried to remove moisture. A mix ratio to produce optimal NPK ratio was attained by considering the carbon-to-nitrogen (C/N) Ratio. Achieving an appropriate C/N ratio is crucial for efficient digestion and nutrient release. Water hyacinth is typically rich in carbon, while poultry waste contains a higher nitrogen content. Balancing the C/N ratio is important to avoid issues such as excess ammonia production or inadequate microbial activity. A C/N ratio in the range of 20:1 to 30:1 was considered suitable for anaerobic digestion, the mix ratio was adjusted in the course of the experiment, and this was done to attain the nutrient requirement, particularly for essential elements such as nitrogen, phosphorus, and potassium (NPK). The performance of the anaerobic digestion system, including biogas production, stability, and retention time was also monitored. The mix proportion was adjusted based on the system's efficiency and performance indicators and the sample was then prepared for analysis.

2.2.2. Anaerobic digestion

The prepared feedstock mixture was transferred into the anaerobic digester, proper operating conditions maintained, including temperature, pH, and moisture content, to facilitate microbial activity and maximize biogas production. Sufficient retention time was provided for the digestion process to occur, typically ranging from several days to a few weeks, depending on the system design and feedstock characteristics. The biogas production throughout the digestion process was monitored to assess the efficiency of co-digestion. After the digestion process was completed, the digestate was collected and the moisture content of the digestate was adjusted to a suitable level for further handling and application.

2.2.3. Evaluation of nutrient (NPK)content

Total nitrogen (N) content

A chemical analysis was performed to quantify the total nitrogen content as a percentage or concentration in the digestate. This was determined using standard laboratory method (the kjeldahl method). The nitrogen determination process involved three stages which were digestion, distillation and titration. The percentage nitrogen was calculated (Khairuddin et al., 2015) using Equation 1.

$$Nitogen\ (\%) = \frac{(V_2 - V_1) \times 0.014 \times C_a \times 100}{Vol.of\ samplwused \times V_d} \qquad (1)$$

Where:

V_2 = Titre value (volume of acid used for titration of the digest)
V_1 = Volume of acid used for the titration of the blank
V_d= Volume of digestate distilled
C_a = Concentration of acid used

2.3. Phosphorus (P) and potassium (K) content

A chemical analysis to measure the phosphorus and potassium content in the digestate was conducted using colorimetry analytical method to determine the percentage of phosphorus and potassium in the digestate.

2.3.1. Nutrient Ratios and Balance

Crops require a balanced nutrient ratio and supply of macro and micro nutrients for optimal growth and the NPK ratio is particularly important. While nitrogen is crucial for crop growth, an excessive nitrogen supply relative to phosphorus and potassium can lead to imbalances and potential yield reductions. Therefore, appropriate NPK ratios based on local recommendations and soil test results was aimed at. From the percentage of NPK that was obtained, the NPK from the slurry nutrient was balanced using the requirement of a crop, maize in this case. The percentage composition of nitrogen, phosphorus and potassium in the digestate are 1.2,% 0.74% and 0.60% respectively as shown in Table 2. From literatures, maize requires NPK 15:15:15 and the obtained NPK composition was balanced thus:

Nitrogen

The nitrogen content in the slurry or digestate was enhanced by adding animal manure (poultry manure or cattle manure). Nitrogen fertilizers (urea, ammonium nitrate, or ammonium sulphate), cover crops or green manure (growing cover crops or green manure plants (legumes e.g., ground nut, clover, vetch, soybeans) and compost or organic amendments high in nitrogen (blood meal or fish meal). For this study poultry dropping was used.

Phosphorus

Animal Bone Meal was used in supplementing the phosphorus level of the digestate. Bone meal is a slow-release organic phosphorus source derived from animal bones. It contains a significant amount of phosphorus, along with some calcium. It can be mixed with the digestate or applied It is commonly used in organic farming and gardening and can be blended with the digestate or applied separately/directly to the soil.

Potassium Sources

Wood ash is a natural source of potassium, obtained by burning wood or plant materials. It contains potassium in the form of potassium carbonate or potassium oxide and it can be used to supplement the digestate and adjust the nutrient balance. Wood ash can be applied to the soil directly or mixed with the digestate. Potassium nitrate is a soluble fertilizer that provides both potassium and nitrogen to plants..

