Bioresource Technology 262 (2018) 194–202

Contents lists available at ScienceDirect

Bioresource Technology

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

Anaerobic digestion of high-yielding tropical energy crops for biomethane production: Effects of crop types, locations and plant parts

K.C. Surendra[a], Richard Ogoshi[b], Annett Reinhardt-Hanisch[c], Hans Oechsner[c], Halina M. Zaleski[d], Andrew G. Hashimoto[a], Samir Kumar Khanal[a,*]

[a] Department of Molecular Biosciences and Bioengineering, University of Hawaiʻi at Mānoa, Honolulu, HI 96822, USA
[b] Department of Tropical Plant and Soil Sciences, University of Hawaiʻi at Mānoa, Honolulu, HI 96822, USA
[c] State Institute of Agricultural Engineering and Bioenergy, University of Hohenheim, Stuttgart, Germany
[d] Department of Human Nutrition, Food and Animal Sciences, University of Hawaiʻi at Mānoa, Honolulu, HI 96822, USA

ARTICLE INFO

Keywords:
Energy crops
Plant parts
Biomass composition
Anaerobic digestion
Methane yield
Biorefinery

ABSTRACT

This study examined the composition and anaerobic digestibility of the different plant parts of two high-yielding tropical energy crops, Energycane and Napier grass, collected across three locations and two seasons. Both biomass composition and biomethane yields varied significantly with crop types, plant parts and harvest seasons. In Energycane, specific methane yield (SMY) (Nm^3 $(kg\ VS_{added})^{-1}$) was higher from stems (0.232 ± 0.003) than leaves (0.224 ± 0.003), while in Napier grass, SMY was higher from leaves (0.243 ± 0.002) than stems (0.168 ± 0.002). Energycane had higher specific and total ($Nm^3\ ha^{-1}\ year^{-1}$) methane yields (0.230 ± 0.002 and 8749 ± 494, respectively) than Napier grass (0.192 ± 0.002 and 5575 ± 494, respectively). The SMYs from biomass correlated negatively with acid detergent fiber, cellulose and lignin content in the biomass. Energycane and Napier grass had lower specific but comparable total methane yields (TMYs) with maize. The ecological, economic and environmental merits associated with perennial crops suggest they could outperform maize as a substrate for bioenergy production.

1. Introduction

Bioenergy is one of the major components of a renewable energy mix for addressing environmental concerns and the energy security issues associated with the heavy reliance on fossil energy resources (Cherubini and Strømman, 2011; IEA and FAO, 2017). Currently, biofuel is the major renewable transportation fuel, accounting for about 4% of global transportation fuel (134 billion liters per year), and is estimated to increase to 4.5% by 2020 (IEA and FAO, 2017). Based on environmental conditions and governmental policies, different feedstocks and conversion technologies have been prioritized and commercialized in different countries. For example, production of ethanol from sugarcane has been extensively employed in tropical countries such as Brazil (~28 billion liters of ethanol was produced in 2016 for use in fuel) (USDA GAIN Report, 2016), while corn-based ethanol is the major biofuel produced in the United States (corn starch accounted for 95% of the feedstocks used for producing 57.73 billion liters of ethanol in 2016) (Renewable Fuels Association, 2017). Similarly, anaerobic digestion (AD) of energy crops, especially maize silage, for biogas production is one of the most commonly practiced biomass to bioenergy conversion technologies in European Union (EU) countries, such as Germany. For example, in Germany (which alone had 10,846 of the 17,376 biogas plants in EU countries in 2015 (European Biogas Association, 2016)), energy crops accounted for 41% of feedstocks in biogas plants, and maize silage alone constituted 78% of energy crops (Senghor, et al., 2017). In recent years, maize cultivation as a feedstock for biofuel production, however, has raised serious debate on use for food and/or feed versus fuels, as well as environmental concerns, such as soil erosion, soil compaction, low biodiversity, nutrients leaching into surface and ground water, and pesticide pollution of soil and water bodies, among others (European Environment Agency, 2006). Thus, various regulations and standards have been set up to regulate the use of food and/or feed crops as feedstocks for biofuel production, such as maize-based biogas in the EU countries (e.g., Renewable Energy Directive I and Renewable Energy Directive II) and corn-based ethanol in the United States (e.g., Renewable Fuel Standard 2, Energy Independence and Security Act, 2007).

Due to high input requirements, environmental issues and the food and/or feed versus fuel debate associated with the conventional feedstocks (e.g., corn and sugarcane) for biofuel production, studies have

* Corresponding author.
E-mail address: khanal@hawaii.edu (S.K. Khanal).

https://doi.org/10.1016/j.biortech.2018.04.062
Received 8 February 2018; Received in revised form 13 April 2018; Accepted 17 April 2018
Available online 18 April 2018
0960-8524/

been conducted using high-yielding perennial energy crops at relatively low input conditions as feedstocks for bioenergy production. Recently, Napier grass (*Pennisetum purpureum*) and Energycane (*Saccharum* hybrid) have attracted significant attention as promising feedstocks for tropical and subtropical regions due to their efficient C_4 photosynthetic pathway (comparatively high biomass yield at low inputs, with better water and nutrient use efficiency), upright growth (facilitates efficient harvesting), and perennial nature (in addition to providing environmental and ecological benefits, requires less labor and inputs for crop management) (Na et al., 2014; Surendra et al., 2018). Studies have reported higher biomass yield of Energycane and Napier grass compared to other dedicated energy crops such as Switchgrass (*Panicum virgatum*), and Miscanthus (*Miscanthus* spp.) (McKendry, 2002; Schmer et al., 2009; Fedenko et al., 2013; Song et al., 2014). Moreover, several studies reported AD of energy crops for biogas production as arguably one of the most energy-efficient and environmentally benign biomass-to-bioenergy conversion pathways (Frigon and Guiot, 2010; Börjesson and Mattiasson, 2008). However, limited literature is available on biomethane yield potential of high-yielding tropical energy crops. Thus, the overall goal of this study was to examine the biomethane yield potential of two high-yielding tropical energy crops, Napier grass and Energycane, which could provide economic, environmental and ecological benefits as a major feedstock for biomethane production.

