Storage and pretreatment of grass for from extensive lowland areas used in a biogas plant

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Abstract

Storage experiments with airtight storage of 3 different grass species, Tall Fescue, Festulolium and Reed Canary Grass showed results on losses similar to what is seen when traditional grass for cattle feed is being ensiled. Without additives the recorded dry matter loss was 3.5 - 6.5% on average in trials with different storage period. Using additives is a well-known method to control the ensiling process and reduce storage losses. Two additives, Sill-All Fireguard and Biotal Axcool Gold have been tested. The dry matter losses were slightly lower, 2.3 - 5.0% and 3.6 - 5.6% for respectively Sill-All Fireguard and Biotal Axcool Gold treated batches. The found differences were not significant.

Comparing fresh grass, hay and silage, the highest specific methane yields were obtained from the silage. Airtight storage may thus be an appropriate storage method for meadow grass as it make it make all year supply to the biogas plan possible and at the same time the biogas potential is improved.

Extruding and briquetting are pretreatment technologies that might be advantageous for grass used in biogas plants due to higher methane yield and easier handling. The energy consumption for extruding and briquetting were 24.8kWh and 98.2kWh per ton respectively. These technologies may be beneficial, but the energy consumption is significant compared to the increased biogas yield.

Keywords: meadow grass, wet land, biomass, pretreatment, biogas production, methane yield.

1. Introduction

The results presented are a part of a project with focus on biomass from extensive lowland areas. The project aims to develop and demonstrate solutions for production, harvest, transport, storage, processing and use of the biomass primarily for energy and fertilizer. The technological methods and solutions described here focus on systems for storage and pretreatment of different species of meadow grass in order to achieve high energy production when used in a biogas plant.

The running of a biogas plant demands regular intake of feedstock. When the feedstock is crops, energy crops or grass from extensive lowland areas the crops are only harvested one or a few times a year. Storage for a shorter or longer period is in that case necessary. To ensure running of the plant, there is a need for efficient supply chains including harvest, transport, storage, preservation and pretreatment of the feedstock. Low-loss storage and preservation of whole crop plant material is essential for economical and well suited use of plant biomass as feedstock in a biogas plant (Herrmann et al., 2011 and Blokhina et al., 2011).

Only a few studies have been made on ensiling used for the preservation and storage of energy crops and extensive grown biomass as grass from wet lowlands areas. However, the process of ensiling is well known for ordinary cattle feed crops such as maize, cultivated grass, whole crop grain etc. (Kristensen, 2010). For these crops the ensiling process is a suitable storage method. Well managed it is a cost efficiency method and the dry matter losses as well as the losses related to feeding value is limited, only a few percent.

The ensiling process is divided into phases or steps. After a short aerobic phase where the present oxygen is used for respiration, the fermentation starts. This process formats lactic acids and thereby lowering the pH to a value below 4.5. The low pH level prevents growth of detrimental microorganisms and yeasts. If the conditions are optimal, this phase with low pH is reached within a few days. After this, the material is in a stable phase until the take out. Anaerobic conditions and the fast production of laic acids are essential for a secure preservation of nutrients, dry matter and energy content. In order to secure or control the ensiling process additives have been introduced. The additives are used for restrict undesirable fermentation processes or aerobic deterioration. The additives may consist of hetero- or homo-fermentative lactic acid and bacteria.

For the storage alone, the ensiling and making silage of the grass biomass can be an appropriate method. In addition, studies have shown that ensiling also may be seen as a pre-treatment of grass crops which can have a positive effect on the biogas potential in the way of a higher methane yield (Herrmann et al., 2011). In order to assess the effect of the ensiling process for meadow grass grown on extensive cultivated low land areas anaerobic digestion experiments were conducted. The experiments have included the use of silage additives as well as different storage periods and grass quality hence different harvest dates.