With a slurry nutrient concentration of 1.2:0.74:0.60 (N:P:K), to adjust it to the target ratio of 15:15:15 for maize, the quantity of the additional materials needed was evaluated by calculating the deficit in nutrient concentration using Equation 2.

Deficit = target concentration - nutrient concentration (2)

Nitrogen (N): The target concentration is 15%. The deficit is 15% - 1.20% = 13.80%.

Phosphorus (P): The target concentration is 15%. The deficit is 15% - 0.74% = 14.26%.

Potassium (K): The target concentration is 15%. The deficit is 15% - 0. 60% = 14.40%.

To maintain the same nutrient ratio of 15:15:15, the proportion of each nutrient (NPK) deficit was added to the digestate. In this case, poultry droppings was used to make up for the nitrogen deficit, bone meal was used to supplement phosphorus and wood ash for potassium, with each contributing 13.80%, 14.26%, and 14.40% to the total nutrient content, respectively.

Using 25kg of the original slurry and poultry droppings, bone meal and wood ash to supplement NPK respectively the quantity of additional materials needed was obtained by dividing the deficit for each nutrient by the nutrient content of the respective material and multiply by the total slurry weight and assuming the nutrient content remains constant throughout the process as in Equation 3.

$$\text{Quantity of needed supplement} = \frac{Deficit}{Target\ concentration} \times total\ slurry\ weight \quad (3)$$

$$\text{Poultry droppings} = \frac{13.80}{15} \times 25 = 23kg$$

$$\text{Bone meal} = \frac{14.26}{15} \times 25 = 23.77kg$$

$$\text{Wood ash} = \frac{14.40}{15} \times 25 = 24kg$$

3. Results and Discussions

Table 2 Nutrient percentage in the slurry after biogas production and supplements

Element	% Composition	Supplement	Quantity (kg)
Nitrogen	1.20	Poultry droppings	23.00
Phosphorus	0.74	Bone meal	23.77
Potassium	0.60	Wood ash	24.00

The co-digestion of water hyacinth and poultry droppings in an anaerobic environment (digester) produced a nutrient rich digestate of 1.2%:0.74%:0.60%of N:P:K respectively, indicating the relative concentrations of nitrogen (N), phosphorus (P), and potassium (K) in the digestate. To take care of the deficit in the digestate nutrient for maize that requires NPK 15:15:15, the NPK nutrients were supplemented with 23kg poultry droppings for N, 23.77kg bone meal for P and 24kg wood ash for K using a 25kg digestate. These are essential nutrients for crop production. The digestate has a nitrogen content of 1.2. Nitrogen is an essential nutrient for plant growth and is responsible for promoting vegetative growth, leaf development, and protein synthesis in plants. The digestate has a phosphorus content of 0.74. Phosphorus is vital for root development, flowering, fruiting, and overall plant energy transfer and storage. The digestate has a potassium content of 0.6. Potassium plays a crucial role in various plant processes, including water regulation, nutrient uptake, enzyme activation, and overall plant health and disease resistance. When using the digestate as a fertilizer, it can help provide essential nutrients to plants, improve soil fertility, and enhance plant growth and yield. However, it's important to note that the nutrient availability and release rates in the digestate may vary depending on factors such as the composition of the feedstock, the digestion process, and the subsequent storage and application methods.

4. Conclusion

The quality of anaerobic digestate depends on characteristics of feedstock or substrate, operational conditions and configuration of anaerobic digestion system and digestate processing techniques. The anaerobic co-digestion of water hyacinth and poultry waste offers a sustainable waste management solution while generating valuable products: biogas and digestate. The digestate obtained from this process serves as an environmentally friendly fertilizer, providing essential nutrients and organic matter to agricultural soils. Its application improves soil fertility, promotes sustainable crop production, and contributes to the reduction of greenhouse gas emissions. The obtained nutrient content of the digestate can be beneficial for plant nutrition and soil fertility but should be compared with the crop's desired NPK ratio, and any imbalances or deviations from the desired nutrient ratio should be identified and adjusted as needed to achieve a balanced nutrient supply. To optimize the use of the digestate, it's recommended to conduct soil testing and consider crop nutrient requirements to determine appropriate application rates and timing. Additionally, local regulations and guidelines for organic fertilizers should be followed to ensure proper and safe use of the digestate. Further research and development in this field are crucial to optimize the co-digestion process and maximize the utilization of digestate as a valuable resource in sustainable agriculture.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Adekunle, K.F. and Okolie, J.A. (2015). A review of biochemical process of anaerobic digestion. Adv. Biosci. Biotechnol., 6: 205-212.

