BIOMASS AND BIOENERGY 47 (2012) 62–70

Available online at www.sciencedirect.com

SciVerse ScienceDirect

http://www.elsevier.com/locate/biombioe

High methane yields and stable operation during anaerobic digestion of nutrient-supplemented energy crop mixtures

Ivo Achu Nges, Lovisa Björnsson*

Department of Biotechnology, Lund University, P.O. Box 124, SE 221 00 Lund, Sweden

ARTICLE INFO

Article history:
Received 25 November 2011
Received in revised form
24 September 2012
Accepted 2 October 2012
Available online 12 November 2012

Keywords:
Anaerobic digestion
Biogas
Energy crops
Macronutrients
Micronutrients

ABSTRACT

The feasibility of digesting energy crops supplemented with macro- and micronutrients instead of manure, without the commonly applied long hydraulic retention time (HRT), was investigated in long-term, single-stage continuous stirred tank processes. The crops used were mixtures of sugar beets, maize and whole crop triticale. The organic loading rate (OLR) measured as a total solid (TS) was 1.5–5.5 kg m^{-3} d^{-1} and the HRT from 30 to 40 days. The results showed high methane yields, comparable to those in batch digestion, and high stability. The digestion of beets only was most stable, and showed the highest average TS-based methane yield (383 ± 26 m^3 kg^{-1}) at an OLR of 4.5 kg m^{-3} d^{-1} and a HRT of 40 days. No significant difference in methane yield was found for all the crop mixtures during stable operation. Nutrient addition therefore showed the same stimulatory and stabilising effects as manure with high methane yields achieved at relatively short HRTs.

1. Introduction

The use of energy crops alone as the feedstock for biogas production via anaerobic digestion has been found to be prone to instability and even process failure [1–3]. On the other hand, co-digestion of energy crops with manure has been reported to greatly improve the anaerobic digestibility of energy crops [4,5]. This has been attributed to the broad spectrum of nutrients, vitamins and trace metals (micronutrients) found in manure [6]. However, increased interest in anaerobic digestion of energy crops and the scarcity of manure (due to declining stock farming), in Germany, for example, has led to many biogas plants being operated without, or with little, manure [2,3,7]. Furthermore, the use of manure in biogas production is regulated by EU directives [8], demanding e.g. heat treatment at 70 °C for 1 h to reduce pathogens when manure from several farms is mixed together. The operational conditions and performance of 45 stirred-tank, mesophilic energy-crop-based biogas plants in Germany have been reported by FNR [7]. The plants using little or no manure (0%–30% of total feedstock measured as wet weight (ww)) were found to operate at average hydraulic retention times (HRTs) of 170 days, while plants using a manure fraction above 50% had an average HRT of 46 days. Braun [9]also reported a mean value of 140 days HRT in the mono-digestion of energy crops and 50 days when equal amounts of crops and manure are co-digested. It would seem, therefore, that anaerobic digestion of energy crops can not proceed with good biodegradability at short HRTs without manure addition.

The outcome of anaerobic digestion depends on the characteristics of the feedstock [10] as well as the amounts of macro- and micronutrients present. Ensuring adequate availability of nutrients for the microbes is a problem when single substrates rather than complex mixtures of materials are used in the biogas process [11]. Some authors have

* *Corresponding author*. Tel.: +46 46 222 8347; fax: +46 46 222 4713.
E-mail address: Nges.Ivo_Achu@biotek.lu.se (I.A. Nges).
0961-9534/$ – see front matter
http://dx.doi.org/10.1016/j.biombioe.2012.10.002

concluded that optimal concentrations of phosphorus (P), sulphur (S), potassium (K), magnesium (Mg), iron (Fe), nickel (Ni), molybdenum (Mo), cobalt (Co), tungsten (W), selenium (Se) and zinc (Zn) are needed to afford process stability and high performance in anaerobic digestion [3,12,13]. Macronutrients such as, nitrogen (N), P and S, and micronutrients such Fe, Ni, Mo, Co, W and Se have been found to play a crucial role in the growth and metabolism of anaerobic microorganisms [14–16]. Macronutrients are known to act as buffering agents [1,16] while micronutrients have been reported to be abundant in the numerous enzymes (carbon monoxide dehydrogenase, Formyl-methanofuran hydrogenase, formate-hydrogenase, methyltransferase etc.) involved in the biochemistry of methane formation [13]. Gerardi [12] concluded that both macro- and micronutrients are required for better functioning of the biogas process. Hence it will be inadequate if only macronutrients or only micronutrients are supplied to a biogas process.

