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Optimization of anaerobic co-digestion of *Solidago canadensis* L. biomass and cattle slurry

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SC (*Solidago canadensis* L.) was digested with CS (cattle slurry). The process stability, methane production by anaerobic digestion, and the efficiency of organic matter removal were measured. The maximum methane production of 143.7 L/kg volatile solids was obtained at a SC:CS ratio of 1:3 and a substrate concentration of 6% (based on volatile solids); however, the difference between total methane production for SC:CS ratios of 1:1 and 1:3 was not significant ($p > 0.05$). Therefore, based on the SC treatment capacity, the optimum SC:CS ratio is 1:1 for this application. For a 6% substrate concentration, the total methane production (129.6 L/kg volatile solids) at a SC:CS ratio of 1:1 was 123.5% higher than that of a control. The pH was fairly constant (6.8–7.6). The removal efficiencies of total solids, volatile solids, cellulose, hemicellulose, and soluble chemical oxygen demand were 37.3, 41.6, 23.6, 34.8, and 38.8%, respectively, and the T_{80} was 30.0% shorter than that for maximum methane production. These results indicate that the process stability and methane production efficiency of SC can be improved by CS addition.

1. Introduction

Invasive plants are widely recognized as a serious environmental problem, which can impact or destroy ecosystem functioning and ecosystem biodiversity [1]. Invasive plants pose a great threat to many terrestrial and aquatic ecosystems, because they can displace native plant species and alter geomorphological processes and nutrient cycles [2,3].

SC (Asteraceae) (*Solidago canadensis* L.), which originated in North America, has successfully invaded Europe, Asia, and Australia [4,5]. This species grows in densely monospecific stands, has the ability to spread locally via rhizomes, and has a high growth rate [6]. SC was introduced to Eastern China in 1913 as an ornamental plant, after which its seeds were dispersed from gardens to natural environments by wind and other mechanisms [7]. Since then, SC has spread into croplands in Shanghai, Jiangsu, and Zhejiang Provinces. SC is currently found in various habitats, including roadsides, orchards, gardens, abandoned farmland, and the green spaces of some cities [8]. In China, the abundance and diversity of native plant communities has decreased greatly, because of the strong allelopathic effects of SC on native plants, arbuscular mycorrhizal fungi, and soil-borne pathogens, and the detrimental effects of SC on soil nutrient cycling, microbial functional diversity, and the trophic structures of insect-associated communities [9–13].

The biomass yields of SC are high, and converting SC to methane by AD (anaerobic digestion) may be a good option for SC disposal. SC produces many seeds, which germinate easily in a wide range of soils and can be dispersed by the wind [6]. However, harvesting SC before flowering for methane production has the potential to control its spread. Additionally, CS (cattle slurry) might be a good candidate for digestion with SC for methane production, because of the presence of additional nutrients and the microorganism populations present in CS; these may improve the process balance and methane production by AD [14,15].

The objectives of this study were to (1) determine whether the process stability of AD of SC can be enhanced by CS; (2) investigate the effects of substrate concentration and CS proportion in the mixture on daily and total methane production and determine the optimum conditions; (3) analyze the AD process performance; and (4) assess the substrate degradation after AD.

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2. Methods

2.1. Feedstock and inoculum

SC was collected before flowering from an abandoned field located in the suburbs of Hangzhou, Zhejiang Province, China. The SC was stored at 4 °C after shredding to a small size (7–12 mm). CS and inoculum were collected from a biogas plant digesting manure in Linxia, Gansu Province, China. The characteristics of SC, CS, and inoculum are shown in Table 1.

2.2. Anaerobic digestion

The required amounts of SC and CS were loaded into digesters. The mixture ratios of SC:CS were 3:1, 1:1, and 1:3, based on VS (volatile solids). The volume of inoculum seeded into each digester was 250 mL/L. For SC (control), and SC:CS ratios of 3:1, 1:1, and 1:3, the substrate concentrations for AD were 4, 6, and 8% (based on VS), respectively. The C/N ratios for the digesters are shown in Table 2. Digestion of SC alone was used as a control, and the VS content of the control was the same as for the three mixture ratios for a specific substrate concentration. The tests were conducted in batch mode at laboratory scale. The volume of each digester was 2 L and the working volume was 1 L. The digester headspaces were flushed with N_2 gas for about 5 min to obtain anaerobic conditions, after which they were capped tightly with rubber stoppers and incubated at 35 °C without shaking. Digestion experiments were conducted in triplicate for each condition.

