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Chemical composition and methane yield of reed canary grass as influenced by harvesting time and harvest frequency

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HIGHLIGHTS

- ▶ Harvest time and frequency had significant influences in methane yield.
- ▶ 45% more methane was produced in two-cut management compared to one-cut management.
- ▶ Chemical composition of biomass influenced concentration of methane in the biogas.
- ▶ Biogas produced from young biomass had lower fraction of CH_4 at the start of assay.

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ABSTRACT

This study examined the influence of harvest time on biomass yield, dry matter partitioning, biochemical composition and biological methane potential of reed canary grass harvested twice a month in one-cut (OC) management. The regrowth of biomass harvested in summer was also harvested in autumn as a two-cut management with (TC-F) or without (TC-U) fertilization after summer harvest. The specific methane yields decreased significantly with crop maturity that ranged from 384 to 315 and from 412 to 283 NL (normal litre) $(\text{kg VS})^{-1}$ for leaf and stem, respectively. Approximately 45% more methane was produced by the TC-F management (5430 Nm^3 ha^{-1}) as by the OC management (3735 Nm^3 ha^{-1}). Specific methane yield was moderately correlated with the concentrations of fibre components in the biomass. Larger quantity of biogas produced at the beginning of the biogas assay from early harvested biomass was to some extent off-set by lower concentration of methane.

1. Introduction

Biogas production by anaerobic digestion of various feedstocks has increased in recent years in European countries. Traditionally, biogas is produced from manure, industrial waste, and sludge but there is growing interest in using biomass from plants as energy rich substrate for biogas production (Amon et al., 2007; Gunaseelan, 2007; Chandra et al., 2012). In addition to biogas production, anaerobic digestion of biomass also produces digestate that can be used as a valuable fertilizer in crop production (Herrmann et al., 2012).

Although a wide range of agricultural crops and their residues can be used for biogas production, perennial grasses are considered as a better option because of their high biomass yield potential and little environmental impacts in crop cultivation (Lewandowski et al., 2003). Reed canary grass (RCG, *Phalaris arundinacea* L.) is one of the promising perennial grasses to be used as energy crop under Nordic climatic conditions because of its higher biomass yield potential in colder climate (Lewandowski et al., 2003; Wrobel et al., 2008). RCG can be cultivated in water logged peat soils in river valleys as it has aerenchymatous tissues that allow oxygen supply to the root system. Furthermore, RCG is a relatively short crop suitable to cultivate in river valleys where open landscapes are desired (Venendaal et al., 1997). In Denmark, commercial production of RCG for bioenergy purpose has not started yet but there is a growing interest to cultivate this crop for biogas production (Raju et al., 2011; Triolo et al., 2011).

Harvest time significantly influences biomass yield of RCG (Seppälä et al., 2009; Tahir et al., 2011). Moreover, chemical composition of the biomass changes significantly with crop development which subsequently may affect biodegradability and specific methane yield (Amon et al., 2007; Massé et al., 2010; Hübner et al., 2011). Less lignified biomass with high concentration of easily degradable components such as non-structural carbohydrates, soluble carbohydrates and soluble cell components is considered suitable for high specific methane yield (Seppälä et al., 2009; Massé et al. 2010; Triolo et al., 2011). Harvest time also affects the proportion of leaf and stem in harvested biomass

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(Hübner et al., 2011). Usually, the fraction of leaves in grasses decreases with increasing maturity. Biomass with higher proportion of leaves is considered better for biogas production as the leaves of the grasses are less lignified and they contain more protein than the stems (Bruinenberg et al., 2002). Thus, harvesting at early stage of crop development may provide a better quality of the biomass for biogas production, but the total methane yields per hectare may not be improved if the biomass yield at early harvest is too low (Schittenhelm, 2008; Massé et al. 2010; Hübner et al., 2011).

Therefore, it is important to determine the optimum stage of harvesting to balance the trade-off between quantity and quality of biomass for biogas production (Schittenhelm, 2008; Bruni et al., 2010). In case of perennial grasses like RCG and switchgrass, this trade-off could be avoided by harvesting biomass multiple times in a year where an increase in both biomass quality and yield may be achieved (Seppälä et al., 2009; Massé et al., 2010). However, the extra biogas produced by multiple harvesting should also pay for extra harvesting costs and probably also for increased fertilizer requirement (Reynolds et al., 2000). Moreover, the growing season should be long enough for sufficient regrowth of the plants when multiple harvesting is practiced. Under Danish climatic conditions, RCG normally starts to grow at the end of March and it starts to flower at the beginning of June. The growing season lasts until September which permits to harvest RCG at least two times in a year.

Although RCG is recognized as a candidate crop for biogas production in Denmark, there is no information available about the effect of harvesting time and harvest frequency management on methane yields. Knowledge on effects of harvest time and harvest frequency on dry matter partitioning, biochemical composition of the harvested biomass, and their subsequent effects on specific methane yield are still lacking. Therefore, this study aims to determine the influence of crop maturity and harvest frequency on aboveground biomass yield, dry matter partitioning, biochemical composition and biological methane potential of RCG biomass.