Extruding is another pre-treatment that might be used for straw, grass and similar biomass for biogas production. The effect of extrusion as pretreatment on wheat straw and deep litter has been evaluated in a study conducted at Aarhus

University, Department of Engineering. In the study five screw configurations of the extruder were tested, namely, mild kneading, long kneading reverse, kneading and reverse, and kneading with reverse. Energy consumption, temperature, and residence time of samples during extrusion were measured. The results showed an increment in methane yields of about 4-29 and 1-16% of extruded samples after 28 and 90 days of anaerobic digestion, respectively (Wahid et al., 2015). Based on these positive results, it was assumed that the extruding process also will be a relevant pre-treatment method for biomass from the extensive cultivated meadow areas. Therefore trials with extrusion of the meadow grass were included. The focus was on engineering solutions, capacity and energy consumption for the process.

Briquetting of straw and similar biomass is mainly seen as a method to increase the bulk density or the material. Thereby handling, transport and storage can be made more effectively and the costs can be reduced (Lin et al., 2015). However, briquetting can also be an advantageous pre-treatment of biomass for biogas production. Research has shown that the methane yield of wheat straw increased with the use of briquettes instead of traditional shredded wheat straw (Moset et al 2015). Only relative dry biomass can be used in the briquetting process. Thus, fresh harvested grass has to pass a drying process before the briquetting can be made. Meadow grass dried on swath in the field has been used for a briquetting trial.

2. Materials and Methods

2.1. Experimental field and biomass

The grass used for the experiments on storage, silage and testing of pre-treatments processes were harvested on an experimental field located in Nørreådalen near the city Viborg. The soil consists of very moist but drained peat land near to a stream.

A total of 3 different grass species were included: Tall Fescue, Festulolium and Reed Canary Grass. The growing experiments were made with replicates, - three experimental plots for each grass specie. The gross area of each experimental plot was 432 m^2. Prior to the silage experiments grass from the 3 plots were mixed. Thus no growing or field variations are included in these experiments. Harvest was made two times per year. First cut in June and second cut in October.

2.2. Ensiling experiments

The ensiling was carried out as pilot-scale experiments. At harvest the grass was chopped with a conventional JF forage harvester type FCT 90. The theoretical chopping length was set at 10 mm. Immediately after harvest the grass was put into 60 liters barrels, compressed manually, and the filled barrels were closed airtight. The amount of grass in each barrel was determined by weighing, and representative samples for determining the dry matter content and the methane yield before storage was taken. The material was then stored for 4 months, 6 months and 9 months respectively before the barrels was opened. When opened, the biomass was weighed and representative samples were taken for determination of dry matter content and laboratory analysis for methane yield. There were made triplicates of each combination of grass species, storage period, harvest date and additive. Additives were mixed manually into the grass. Standard dosages specified by the manufacturer of the additive were used. The following grass species and treatments were included:

- Tall fescue
- Festulolium
- Reed Canary Grass
- Control without silage additive
- Additive 1: Sill-All Fireguard, (Homofermative lactic acid bacteria. Cellulase. Amylase. Sodium benzoate and Potassium)
- Additive 2: Biotal Axcool Gold (Hetero- and homofermative lactic acid bacteria. Xylanase. Beta-glucanase)

2.3. Extruding

The extruding was made in a full scale co-rotating twin screw extruder. The stated capacity of the extruder was 1250 kg h^{-1} (55% dry matter content). Figure 1 shows a photograph of the extruder and the mixer for feeding in the biomass and a close up of the screws in the machine. The dry matter content of the treated grass was determined and the machine capacity and energy consumption was measured. The energy consumption was recorded separately for the core extruder and the feeding system consisting of mixer, shredder and feed conveyor.

Figure 1. The extruder and the mixer for feeding in of biomass. At the right, a look into the mixer and a close up photo of the two co rotating screws.

2.4. Briquetting

Shredding and briquetting was performed by means of full scale equipment. A BP 6500 briquetting unit from the company CF Nielsen was used for briquetting. The machine was linked to a Cormall hammer mill type HDH 770 with a 20 mm sieve (Cormall Agro Holding A/S, Denmark). The stated capacity of the briquetting machine was 900–1400 kg h^{-1} producing cylindrical briquettes with 68 mm diameter. Figure 2 shows a photograph of the hammer mill, the CF Nielsen briquette machine and produced briquettes.

Figure 2. The shedding and briquetting set up. At the right, the produced briquettes.

The dry matter content of the treated grass was determined prior to the test. For a test period of about 5 hours the machine capacity and energy consumption was measured. The diameter and density were determined for a representative sample of the produced briquettes.

