Bioresource Technology 100 (2009) 2952–2958

Contents lists available at ScienceDirect

Bioresource Technology

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

Biogas production from boreal herbaceous grasses – Specific methane yield and methane yield per hectare

Mari Seppälä *, Teija Paavola [1], Annimari Lehtomäki [2], Jukka Rintala

University of Jyväskylä, Department of Biological and Environmental Science, P.O. Box 35, FI-40014 University of Jyväskylä, Finland

ARTICLE INFO

Article history:
Received 5 November 2008
Received in revised form 22 January 2009
Accepted 25 January 2009
Available online 3 March 2009

Keywords:
Biogas production
Grass
Harvest time
Specific methane yield

ABSTRACT

The objective of this study was to determine the specific methane yields of four grass species (cocksfoot, tall fescue, reed canary grass and timothy) cultivated under boreal conditions as well as how harvesting time and year of cultivation affects the specific methane yields per ha. The specific methane yields of all grasses and all harvests varied from 253 to 394 Nl CH_4/kg volatile solids (VS) added. The average specific methane yield of the 1st harvest of all grasses was higher than the 2nd harvests. In this study the methane and energy yields from different harvest years were ranged from 1200 to 3600 Nm^3 CH_4/ha/a, corresponding from 12 to 36 MWh_{CH_4}/ha/a. The methane yield per hectare of the 1st harvest was always higher than that of the 2nd harvest per hectare because of the higher dry matter yield and specific methane yield. High biomass yield per hectare, good digestibility and regrowth ability after harvesting are important factors when choosing grass species for biogas production. If 30% of fallow and the second harvest of grassland were cultivated grasses and harvested for biogas production in Finland, the energy produced could be 4.9 TWh_{CH_4}.

1. Introduction

Application of the anaerobic digestion process for the production of renewable energy has increased in recent years. Anaerobic digestion can be applied to convert biodegradable wastes, plant biomass, crop residues, manure and energy crops for the purpose of producing renewable energy, biogas. The methane-rich biogas is carbon-neutral source of renewable energy and, it is a competitive alternative in energy production in both its energy efficiency and environmental impact (Fredriksson et al., 2006; Gerin et al., 2008). In addition to producing renewable energy the digestate, a nutrient-rich product, can be used as fertiliser and the nutrient cycle is almost closed. The methane-rich biogas can be used for to produce heat and power and transport biofuel while the use of carbon dioxide (biogas contain 25–45% carbon dioxide) for various purposes can also be considered.

Electricity is being produced by farm-scale biogas plants in particularly in Germany and Austria (Weiland, 2000). Manure is an easily available resource on farms, but a limited production rate, low biogas yield and high investment cost do not make the production of biogas from manure economically feasible (Gerin et al., 2008). Biogas production can be greatly improved by using energy rich co-substrates such as energy crops, crop residues, industrial by-products and other biodegradable wastes in anaerobic digesters. Currently, biogas production from energy crops is mainly based on the anaerobic digestion of maize (Amon et al., 2007a,b), but fodder and sugar beets, grass silages and grain crops (Amon et al., 2007a; Lehtomäki et al., 2008) have also been studied in biogas processes. Clearly, energy crops suitable for cultivation in one country might be less suitable in another country.

The area of arable land in Finland is 2.3 Mha of which about 27% is grasslands (650,000 ha) (TIKE, 2007). The Ministry of Agriculture and Forestry has proposed that 500,000 ha of arable land (corresponding to 22% of all arable land in Finland) could be dedicated to energy crop production (Vainio-Mattila et al., 2005). Grassland cultivation is very extensive in Finland. At present, the first harvest of grasses is utilized as forage, as it is the most suitable for animal feed. Usually only the first harvest is fertilized while it is not common to fertilize, or even harvest, the second or third (only in southern Finland) growth.

Domestic animal production based on cultivated grassland for forage has a good competitive advantage, as grass yields in Finland are very close to those in Central Europe (Hyytiäinen et al., 1999). Grassland cultivation is also a good environmental use of arable land. Grasses take up nutrients efficiently and arable land is covered in autumn and winter by grasses, which decrease nutrient leaching (Hyytiäinen et al., 1999).

* Corresponding author. Tel.: +358 14 260 4252; fax: +358 14 260 2321.
E-mail address: mari.p.seppala@jyu.fi (M. Seppälä).
[1] Present address: MTT Agrifood Research Finland, FI-31600 Jokioinen, Finland.
[2] Present address: Jyväskylä Innovation Ltd., P.O. Box 27, FI-40101 Jyväskylä, Finland.

0960-8524/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biortech.2009.01.044

The length of the growing season varies from north to south and in Nordic countries, such as Finland (growing season 5–6 months, heat summation 900–1300 °C degree days), crops with a short growing season must be chosen. Crops have to have good tolerance to snow, low temperatures and a long day. Perennial grasses (e.g. timothy and meadow fescue) are the most efficient producers of biomass in boreal conditions (Hyytiäinen et al., 1999). Perennial grasses are commonly cultivated as forage in northern countries and grasses have the advantage of being familiar to farmers and suitable for harvesting and storing with existing methods and machinery. The grasses can also be included in current crop rotation practices. Because grasses have been bred for animal feed, they are often characterized by good digestibility.

When choosing the most appropriate crops for biogas production, net energy yield per hectare is the most important parameter. Net energy yield is defined by energy yield (biomass dry matter yield × specific methane yield) minus cultivation inputs. In addition, high biomass yield, high digestibility, low energy, nutrient and pesticide inputs, low cultivation, harvest and storage costs, and ease of cultivation, harvesting and storage have to be considered when choosing crops for biogas production.

