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Reduction in greenhouse gas emissions from vinasse through anaerobic digestion

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HIGHLIGHTS

- This study assessed the effect of AD treatment of vinasse on CH_4 and N_2O emissions.
- CH_4 emissions were not detected from digested vinasse during storage.
- Anaerobic digestion increased NH_3 emissions from vinasse during storage.
- CH_4 emissions of untreated vinasse were equivalent to 43.8 kg CO_2 eq kg^{-1} C-vinasse.
- AD of vinasse before soil application decreased N_2O emissions by up to 78%.

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ABSTRACT

Vinasse is a residue from bioethanol production that is produced in large quantities in Brazil and Europe and is applied to fields as a source of plant nutrients (fertirrigation). A side effect of this use is greenhouse gas (GHG) emissions during storage and transport in open channels to fields, and from fertirrigated soils. This study assessed GHG emissions in experiments simulating this vinasse management system, and the potential for reducing emissions of methane (CH_4) and nitrous oxide (N_2O) from vinasse *via* anaerobic digestion (AD) in biogas plants. During 21 days' storage of untreated vinasse, 29% of dry matter (DM) and 40% of volatile solids (VS) were lost, which resulted in cumulative CH_4 emissions of up to 43.8 kg CO_{2eq} kg^{-1} C-vinasse. In contrast, there were no CH_4 emissions from AD-treated vinasse (digestate) during storage. GHG emission was related to the biochemical characteristics of the untreated and digested vinasse. The accumulation of oxidised nitrogen (N) compounds was up to four-fold higher in soil amended with untreated vinasse than from digestate-amended soil. The N_2O emissions from soil amended with untreated vinasse were also higher than from soil amended with digestate, ranging from 0.173 to 0.193 kg CO_{2eq} m^{-2} in the former and from 0.045 to 0.100 kg CO_{2eq} m^{-2} in the latter. Extrapolation of the results to a Brazilian case indicated that AD treatment prior to storage/transport and field application could reduce GHG emissions from the vinasse management chain by at least 48%, with further reductions from the use of biogas in power production.

1. Introduction

Anaerobic digestion (AD) for biogas production is one of the most efficient technologies for providing clean and renewable energy from organic waste and also has the potential to reduce greenhouse gas (GHG) emissions from digestate [1,2]. The technology can therefore contribute towards meeting the mandatory national target for renewable energy set by the European Commission [3] of covering 20% of energy consumption by 2020 while also reducing GHG emissions [4]. AD technology can also increase the renewable contribution to the energy matrix of developing countries such as Brazil that have little experience in this particular field, but considerable potential. The Brazilian Decennial Expansion Energy Plan 2024 includes 4.5% annual growth in renewable energy production up to 2024, but the focus is on solar and wind

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energy and biodiesel [5]. Biogas targets are being considered in the Brazilian National Energy Plan 2050 (under development), which includes the development of a biogas services chain in 2030 and the use of 13% of the theoretical biogas production potential from agricultural wastes for electricity generation in 2050 [6].

Vinasse is the main organic waste from bioethanol production and offers great potential for biogas production, although this alternative use is currently underexplored. In Brazil, as well as in Japan, Europe and the United States (US), vinasse has traditionally been managed [6] as an additive for animal feed [7,8], applied to fields as a nitrogen-phosphorous-potassium (NPK) fertiliser for crop production or been used to ameliorate soil organic matter [9]. Concerns about the potential environmental impacts on surface water and groundwater have resulted in a ban on the use of vinasse as a fertiliser in the US [10] and Uruguay [11]. In contrast, the application of vinasse is still recommended and legal in Brazil, the European Union and Canada. Between 1.0 and 1.7 million m^3 of vinasse are recycled annually to sugarcane fields by fertirrigation in Brazil – the largest sugarcane ethanol producer in the world [12]. Application rates are limited by the amount of K added per hectare set by a law aiming to protect soil, surface water and groundwater [13].

In addition to the risk of nutrient leaching from field-applied vinasse [14–16], its storage, transport and field application may be a source of methane (CH_4) and nitrous oxide (N_2O), which have respective Global Warming Potentials (GWP) of 34 and 298 times that of carbon dioxide (CO_2) [17]. The vinasse is stored in lagoons before transport or is transported directly in open channels from the bioethanol producer to fields for application to sugarcane crops. Methane is produced in vinasse during storage and transport, and may account for 98% of the total GHG emissions from vinasse management in this step, which has been assessed to be 1.43 kg CO_{2eq} m^{-3} [16]. After application of vinasse to fields with unburnt sugarcane, the accumulated N_2O emission corresponded to 142.3 kg CO_{2eq} ha^{-1} [18], and 361.5 kg CO_{2eq} ha^{-1} when applied to fields with sugarcane ratoon [19]. In the latter case, emissions were more than twice as high when N fertiliser was applied together with vinasse.