2.3. Analytical methods

2.3.1. Chemical analyses

TS (Total solids), VS, sCOD (soluble chemical oxygen demand), VFAs (volatile fatty acids), and pH were determined according to standard methods [16]. An elemental analyzer (varioEL cube; Elementar Analysensysteme GmbH) was used to measure total carbon, total nitrogen, and total hydrogen. The cellulose and hemicellulose contents were determined using the procedure described by Van Soest et al. [17].

2.3.2. Biogas analyses

Biogas production was measured every 2 d using the water-displacement method; the total volume of biogas was calculated after the test. A GC (gas chromatograph) (7890A; Agilent Technologies, Wilmington, DE, USA) equipped with a thermal conductivity detector and a 25 m × 530 μm × 20 μm chromatographic column was used to analyze the methane content of the biogas. For GC analysis, the carrier gas was hydrogen (35 mL/min), the injector port and detector temperatures were 75 °C and 150 °C, respectively, and the composition of the standard gas (YQD-09; Qingdao Hua Qing Co., Shandong, China) was 30.1% N_2, 39.9% CH_4, and 30.0% CO_2.

Table 1
Characteristics of different materials.

Parameter	Solidago Canadensis	Cattle Manure	Inoculum
Total solids (%)	35.3 ± 0.01	25.6 ± 0.00	15.2 ± 0.14
Volatile solids (%)	90.5 ± 0.01	72.6 ± 0.04	56.3 ± 0.14
Total carbon (%)	55.2 ± 0.20	36.4 ± 0.00	33.8 ± 0.12
Total nitrogen (%)	1.4 ± 0.02	1.8 ± 0.13	2.0 ± 0.04
pH value	5.6 ± 0.04	8.3 ± 0.02	7.6 ± 0.00

Table 2
C/N ratios for mixtures.

Concentration (%)	Control	3:1	1:1	1:3
4%	27.8	27.3	24.2	19.8
6%	30.6	29.0	25.1	21.7
8%	32.3	31.0	26.1	22.3

2.4. Statistical analyses

ANOVA (Analysis of variance) was performed to determine whether the observed differences between two or more groups of experimental results were significant. A p value less than 0.05 was considered to indicate significance.

3. Results and discussion

3.1. Methane production

As shown in Fig. 1, daily methane production was significantly affected by the substrate concentration and the mixture ratio. For the control, daily methane production with a 4% substrate concentration was continued until the end of AD. When the substrate concentration was increased from 4 to 6%, the level of daily methane production was very low during the first 20 d of AD, and then increased gradually. This can be attributed to the high

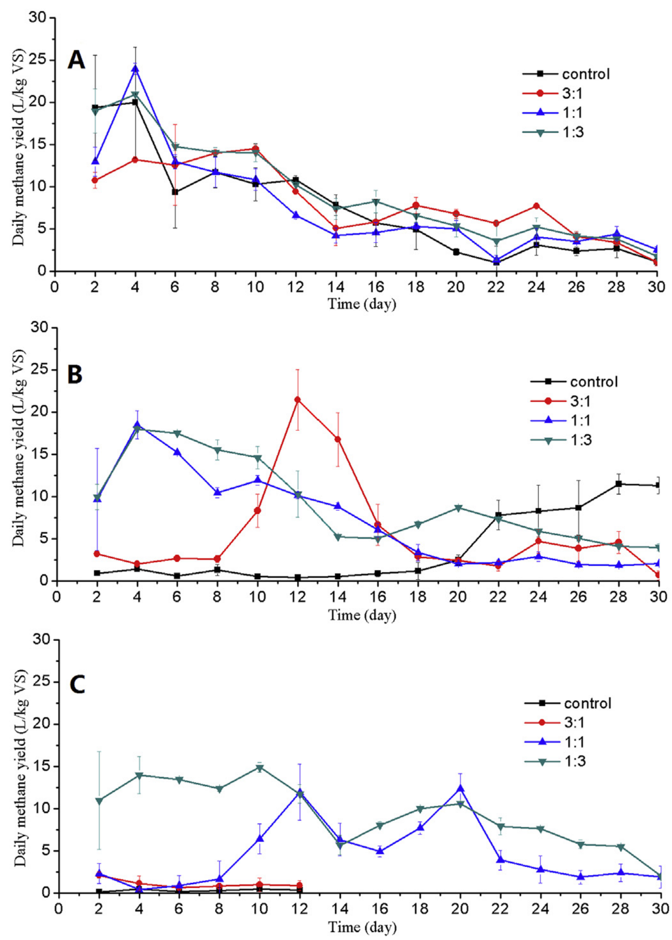

Fig. 1. Effects of SC:CS ratio on daily methane production at different concentrations (digestion time: 30 d). A: 4% concentration; B: 6% concentration; and C: 8% concentration.

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