Chemical composition affects the biodegradability and specific methane yield of plant substrates (Amon et al., 2007b). Many factors influence the chemical composition of plants, including harvest time, growth stage, plant type, leaf/stem ratio, growing conditions and fertilisation. To achieve high specific methane yields, crop substrates need to be low in lignin content and have a high content of easily degradable components such as non-structural carbohydrates, soluble carbohydrates and soluble cell components (Chynoweth et al., 1993; Amon et al., 2007b; Schittenhelm, 2008).

Methane production potential is usually determined only from the grass mixtures such as timothy-meadow fescue (Lehtomäki et al., 2008), and the literature on the methane production potential of different grass species is slightly. The objective of this study was to determine the specific methane yields of different grass species cultivated under boreal conditions as well as how the harvesting time and cultivation year affects the specific methane yields per ha.

2. Methods

2.1. Grass material

The grass material consisted of four grass species (Table 1). Cocksfoot (*Dactylis glomerata* L.), tall fescue (*Festuca arundinaceae* Schreb.) and reed canary grass (*Phalaris arundinaceae* L.) were cultivated in Saarijärvi (N 6957311° E 3410645° Coordinate system EUREF –FIN ∼WGS84), Central Finland and Hahkiala (N 6783511°, E 3372445°) Southern Finland. Timothy (*Phleum pratense* L.) was also cultivated in Hahkiala.

In Saarijärvi cocksfoot, tall fescue and reed canary grass and in Hahkiala all the grasses, except reed canary grass which was sown in 2006, were sown in the year 2004 (Table 1). All the grasses were fertilized during the growing season in both Saarijärvi and Hahkiala (Table 1). The grasses were harvested at different times during years 2005–2007.

In Saarijärvi in the year 2005, the grasses were harvested once (1st), but reed canary grass two times (1st and 2nd harvest). In 2006 the grasses were also harvested once (the grasses were dried on the field 24 h), because of the dry growing season. Reed canary grass was harvested twice, the earlier harvest was gathered during the early flowering stage (referred as RCG SA 06 a) and the later harvest in the flowering stage (RCG SA 06 b) on different plots (Table 1). In year 2007, the grasses were harvested at two maturity stages, the early flowering stage (1st) and the vegetative regrowth stage (2nd), on the same plot.

In Hahkiala in the year 2006 cocksfoot, tall fescue and timothy were harvested three times each year and samples for methane potential assays were taken from the second (2nd) and the third (3rd) harvest in the second harvest year (Table 1). Timothy was also harvested twice a year and samples for methane potential assays were taken from both harvests (TIM HA 06 1st and TIM HA 06 2nd). Reed canary grass was harvested once a year (RCG HA 07).

The yield of the grasses in Saarijärvi was determined by taking 4–7 samples from an area of 0.25 m^2 area and weighing them. The grass material was cut using a mowing machine. The harvested grass material was taken to the laboratory and chopped into particles of ca. 1 cm with scissors (grasses in Saarijärvi) and stored for

Table 1
Dates of harvest, cultivation sites, harvest yield and fertilisation of grasses used in this study.

Grass species	Cultivation site	Harvest time	Code	Harvest yield (tTS/ha)	Fertilisation (kg N–P–K/ha)
Cocksfoot	Saarijärvi	12.9.2005	CF SA 05	2.3	27–5–8[a]
Cocksfoot	Saarijärvi	21.6.2006	CF SA 06	5.6	60–0–45
Cocksfoot	Hahkiala	17.7.2006	CF HA 06 2nd	2.3	88–12–32
Cocksfoot	Hahkiala	13.9.2006	CF HA 06 3rd	3.2	88–12–32
Cocksfoot	Saarijärvi	20.6.2007	CF SA 07 1st	6.4	52–8–13
Cocksfoot	Saarijärvi	20.8.2007	CF SA 07 2nd	5.1	60–0–45
Tall fescue	Saarijärvi	12.9.2005	TF SA 05	1.1	27–5–8[a]
Tall fescue	Saarijärvi	21.6.2006	TF SA 06	4.3	60–0–45
Tall fescue	Hahkiala	17.7.2006	TF HA 06 2nd	3.2	88–12–32
Tall fescue	Hahkiala	13.9.2006	TF HA 06 3rd	3.5	88–12–32
Tall fescue	Saarijärvi	20.6.2007	TF SA 07 1st	6.0	52–8–13
Tall fescue	Saarijärvi	20.8.2007	TF SA 07 2nd	5.2	60–0–45
Timothy	Hahkiala	13.6.2006	TIM HA 06 1st	3.8	110–15–40
Timothy	Hahkiala	2.8.2006	TIM HA 06 2nd	2.7	88–12–32
Timothy	Hahkiala	17.7.2006	TIM H A3 06 2nd	1.5	88–12–32
Timothy	Hahkiala	13.9.2006	TIM H A3 06 3rd	2.1	88–12–32
Reed canary grass	Saarijärvi	22.6.2005	RCG SA 05 1st	5.2	27–5–8[a]
Reed canary grass	Saarijärvi	19.8.2005	RCG SA 05 2nd	2.9	–
Reed canary grass	Saarijärvi	21.6.2006	RCG SA 06 a	4.2	60–0–45
Reed canary grass	Saarijärvi	10.7.2006	RCG SA 06 b	7.5	56–0–42
Reed canary grass	Saarijärvi	20.6.2007	RCG SA 07 1st	3.4	52–8–13
Reed canary grass	Saarijärvi	20.8.2007	RCG SA 07 2nd	3.4	60–0–45
Reed canary grass	Hahkiala	24.9.2007	RCG HA 07	13.7	80–12–32

[a] Also cow manure fertilisation 24 kg N/ha and 18 kg P/ha.