GHG emissions from the vinasse management chain may be reduced by AD treatment of vinasse to produce biogas. During AD, organic carbon is transformed into CH_4 and CO_2, and the potential for CH_4 emissions during subsequent storage is therefore reduced [20]. Similarly, N_2O emissions from vinasse after field application may be reduced, although this depends on soil conditions [21]. Potassium, N and P are not lost during AD, and this treatment technology therefore preserves the nutrient value of vinasse. The use of biogas for heat and power production may thus substitute fossil fuels and reduce GHG emissions. This conception is in accordance with the recent trends worldwide aiming to identify and exploit bioenergy technologies as mitigation measures [22].

When introducing a treatment technology for renewable energy production in a biomass management chain, it is important to assess how the technology affects all stages of the biowaste management chain [2,23,24], and a whole-farm approach is recommended for evaluating the overall effect of one or more GHG mitigation measures [23]. To the authors' knowledge, there are no published studies on the effect of AD treatment of vinasse on GHG emissions from the vinasse management chain. Therefore, this study aimed to quantify how AD treatment of vinasse affects CH_4 and N_2O emissions during storage or transport and after application to soil through bench-scale experiments. This study thus constitutes one of the first sources of experimental data on the theme and should contribute to stimulate the adoption of mitigation measures in a traditional and long-established management chain within the bioethanol sector in Brazil.

2. Material and methods

2.1. Sources of organic wastes and soil

The experiments were performed in the laboratory of the University of Southern Denmark. Vinasse from sugar beet ethanol production was provided by Nordic Sugar (Copenhagen, Denmark) and diluted 10 times prior to use to better represent the composition of sugarcane vinasse as used in Brazil. A digestate was produced in a stable codigestion process with the aforementioned vinasse, cow manure and straw (in proportions of 61:2:37% respectively in terms of total VS) and at a C/N ratio of 10:1 [25]. AD was performed in a mesophilic (37 °C) continuous stirred tank reactor (CSTR) at a hydraulic retention time (HRT) of 35 days [25]. The composition of the vinasse and the digestate used in the experiments are presented in Table 1. GHG emissions of this digestate were compared with emissions from untreated diluted vinasse during storage and after application to soil.

The soil was collected in November 2013 from 0 to 20 cm depth in a stubble field at the Foulum Research Centre in Denmark (55°52′ N, 9°34′ E). The soil is characterised as a sandy loam soil (Typic Hapludult) with 2.7% C, 0.18% N, pH (H_2O) 6.3, and a cation exchange capacity (CEC) of 8.7 cmol kg^{-1}. At the time of sampling the gravimetric soil moisture content was 15.2%, or around 80% of field capacity (FC). After sampling, the soil was passed through a 4-mm mesh sieve to remove roots and stones and stored at 4 °C. The soil was then stored at 22 °C for 24 h before the start of the experiment.

2.2. Gas emission from vinasse and digestate during storage

Storage conditions and emission measurements followed the methodology of Petersen et al. [26]. Aliquots of 15 L untreated and digested vinasse were stored in 25-L polyethylene containers in triplicate. For the experiments with untreated vinasse, 10% v/v of digestate was added in order to simulate the inoculation with a microbiota that is retained in vinasse stores or transport channels of sugarcane mills in Brazil [27]. The containers were immediately closed with a lid, to which a tube 1 cm in diameter and 15 cm long was connected to allow for the exchange of gases between the vinasse and the atmosphere.

Rates of CH_4, CO_2 and NH_3 emissions from stored untreated vinasse and digestate were measured during a period of 21 days at 37 °C, which is in accordance with the temperature of digestate

Table 1
Characterisation of sugar beet vinasse (diluted 10 times) and digestate used in the experiments.

Parameter	Unit	Sugar beet vinasse	Digestate from codigestion
Dry matter	g kg^{-1}	114.0	46.4
Volatile solids	g kg^{-1}	83.5	24.8
Total ammonia nitrogen	g L^{-1}	0.84	2.76
Total Kjeldahl nitrogen	g L^{-1}	4.90	3.56
Protein	% in VS	30.4	20.2
pH	n.a.	4.96	7.97
Chemical oxygen demand	g L^{-1}	77.41	33.16
C	g L^{-1}	29.03	12.44
C/N ratio	n.a.	5.92	3.5
Acetic acid	g L^{-1}	2.33	3.03
Propionic acid	g L^{-1}	0.02	1.64
Iso butyric acid	g L^{-1}	0.00	0.07
Butyric acid	g L^{-1}	0.03	0.08
Iso valeric acid	g L^{-1}	0.01	0.07
Valeric acid	g L^{-1}	0.00	0.00
Total volatile fatty acids	g L^{-1}	2.39	4.89

n.a.: not applied.