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Screening of novel plants for biogas production in northern conditions

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HIGHLIGHTS

- The methane yields of nine novel plants were measured.
- The specific methane yields varied 170–381 Nm^3/t VS and TS yields 9–23 t TS/ha.
- Highest methane yield was achieved brown knapweed 6100 Nm^3 CH_4/ha.
- The cultivation and sustainability of novel plants have to be studied more carefully.

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ABSTRACT

The objective of this study was to screen nine annual or perennial novel plants for biogas production cultivated in years 2007–2010 in Finland. The most promising novel plants for biogas production were found to be brown knapweed, giant goldenrod and Japanese millet producing 14–27 t total solids/ha and 4000–6100 Nm^3 CH_4/ha. The specific methane yields of all studied plants varied from 170 to 381 Nm^3 CH_4/t volatile solids (VS), depending on harvest time and plant species. Co-digestion of brown knapweed with cow manure in continuously stirred tank reactor was investigated and the highest methane yield was 254 NL CH_4/kg VS, when the share of brown knapweed was 50% in the feed VS (organic loading rate (OLR) 2 kg VS/m^3/d). The cultivation managements and sustainability of novel plants for biogas production have to be investigated.

1. Introduction

Biogas production is increasingly used to produce bioenergy from energy crops, crop residues and organic wastes and the number of biogas plants has been increased in Central Europe and also in Northern Europe. The most suitable feedstocks for biogas production are manures, crops and crop residues in the agricultural sector. Among crops, grasses and energy maize are the most commonly used feedstocks today in biogas production. In order to promote the sustainability of energy crops, fallow land areas (4.3 million hectares set-aside land with no economic use in EU-15, in 2005 (Fischer et al., 2010)) could be considered to avoid competition with land for food and feed production and 8.3 million hectare of fallow land could be available in EU-15 by year 2030 (Fischer et al., 2010).

Nowadays, maize is the most popular feedstock in the biogas plants in Germany and Austria and the grasses have been studied in the best feedstock among crops in the biogas plants in northern conditions, where the maize is not traditionally cultivated (McEniry and O'Kiely, 2013; Murphy and Power, 2009; Seppälä et al., 2009). The cultivation and use of non-food plants is certainly a more sustainable option for renewable energy production than using crops, which can be used as a food and feed production also. There is a need to find novel plants for energy production, which can produce high total solid (TS) yields and methane yields per hectare. Especially novel plants for biogas production will be needed for northern growing conditions, because maize can be cultivated only in southern parts in Finland and Sweden and the TS yields have been 13–20 t/ha in Finland (Seppälä et al., 2012). The cultivation of grass is almost the only way to produce biomass for energy production and yields per hectare have been 7–11 t TS in Finland (Seppälä et al., 2009). The cultivation of maize for biogas production can produce high yields 20–30 t TS/ha in Central Europe (Amon et al., 2007; Oslaj et al., 2010).

The searching of novel plants for biogas production could be done for example weeds, other wild plants or fodder plants, which have not been used for bioenergy nor biogas production before. Weeds and wild plants usually need lower fertilisation input, they use nitrogen efficiently and can grow in poorer conditions than

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Table 1
The sowing and harvest time and fertilisation rate of plants used in this study.

Plant		Annual/perennial	Sowing time	Harvest time	Fertilization N–P–K kg/ha
Jerusalem artichoke		Perennial	2007	2.9.2007	7–2–8
Sunflower		Annual	2007	2.9.2007	21–6.5–26.5
Brown knapweed	A07[a]	Perennial	2006	14.6.2007	30–2.3–3.5
	B07		2006	14.8.2007	30–2.3–3.5
	A08		7.6.2007	16.6.2008	30–2.3–3.5
	B08		7.6.2007	7.7.2008	30–2.3–3.5
	C08		7.6.2007	5.8.2008	30–2.3–3.5
	D08		7.6.2007	1.9.2008	30–2.3–3.5
Sorghum		Annual	26.5.2008	1.9.2008	120–9–14
Japanese millet		Annual	26.5.2008	1.9.2008	120–9–14
Giant knotweed		Perennial	2008	24.8.2010	60–4.6–7
Giant goldenrod		Perennial	2007	24.8.2010	60–4.6–7
Hemp–agrimony		Perennial	2008	24.8.2010	60–4.6–7
Amaranth		Perennial	2010	24.8.2010	60–4.6–7

[a] A, B, C, D are different harvest times in year 2007 and 2008.

crops for food and feed production. Annual and perennial plants and weeds can generally be cultivated on fallow lands and marginal lands, which cannot be used to cultivate food or feed crops for example fields with poor growing conditions, old peat bogs and land close to roads.