[2] Alvarez, R. and Liden, G. (2008). The effect of temperature variation on biomethanation at high altitude. Biores. Technol., 99: 7278-7284.

[3] Diaz, J.P., Reyes, I.P. Lundin, M. and Horvath, I.S. (2011). Co-digestion of different waste mixtures from agro-industrial activities: Kinetic evaluation and synergetic effects. Bioresour. Technol., 102: 10834-10840

[4] Frischmann P (2012) Enhancement and treatment of digestates from anaerobic digestion. Available at: http://www.wrap.org.uk/sites/files/wrap/Digestates%20from%20Anaerobic%20Digestion%20A%20review %20of%20enhancement%20techniques%20and%20novel%20digestate%20 products_0.pdf (accessed 11 July 2018).

[5] Ganiyu, S.A., et al. (2019). Nutrient recovery from anaerobic co-digestion of water hyacinth and poultry waste for sustainable agriculture. Journal of environmental management, 230, 119-126.

[6] Gao, J., et al. (2021). Effects of digestate from anaerobic co-digestion of water hyacinth and swine manure on soil fertility and plant growth. Science of the total environment, 764, 142860.

[7] Gustavsson, M (2000). Biogas Technology- Solution In search of Its problem: A study of

[8] Interdisciplinary Studies. Goteborg University, Sweden.

[9] Khairuddin, N., Manaf, L.A., Halimoon, N., Ghani, W.A.W.A.K. andHassan, M.A. (2015). High solid anaerobic co-digestion of household organic waste with cow manure. Procedia Environ. Sci., 30: 174-179

[10] Khanal, S.K. (2015). Anaerobic biotechnology for bioenergy production: principles and applications. John Wiley & Sons.

[11] Logan, M. and Visvanathan,C. (2019). Management strategies for anaerobic digestate of organic fraction of municipal solid waste: Current status and future prospects. Waste Management & Research 37(1), 27–39.

[12] Mapfumo, P. and Giller, K.E. (2001). Soil fertility management strategies and practices by smallholder farmers in semi-arid areas of Zimbabwe. ICRISAT/FAO., Patancheru, AP, India, pp: 53

[13] Massaccesi, L, Sordi, A, Micale,C, et al. (2013) Chemical characterisation of percolate and digestate during the hybrid solid anaerobic digestion batch process. Process Biochemistry 48: 1361–1367.

[14] McCrum, I.T., (2011). The DARIES model: Modeling co-digestion and multi-phase digester systems. Thesis Proposal, Department of Civil and Environmental Engineering, Clarkson University, New York.

[15] Möller, K. and Müller, T. (2012). Effects of anaerobic digestion on digestate nutrient availability and crop growth. Engineering in Life Sciences 12: 242–257.

[16] Oviasogie, P.O., Odewale, J.O. Aisueni, N.O. Eguagie, E.I. Brown G. and Okoh-Oboh, E. (2013). Production, utilization and acceptability of organic fertilizers using palms and shea tree as sources of biomass. Afr. J. Agric. Res., 8: 3483-3494.

[17] Pognani, M., Barrena, R., Font, X, et al. (2012) A complete mass balance of a complex combined anaerobic/aerobic municipal source-separated waste treatment plant. Waste Management 32: 799–805.

[18] Popoola, L.K., Aderibigbe, T.A. and Korave, K.T. (2018). Operation Parameters Impact on Fertilizer NPK Produced by Anaerobic Co-digestion of Plantain Extract and Cow Dung. International Journal of Agricultural Research, 13(2), 58-64.

[19] Prasertsak, P., Freney, J.R. Saffiga, P.G. Denmead, O.T. and Prove, B.G. (2001). Fate of urea nitrogen applied to a banana crop in the wet tropics of Queensland. Nutr. Cycl. Agroecosyst., 59: 65-73

[20] Rosen, C.J. and Horgan, B.P. (2005). Preventing pollution problems from lawn and garden fertilizers. Minnesota Extension Service Factsheets, USA.

[21] Scarlat, N., Fahl, F., Dallemand, J.F., Monforti, F., Motola, V. (2018). A spatial analysis of biogas potential from manure in Europe. *Renew. Sustain. Energy Rev. 94,* 915–930