Waste Management 34 (2014) 747–752

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Fertilizer and sanitary quality of digestate biofertilizer from the co-digestion of food waste and human excreta

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ARTICLE INFO

Article history:
Received 13 September 2013
Accepted 27 January 2014
Available online 18 February 2014

Keywords:
Anaerobic digestion
Digestate
Biofertilizer
Pathogens
Public health

ABSTRACT

This research was aimed at assessing the fertilizer quality and public health implications of using digestate biofertilizer from the anaerobic digestion of food wastes and human excreta. Twelve (12) kg of food wastes and 3 kg of human excreta were mixed with water in a 1:1 w/v to make 30-l slurry that was fed into the anaerobic digester to ferment for 60 days at mesophilic temperature (22–31 °C). Though BOD, COD, organic carbon and ash content in the feedstock were reduced after anaerobic digestion by 50.0%, 10.6%, 74.3% and 1.5% respectively, nitrogen, pH and total solids however increased by 12.1%, 42.5% and 12.4% respectively. The C/N ratios of the feedstock and compost are 135:1 and 15.8:1. The residual total coliforms of 2.10×10^8 CFU/100 ml in the digestate was above tolerable limits for direct application on farmlands. Microbial analysis of the digestate biofertilizer revealed the presence of *Pseudomonas, Klebsiella, Clostridium, Bacillus, Bacteroides, Penicillum, Salmollena*, and *Aspergillus. Klebsiella, Bacillus, Pseudomonas, Penicillum* and *Aspergillus* can boost the efficiency of the biofertilizer through nitrogen fixation and nutrient solubility in soils but *Klebsiella* again and *Salmollena* are potential health risks to end users. Further treatment of the digestate for more efficient destruction of pathogens is advised.

1. Introduction

Research into the development of alternative energy sources has been increasing as a result of the non-renewable nature of fossil energy sources and recent environmental challenges (Alburquerque et al., 2012). Production of biogas through anaerobic digestion of organic waste materials is on the frontline of this alternative energy research. The major products of anaerobic digestion are biogas and digestate. Digestate comprises microbial biomass, semi-degraded organic matter and inorganic compounds, and therefore can be used as soil conditioners on farmlands (Alburquerque et al., 2012). It contains more readily available nutrients than the undigested products which make it better for crops fertilization (Goberna et al., 2011; Garfi et al., 2011; Lansing et al., 2010).

Large scale use of chemical fertilizers has resulted in soil quality and environmental degradation, eutrophication, and heavy metals pollution (Owamah, 2013; Zhu et al., 2012). The importance of biofertilizer therefore is to provide socioeconomic and ecological benefits among which are improvements of soil quality, food quality and safety, human and animal health as well as environmental quality (Johansen et al., 2013; Mohamed et al., 2009). There are different types of digestate biofertilizers and their differences are mainly in the raw materials used, forms of utilization, the source of microorganisms, and digester configurations, etc. (Garfi et al., 2011; Higa and Parr, 1994). The use of digestate biofertilizers is one of the important components of integrated nutrient management, as they are cost effective and are renewable sources of plant nutrients for sustainable agriculture (Grigatti et al., 2011; Tamil Nadu Agricultural University, 2008).

Anaerobic digestate usually contains microorganisms like *Pseudomonas*, *Klebsiella*, *Samonella*, *Penicillum*, *Shigella*, *Bacteriodes*, *Aspergillus* and *Bacillus*. These microorganisms can be exploited in the production of biofertilizers (Tamil Nadu Agricultural University, 2008). *Klebsiella* and *Clostridium spp.* are free living nitrogen fixing biofertilizers while *Bacillus* and *Pseudomonas spp.* are phosphate solubilizing biofertilizers (Alfa et al., 2014). These organisms quicken the microbial processes in the soil and increase the availability of nutrients that can be assimilated by plants (Tamil Nadu Agricultural University, 2008). Biofertilizers hold

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http://dx.doi.org/10.1016/j.wasman.2014.01.017
0956-053X/

great promises for improving world food security through the enhancement of agricultural yield in developing continents such as Africa and Asia, which together hold approximately 50% and 74% of the total land mass and population of the globe, respectively (Population Reference Bureau, 2012).

Unlike chemical fertilizers, digestate biofertilizers can be cheaply produced through anaerobic digestion anywhere, utilizing a wide range of raw materials including agro, commercial and domestic wastes. Population growth and rising living standard have led to a great increase in food waste generation (Curry and Pillay, 2012). Sewage sludge has also been predicted to increase continuously in the next decade as a result of increasing population connected to sewage networks (Dai et al., 2013). Direct landfiling of food wastes has created various problems such as putrid smell and leachate pollution of ground and surface waters (Ming et al., 2008), and incineration has also been restricted due to its generation of greenhouse gases (Donald, 1988). Anaerobic digestion as a sustainable waste treatment technology transforms organic matter into biogas and reduces the amount of pathogens in digestates (Martínez et al., 2012).

