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Storing energy crops for methane production: Effects of solids content and biological additive

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Abstract

The effect of storage on chemical characteristics and CH_4 yield (taking into account loss of VS during storage) of a mixture of grasses and ryegrass, ensiled as such (low solids content) and after drying (medium and high solids) with and without biological additive, were studied in field and laboratory trials. Up to 87% and 98% of CH_4 yield was preserved with low solids grass (initial TS 15.6%) and high solids ryegrass (initial TS 30.4%), respectively, after storage for 6 months, while under suboptimal conditions at most 37% and 52% of CH_4 yield were lost. Loss in CH_4 yield was mainly due to VS loss, presumably caused by secondary fermentation as also suggested by increasing pH during storage. Biological additive did not assist in preserving the CH_4 yield.

Keywords: Anaerobic digestion; Biogas; Energy crop; Grass; Storage

1. Introduction

Renewable energy can be produced from crops through different conversion processes. CH_4 production through anaerobic digestion appears to be a competitive concept in both energy efficiency and environmental impact comparison studies (e.g. Fredriksson et al., 2006). Anaerobic digestion appears as a widely applicable technology, as it can use various crops and wastes as substrates and nutrients can be recirculated. The valuable gaseous end-product, CH_4, is a flexible energy carrier which can be used for heat, power and traffic biofuel production (e.g. Plöchl and Heiermann, 2006).

It has been proposed that 1545 million tons of agricultural biomass, half in the form of energy crops, could be used for CH_4 production each year in the European Union (Amon et al., 2001). In Europe, especially in Austria and Germany, the biogas production is tightly linked to agricultural sector (Plöchl and Heiermann, 2006). For example, up to 4000 m^3 of CH_4 could be obtained from 1 ha of grass cultivated in Finland (Lehtomäki et al., in press) and up to 9000 N m^3 from maize cultivated in Austria (Amon et al., 2007). Grasses are classified among potential crops for biogas production in northern conditions due to their potential high CH_4 yield per hectare and suitability in current agricultural cultivation, harvest and storage practices (e.g. Lehtomäki et al., in press).

Energy crops can rather easily be stored so that energy can be produced throughout the year and/or when the demand and/or price for energy are highest. Crops contain high amounts of non-structural carbohydrates which are easily degradable and thus can be lost during processing and suboptimal storage conditions. Ensiling is a traditional way of storing fodder crops and may also suit energy crops used for CH_4 production (Egg et al., 1993). Ensiling is a biological process during which LAB break down the sugars in the crop (lactic acid fermentation) and lower the pH to a level inhibitory to other bacteria (McDonald et al.,

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Nomenclature

CFU	colony-forming unit	oww	original wet weight
FID	flame ionization detector	SCOD	soluble chemical oxygen demand
GC	gas chromatograph	TCOD	total chemical oxygen demand
h	hour	TS	total solids
LAB	lactic acid bacteria	VFA	volatile fatty acid
NH_4-N	ammonium nitrogen	VS	volatile solids
N_{tot}	total nitrogen	WSC	water soluble carbohydrates

1991). During storage, it is important to minimize energy losses, and ensiling has been shown to conserve over 90% of the energy content of crops (Egg et al., 1993). Both fresh and ensiled grass species have been found suitable for biogas production in previous studies (Mähnert et al., 2002, 2005).

Ensiling is affected by several factors such as the solids content (i.e. moisture content) and chemical characteristics of the crop in question. Previous studies, performed mostly with fodder crops, have shown that the solids content of silage can be controlled by the stage of maturity of the crop, by pre-wilting (Egg et al., 1993) and by using an absorbent during ensiling (Singh et al., 1996). The solids content of the crop to be ensiled affects the total bacterial count and the rate of fermentation, which is usually more restricted the higher the solids content, as reflected in higher pH, higher soluble carbohydrate values, lower levels of lactic, acetic and butyric acids, and inhibition of the deamination of amino acids (McDonald et al., 1991). With low solids content pH critical for well preserved silage is lower compared to that in high solids contents. For grasses with dry matter content of 20% the critical pH has been found to be 4.0. Unless the soluble carbohydrate levels are very high, the ensiling of crops with a low solids content will encourage a clostridial fermentation, resulting in energy losses and a silage of low nutritional value (Egg et al., 1993; McDonald et al., 1991). During the storage of low solids crops baling might be impossible due to leachate formation. It has been assumed that leachate would not be formed, if crops are dried to a TS content of 29% or above and that overall losses of solids would be minimized around a TS content of 25–30% (McDonald et al., 1991). In contrast, if the pre-wilting period is too long, respiration will cause energy losses and the sugar content of the crop may fall. Moreover, high solids crops are also susceptible to mould (Buxton and O'Kiely, 2003). When the crops are used for energy production, ensiling conditions do not necessarily have to be as strictly controlled as with fodder crops. Field drying can lower transportation costs since much less water would be transported with the biomass; however, the savings in transportation must be balanced with the dry matter losses that occur during field drying (Egg et al., 1993). To our knowledge the effect of initial solids (TS) content on ensiling and CH_4 production has not been reported earlier.

Different kind of additives can be used to promote the ensiling process. Addition of acid lowers the pH; however, acids may cause corrosion of equipment and health problems. Enzymes enhance the hydrolysis of crop material and subsequently increase the content of sugars convertible by LAB. Bacterial inoculants can be used to increase the amount of LAB, and in combination with the addition of enzymes and LAB, enzymes degrade the plant cell wall and release carbohydrates for lactic acid fermentation (McDonald et al., 1991). Some authors suggest the use of these inoculants in the storage of grasses (e.g. Lehtomäki et al., submitted for publication).

The objective of this study was to evaluate the effect of storage (2–11 months) with and without biological additive containing both enzymes and LAB in boreal field conditions and in the laboratory on the CH_4 yield and chemical characteristics of a mixture of grasses (timothy, red clover and meadow fescue) and ryegrass, considered suitable for CH_4 production. Also the effect of drying, i.e., initial solids content was studied in the laboratory.

2. Methods

2.1. Substrates

The substrates used were (1) a mixture of timothy (*Phleum pratense*, 63% of seed mixture), red clover (*Trifolium pratense*, 17%) and meadow fescue (*Festuca arundinacea*, 20%), henceforth grass, and (2) ryegrass (*Lolium multiflorum*, 17% of seed mixture, 83% oat, *Avena sativa*, harvest was mainly composed of ryegrass as oat was only used as a companion crop and was harvested at the first harvest in June) harvested (Laukaa, Finland) in June (grass) and in August 2005 (ryegrass) for field and in September for the laboratory trials.

2.2. Laboratory trials

Crop material was first chopped with a garden chopper to ca. 5 cm particle size. Part of the chopped material was spread on top of a plastic net and dried in a thin layer for 24 and 48 h at 20 °C, while part of the material was used fresh.

Biological ensiling additive (Josilac, manufacturer Josera Erbacher GmbH & Co) containing both LAB (*Lactoba-*