2. Methods

2.1. Field experiment and plant material

The experiments were conducted on a cultivated peatland located in Nørreå river valley of Denmark (56°44’N, 9°68’E) near to Viborg. Details of soil properties at the experimental site can be found in Kandel et al. (2012). In brief, average peat depth was more than 1 m, and bulk density at the surface of the peat (0–20 cm depth) was 0.29 g cm^{-3}. Total organic carbon (TOC) and total nitrogen (TN) at 0–30 cm depth were 38.5% and 3.2%, respectively.

The field was ploughed in 2009 and three large (18 × 24 m) plots were sown with RCG (cv. Bamse). RCG biomass was not harvested in the first year but it was harvested regularly from second year as green biomass in autumn. This experiment was performed in 2011, so the biomass in this experiment represents the biomass from the third year after establishment of the RCG stand. When regrowth of the RCG was observed after the winter, the three plots were fertilized with standard mineral fertilizer at a rate of 60–13–77 kg N–P–K ha^{-1} on 4 April 2011. Each large plot was divided into two subplots (18 × 12 m). An area of 5 × 4 m in each subplot was used for two-cut (TC) management and the rest of the subplot area was used for one-cut (OC) management (i.e., harvested once in a growing season). Aboveground biomass from an area of 1 × 1 m was harvested manually from each OC subplot area twice a month until the end of September 2011 to monitor the development in biomass yield and quality during growing season. A new 1 × 1 m area was selected on every sampling date. The reason for taking biomass samples from two subplots in a plot was to increase the representativeness of the large plot. Biomass harvest started very early in this experiment to obtain biomass with a broad range of chemical composition which would allow to better understand the effect of biochemical composition on biogas production. Ten tillers from each harvested sample were chosen randomly and leaves and stems were separated manually to determine leaf/stem ratio and dry matter partitioning. The panicle represented a very small portion of the plant (less than 15% in its maximum); therefore total culm including panicle is referred to as stem. The biomass was oven dried at 70 °C to constant weight for dry matter (DM) determination. Then the two subsamples taken from the two subplots of each plot were mixed well and ground in a mill with 1 mm sieve size for further analysis of chemical composition and biological methane production (BMP) as suggested by Hübner et al. (2011).

To study the effect of harvest frequency on dry matter yield and biogas production, biomass from the TC subplots was harvested on 15 June 2011 as a first cut of the TC management. After the summer harvest, one of the harvested TC subplots in each large plot was fertilized with an additional amount of 60–13–77 kg N–P–K ha^{-1} standard mineral fertilizer whereas the other TC subplot was left unfertilized. The objective of this fertilizer treatment was to understand the fertilization requirement of RCG for effective regrowth after summer harvest. Regrowth of RCG biomass in the TC subplots were harvested again on 22 September 2011 and the samples from both cuts were handled in a similar way as described previously. Biomasses harvested as regrowth in fertilized and unfertilized subplots are referred to as TC-F and TC-U, respectively. Biomass yield from the summer harvest and regrowth from the same plot were pooled to get the total biomass yield for comparison with the maximum biomass yield in OC management.

2.2. Biochemical analyses of the biomass

Part of the ground sample was used for biochemical composition analysis and another part was used for the BMP assay. The ash concentration was determined as the residue after incineration at 525 °C in a muffle furnace. Total nitrogen (N) and carbon (C) concentrations were determined by the LECO dry combustion system (LECO Corporation, St. Joseph, MI, USA). The C concentration was determined only in the biomass from last harvest in the OC management and from regrowth after first cut in the TC managements. Neutral detergent fibres (NDF), acid detergent fibres (ADF) and acid detergent lignin (ADL) of the plant samples were determined by the van Soest and Wine (1967) method with the Fibertec™ 2010 Systems (Foss Electric, Hillerød, Denmark). Cellulose was calculated as the difference between ADF and ADL, and hemicelluloses as the difference between NDF and ADF. The ADL was considered as lignin assuming that the fraction of lignin-bound nitrogen is trivial.

2.3. Inoculum preparation and properties

Inoculum for anaerobic digestion of the biomass was obtained from a post digestion tank of a mesophillic biogas plant at research centre Foulum, Denmark. The inoculum was degassed for 3 weeks before it was used in the BMP assays to ensure that the biogas production from the inoculum itself was minimal. The inoculum was further strained with a manual sieve with a mesh size of 500 μm (Retsch, Inc., Haan, Germany) to remove the solid fractions. Biophysical and biochemical analysis of the inoculum were performed after removing the solid fractions. The average pH of the inoculum was 7.74. The average total solid (TS) and volatile solid (VS) of the inoculum were 2.63% and 1.44%, respectively. The average total ammoniacal nitrogen (TAN) in the inoculum was 1.78 g L^{-1} and total volatile fatty acid (VFA) was 111 mg L^{-1}.