It has been concluded in a few studies that the addition of nutrients (in lieu of manure) improved methane production and process stability in the digestion of energy crops. Lei [17] reported that the addition of an adequate amount of P (465 mg L^{-1}) could accelerate the bio-gasification process of rice straw, while [2] reported a boost in methane production as a result of the addition of the same ratio of P and S. The addition of Ni (0.6 mg L^{-1}) and Co (0.1 mg L^{-1}) to the anaerobic digestion of maize silage was found to improve the methane yield by 25% and 10%, respectively [11]. Lebuhn [18] reported a total recovery in an acidified crop-based anaerobic process after the addition of micronutrients.

The above findings are encouraging and warrant further study to investigate the potential of digesting different energy crops with both macro- and micronutrient addition to improve biogas production. Producing biogas from energy crops places demands on arable land as compared to waste-based renewable energy production. Consequently, high process efficiency is particularly important. High conversion efficiency and high biogas yields influence process economy, land use efficiency and the process energy balance [19].

The hypothesis investigated in this study was that energy crops can be digested with good methane yields at relatively short HRTs when selected macro- and micronutrients are added. The aim was not to optimise nutrient addition, but to investigate a set of macro- and micronutrient which have the potential to provide stable operation and high methane yields. Single-stage continuously stirred tank reactors (CSTRs) were used, with HRTs between 30 and 40 days. The organic loading rate (OLR) was increased until process instability/failure occurred. The crops investigated were sugar beet, maize and whole crop triticale, which are commonly used as feedstock in biogas production [7,20]. In addition to nutrients, the impact of feedstock characteristics on the anaerobic digestion process was also investigated. Three different mixtures of crops were composed and tested in parallel.

(i) Sugar beet roots and beet leaves/tops mixed at the ratio at which they were harvested, i.e. 2:1 based on the weights at harvest i.e. ww (un-dried material).
(ii) Beet roots constituting half of the feedstock, with the addition of equal amounts of beet leaves/tops and maize in based on ww. The reason for studying this mixture was that beet leaves and maize can be stored as silage at a 1:1 ww ratio.
(iii) Whole crop triticale contributing almost half of the feedstock while beet roots, beet leaves/tops and maize made up the rest. The reason for investigating this crop mixture was that an autumn-sown, summer-harvested crop should provide half the methane production, while the other half would be made up of spring-sown, autumn-harvested crops.

2. Materials and methods

2.1. *Feedstock and inoculum*

2.1.1. *Energy crops*

The crops were grown in an energy crop cultivation trial in southern Sweden (Lönnstorp, Lomma, 55 40′N 13 6′E), fertilized with effluent from a biogas plant. Lomma receives an average of 1000 mm of rainfall per year and is 10 m above sea level. The Cultivars chosen were based on high biomass yield rather than quality for food or feed. Sugar beets, *Beta vulgaris* (roots, tops, and leaves), ‘Biogas type’ (EB 726, Syngenta, Basel Switzerland) a non-commercially available cultivar with high biomass yield was harvested at full maturity (late October). Whole maize plant, *Zea mays*, (Arabica cultivar, stay green type) was harvested at full ripeness (late September) based on the recommendations of [20] for late ripening cultivars. Triticale, ‘*x Triticosecale talus*’, (a Talus cultivar, fodder type) was harvested as whole crop at the vegetation stage (mid July), where the highest biomass yield per hectare is obtained [20]. Maize and triticale were harvested with a precision chopper set at a chopping length of 10 mm. Beet leaves/tops were chopped in a garden shredder (AXT 2500 HT, Robert Bosch GmbH, Germany) into pieces about 2 cm long. Beet roots were cut into 1 cm slices. The chopped crop samples were weighed and immediately transported to the experimental site and frozen. Mineral concentrations and total solids (TS) were determined in triplicates for each crop sample prior to freezing. Three different crop mixtures were investigated (based on ww), as follows:

- 67% of beet roots and 33% of beet leaves/tops (denoted mixture B),
- 46% of beet roots, 28% of beet leaves/tops and 26% of maize (denoted mixture BM), and
- 28% of beet roots, 14% of beet leaves/tops, 20% of maize and 38% of triticale (denoted mixture BMT).

The TS were used to calculate the crop: water ratio in feedstock preparation to achieve process operation with a constant HRT. Before use, the crop mixtures were partly defrosted and ground batch-wise in a homogenizer (Grindomix 200, Retsch, Germany) so as to pass through a 4 mm mesh. In CSTRs experiments, the ground crop mixtures were mixed with minerals, and in some cases water, to prepare the feedstock, which was stored for about 5 days in a refrigerator (4 °C) prior to use in the experiments.