The complexity of biomass structure is the major challenge during AD of lignocellulosic biomass for biomethane production. The interaction of cellulose, hemicellulose and lignin, the major components of any lignocellulosic biomass, makes lignocellulosic biomass highly recalcitrant to anaerobic degradation and ultimately results in low biomethane yield (Surendra and Khanal, 2015). Various strategies, including biomass pretreatment, have been extensively explored to enhance the anaerobic digestibility of lignocellulosic biomass and ultimately the biomethane yield. However, most of the approaches to improve the digestibility of the lignocellulosic biomass were applied to the whole crop. The composition of the lignocellulosic biomass, however, varies with genotype, environmental conditions, crop management practices and plant parts (Surendra et al., 2018; Na et al., 2016), and ultimately governs the overall efficacy of biomass-to-bioenergy conversion technology. Since composition of lignocellulosic biomass varies with the crop types and plant parts within the crop type (Surendra et al., 2018), different plant parts of the energy crops may have different digestibility during AD and have different contributions to biomethane yield. Understanding any variability in anaerobic digestibility (between the crop types and plant parts within the crop type), will provide critical guidelines in selecting an appropriate pretreatment/preprocessing method for a particular crop or plant part for enhanced biomethane yield or a technology for efficient conversion of the selected energy crop or plant part into biofuel and biobased products. To the best of our knowledge, there have been very limited studies on the way the composition of the different parts of the high-yielding tropical lignocellulosic energy crops affects their anaerobic digestibility for biomethane production. Thus, the objectives of this study were to characterize the composition of the different parts of the selected perennial tropical lignocellulosic energy crops, Energycane and Napier grass, grown at different locations, and to examine their anaerobic digestibility for biomethane production. Such information will be crucial in designing an appropriate conversion technology based on their composition.

2. Materials and methods

2.1. Substrate

Biomass sample collection, preparation and characterization have been described in detail in Surendra et al. (2018). Briefly, two C_4 perennial grasses, namely Energycane (*Saccharum* hybrid) and Napier grass (*Pennisetum purpureum*) with two cultivars of each crop, Energycane (MOL-6136 and 77-9271) and Napier grass (Green and Purple), harvested in 2015 across three locations separated by elevation (30 m, 305 m, and 915 m) were examined for their composition and anaerobic digestibility. Energycane was separated into four parts, bottom (stems and leaves) and top (stems and leaves), while Napier grass was separated into stems and leaves. Since Napier grass was harvested twice a year (March and September), samples collected at different harvests were separately digested to examine the effect of harvest season on digestibility and subsequent biomethane potential.

The dried and milled biomass (1 mm in size) samples were used for the digestibility study. Biomass samples were characterized for total solids (TS), volatile solids (VS), ash, fiber and ash-free extractives contents. TS, VS and ash content were determined as per Standard Methods (APHA, 2005). Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), Acid Detergent Lignin (ADL), cellulose, hemicellulose and ash-free extractives content in the biomass were determined as described in Surendra et al. (2018).

2.2. Inoculum

The inoculum was taken from the mother reactor maintained in the State Institute of Agricultural Engineering and Bioenergy at University of Hohenheim, Stuttgart, Germany. The mother reactor, maintained at 40 °C, was fed mainly with cattle manure. To minimize the contribution of inoculum to methane yield, the contents of the mother reactor were sieved using a kitchen strainer and the filtrate was used as an inoculum. The TS and VS contents of the inoculum were $6.24 \pm 0.25\%$ and $60.97 \pm 0.52\%$ of TS, respectively.

2.3. Digestion test

The digestion study was conducted following the Hohenheim Biogas Yield Test (HBT) method (Mittweg et al., 2012). A series of 100 mL glass syringes was used as a digester in which 500 mg of dried and milled (1 mm size) biomass was digested using 30 g (wet weight) of active anaerobic inoculum at mesophilic condition (37 ± 0.5 °C) for 35 days. Two standard biomass samples (hay and concentrated feed) with known biomass composition and methane production potential were used as controls to check the quality of inoculum as well as to account for the variation among the batch tests due to inoculum activity and other analytical variation. Three HBT syringes containing only the inoculum were used as a control to account for the volume of methane produced from the inoculum alone. Digestion tests were conducted in triplicates. The biogas volume was determined by reading the filling level of the glass syringe. The methane content in the biogas was determined using an infrared-spectrometric methane-sensor (Advanced Gasmitter, Pronova Analysetechnik, Berlin, Germany). The calculated volumes of methane were normalized to standard conditions (273 K and 1 atm). The standard incubation time for HBT was 35 days. However, the digestibility test of selected biomass samples was conducted for an incubation time of 90 days to examine the effect of incubation time on methane production potential.

2.4. Statistical analyses

The data were analyzed using a split-split-split-plot model using JMP Pro statistical software (v.12, SAS Institute Inc., USA), in which elevation, cultivar, plant part and harvest season (Napier grass) were treated as the main plot, sub-plot, sub-sub-plot and sub-sub-sub-plot effect, respectively. Total above ground biomass composition and total methane yield (TMY) were derived as the weighted average of plant parts, and were compared for elevations, cultivars, harvest seasons and crop types. Pearson's correlation coefficients were calculated to determine the correlation between biomass composition and methane yield.