The demand for digestate biofertilizer is dependent on compliance with quality standards (Alburquerque et al., 2012). Though the use of digestate biofertilizer to increase agricultural food production, and soil improvement has been established, its safety as determined by the amount of pathogens contained is still of public health concern to end users (Alfa et al., 2014). Reports on the fertilizer and sanitary quality of digestate from anaerobic digestion are scanty in scientific literature, despite the large volume of literature on biogas yield from various substrates. However, the fertilizer potential of digestate from farm and agro-industrial residues was investigated by Alburquerque et al. (2012). Johansen et al. (2013) have also reported that digestate biofertilizer increases soil microbial community. Alfa et al. (2014) have assessed the biofertilizer quality of digestate from the digestion of cow dung and chicken droppings. The properties of guinea pig manure digestate were reported by Garfi et al. (2011).

Despite the numerous benefits of digestate biofertilizer to agricultural production, the relative abundance and ease of generation of chosen substrates within the particular region of proposed usage should also be given due consideration, inorder to meet with demands. Food wastes and excreta are among the most common wastes generated in Nigeria and are carelessly disposed into the environment to constitute public health risk. The objective of this research therefore is to assess the biofertilizer and sanitary quality of the digestate resulting from the mesophilic anaerobic co-digestion of food waste and human excreta.

2. Materials and methods

2.1. Digester design

A 40-l-biogas reactor of height 0.5 m and diameter 0.25 m was fabricated from galvanized steel. Galvanized steel was used as building material because of its strength and durability in acid or basic environment. Five different holes were bored on the lid of the digester for insertion of temperature and pH probes using threaded steel adapters and rubber stoppers to avoid gas leakage. The cylindrical shape was adopted to enhance better mixing. The tank was air tight and was clearly placed above the ground level where it was exposed to sunlight for partial heating. A 12.1 L gas holder tanks each of height 0.25 m and diameter 0.25 m were fabricated from thin sheet metal and was used to temporarily store the biogas until it was used to produce heat or used to replace or supplement the supply of cooking gas. Plastic hose was used to connect the digester to the gas collection system and the biogas stove burner while plastic valves were installed to control the gas flow. The gas holder stores the biogas and allows the volume of biogas produced to be measured through the indirect measurement of a liquid column height. The digester and gas holder were designed, built and operated by the methods described in (Fountoulakis et al., 2008; Karki, 2002) with slight modifications. The composition of biogas (CH_4 and CO_2 contents) was determined using a gas chromatography (GC) (Hp 5890, Avondale, USA). Biogas composition measurement was taken two times a week in duplicate from each digester. A 100 µl gas tight syringe was used to take biogas samples from the digesters head space after releasing the gas. This was followed by injecting the biogas sample into the GC (Owen et al., 1979; Zhang et al., 2006). The schematic of the setup is as shown in Fig. 1.

2.2. Feedstock and materials

Carbohydrate food wastes (boiled rice, boiled cassava products, bread, boiled yam and boiled maize), human excreta, a forty litre size anaerobic digester, pH meter (HI 9024-C, Hanna Instruments, Smithfield, RI, USA), thermometer (HI 98517, Hanna Instr.), anaerobic jar (Oxoid), gas generating kit (Bio-oxoid), different media (Nutrient agar, Potato dextrose agar, MacConkey agar, Eosin methylene blue agar, and Fastidious anaerobic agar) were the materials used in this study.

2.3. Sampling, physico-chemical analysis and experiment

Carbohydrate food wastes were collected from a university cafeteria in two batches (10 am in the morning and 7 pm in the evening) and sorted out for ease of pre-treatment. The periods of collection were selected to approximately match the periods of either peak consumption or defecation. The food wastes were thoroughly homogenized using a blender (BLG-401-18N) to achieve minimal particulate size suitable for easy digestion. After this, they were seeded with the human excreta which have also undergone thorough mixing. The mixture was a combination of 12 kg of food wastes and 3 kg of human excreta serving as an easy source of microbes. This was further mixed with water in a 1:1 w/v to make approximately 30-l slurry. The feedstock was fed into the digester (the digester was not in operation before the fermentation experiment) and the fermentation process lasted for 60 days. Parameters monitored and or determined during the fermentation are: (a) daily recording of volume of gas produced, (b) the temperature of the digester content was taken twice daily, (c) the pH of the digester content was taken weekly, (d) weekly collection of samples for the isolation and assessment of the microbial population causing the bio-conversion at different stages, (e) analysis of the gas to separate it to its different components and (f) physico-chemical analysis of the digestate at the end of the experiment.

After the 60 days retention period, the slurry was removed from the digester, dewatered by filtration, using geo-textile tubes and cured for 20 days to form compost. This was then applied to a demonstration farmland for the cultivation of maize and vegetables. However, the experiment on the effect of the cured digestate on the growth and yield of the maize and vegetables is still on going. The physico-chemical characteristics of the feedstock and the digestate were evaluated before and after fermentation respectively using standard procedures (Owamah et al., 2013; APHA, 2012). The physiochemical parameters analyzed include pH, temperature, organic carbon, moisture content, total solids, total nitrogen, ash content, biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Three replicates were used and the mean values of the parameters recorded. Mesophilic fermentation was preferred to thermophilic as it has been reported