Gunaseelan (1997) reviewed specific methane yields from fruit and vegetables, grasses, woody biomass, terrestrial weeds, marine biomass and freshwater biomass. He reported that weeds were a potential biomass source for bioenergy production and their large scale utilisation represented one of the best strategies for weed management (Gunaseelan, 1997). In fallow lands weeds grow more efficiently than main crops, because weeds usually have very efficient use of nutrients and water (Nissinen et al., 2010). Subramanian and Sampathrajan (1999) studied the physical and chemical properties of 26 weed species and found promising species for biogas production in India. Many perennial and annual plants have been studied for combustion and 2nd generation biofuel production like amaranth (Viglasky et al., 2009), common reed (Kuhlman et al., in press), and hemp (Prade et al., 2011). Some cultivation experiments have been made with weeds and tall perennials in Finland in years 2004–2010 (Nissinen et al., 2010), but were not investigated for bioenergy production. Biogas production assays have been done for many crops, crop residues and weeds some years ago (Gunaseelan, 1997; Lehtomäki et al., 2008; Subramanian and Sampathrajan, 1999), but laboratory scale experiments using novel plants for anaerobic digestion and co-digestion with manure have not been studied. It is important that the plants can produce high methane yields and also that they can be used in biogas process. The novel plants for biogas production in northern conditions could also be screened among C_4 plants, which grow best in the tropics and subtropics (below latitudes of 45°), have a good water use efficiency and which grow best in the high temperatures and produce high TS yields in warm conditions (Mahmood and Honermeier, 2012). The C_4 plants cannot produce feed or food in northern conditions, because the growing season is too short. The quantity of plants and crops increases the diversity of the fields, when also cultivating other crops like traditional grasses, maize and sugar beet.

The objective of this study was to screen novel annual and perennial plants for biogas production. The biomass yield, TS and volatile solid (VS) contents and the specific methane yields were determined from plants. From the most promising plant, brown knapweed, the effect of harvest time on the specific methane yield and methane yield per hectare was studied. Methane yield of brown knapweed and cow manure was studied in continuously stirred tank reactor (CSTR) co-digestion trial with different share of brown knapweed in the feedstock.

2. Methods

2.1. Plant materials

Nine different plants, which were weeds (2), tall annuals (3) and perennials (4), were used in this study. All plant material was cultivated at the research centre of MTT Agrifood research Finland in Piikkiö (N 6698258° E 2420427° Coordinate system EUREF –FIN ~WGS84) during years 2007–2010. The sowing and harvest time and fertilisation rate are presented at Table 1. Jerusalem artichoke (*Helianthus tuberosum*) (only stems) and sunflower (*Helianthus annuus*) were harvested in September in the year 2007. Brown knapweed (*Centaurea jacea*) was harvested at two different harvest times in June and August in year 2007. However, in the year 2008 brown knapweed was harvested four times (Table 1) to measure the optimal harvest time. Brown knapweed was harvested about 15 cm above ground, and a rosette of leaves was left to grow and produce the yield again. Sorghum (*Sorghum sudanese*) (C_4 plant) and Japanese millet (*Echinochola crusgalli*) (C_4 plant) were harvested only once in September in the 2008 (Table 1). In the year 2010 giant knotweed (*Fallopia sachaliensis*), giant goldenrod (*Solidago gigantea*), hemp-agrimony (*Eupatorium cannabinum*) and amaranth (*Amaranthus cruentus* var. *Oeschberg*) (C_4 plant) were cultivated and harvesting was done in August.

The experimental plots of the plants were harvested at 10 cm height and collecting by mowing machinery (Haldrup, Germany) and the harvest plot was 1.375 m $*$ 7 m. The fresh weight of the plant material was weighed (True test). After harvesting, the plant material was first cut using a chopper (SD 180 E, Wolf Garten, Germany) and after that cut with scissors circa 1 cm particle size in the laboratory. The materials were stored at 4 °C in a nitrogen atmosphere until used in the methane potential assays and analysis.

2.2. Batch assays

The specific methane yields were determined in triplicate by batch assays using 1 L glass bottles. The inoculum (average values from (4 batch of inoculums) different assays TS 5.7%, VS 4.7%, soluble chemical oxygen demand (SCOD) 228 mg/g TS, total nitrogen (N_{tot}) 40 mg/g TS and ammonium nitrogen (NH_4-N) 13 mg/g TS) was obtained from a farm digester treating cow manure, grass silage and industrial confectionary by-products (Laukaa, Finland). Firstly, 300 mL of inoculum was added to each bottle followed by the addition of substrate in a $VS_{substrate}/VS_{inoculum}$ ratio of 1 and were filled to a liquid volume of 750 mL with tap water. The methods have been described by Seppälä et al. (2009). Assays with inoc-