3. Results and Discussion

The results on recorded storage losses on the grass harvest in June (first cut) are shown in the tables 1-3. The loss is stated as loss in mass and loss in dry matter content. The initial moisture content of Tall Fescue was 69.7%, initial moisture content of Festulolium 69.6% and initial moisture content of Reed Canary Grass was 59.9%

Table 1. Storage loss of Tall Fescue, Festulolium and Reed Canary Grass silage with and without silage additive ensiled for a storage period of 144 days

Harvest June 2015	Sampling October 2015		
Grass species	**Additive**	**Mass loss, %**	**Dry matter loss, %**
Tall Fescue (strandsvingel)	No additive	1.9	7.1
Festulolium (rajsvingel)		1.4	8.2
Reed Canary Grass		0.0	4.1
Avg.		***1.1***	***6.5***
Tall Fescue	Sill- All	1.0	5.6
Festulolium		1.4	7.2
Reed Canary Grass		1.2	2.2
Avg.		***1.2***	***5.0***
Tall Fescue	Biotal Axcool	0.7	2.1
Festulolium		0.7	7.9
Reed Canary Grass		0.9	6.8
Avg.		***0.8***	***5.6***

Table 2. Storage loss of Tall Fescue, Festulolium and Reed Canary Grass silage with and without silage additive ensiled for a storage period of 223 days.

Harvest June 2015	Sampling January 2016		
Grass species	**Additive**	**Mass loss, %**	**Dry matter loss, %**
Tall Fescue (strandsvingel)	No additive	-0.2	2.7
Festulolium (rajsvingel)		-2.2	7.9
Reed Canary Grass		-0.2	2.7
Avg.		***-0.9***	***4.5***
Tall Fescue	Sill- All	-0.9	1.4
Festulolium		0.6	6.4
Reed Canary Grass		-1.4	-0.9
Avg.		***-0.6***	***2.3***
Tall Fescue	Biotal Axcool	0.2	6.1
Festulolium		0.0	8.2
Reed Canary Grass		-3.4	2.2
Avg.		***-1.0***	***5.5***

Table 3. Storage loss of Tall Fescue, Festulolium and Reed Canary Grass silage with and without silage additive ensiled for a storage period of 304 days.

Harvest June 2015	Sampling April 2016		
Grass species	**Additive**	**Mass loss, %**	**Dry matter loss, %**
Tall Fescue (strandsvingel)	No additive	0.0	3.4
Festulolium (rajsvingel)		-0.2	6.8
Reed Canary Grass		0.9	0.2
Avg.		***0.2***	***3.5***
Tall Fescue	Sill- All	0.4	2.9
Festulolium		-0.2	5.7
Reed Canary Grass		0.0	-1.9
Avg.		***0.1***	***2.3***
Tall Fescue	Biotal Axcool	0.0	-0.3
Festulolium		0.2	7.0
Reed Canary Grass		0.2	4.0
Avg.		***0.2***	***3.6***

In general, the values on mass loss were low, and of no practical importance. The registered differences may be explained by experimental variation and the weighing accuracy. However, some dry matter losses were recorded due to increased moisture content during the storage. The increase in moisture content was in the range from 0.2 up to 2.9 percentage point. In other studies a prolonged storage period resulted in increased losses (Herrmann et al., 2011). This could not be confirmed by these experiments. For the silage batches without additives, the dry matter loss was 6.5, 4.5 and 3.5 % after 144, 223 and 304 days storages respectively.

Besides storage duration the use of additives was expected to influence the ensiling process and reduce losses. Treatment with the additive Sill-All Fireguard decreased dry matter losses 1.2 – 2.2 percent point. The measured decrease in dry matter loss was not statistical significant (P 95%). Treatment with the additive Biotal Axcool Gold gave no clear effect on the losses. Comparing to other studies with ensiling of maize, grass and whole crop grain storage losses about 5% is fully acceptable and to be expected for ensiling and storage during a period of 4 – 10 months (Kristensen, 2010).

Grass quality, e.g. sugar- and protein content, is essential to the ensiling process. For the experiments a different grass quality was obtained by using grass from the second cut, harvested 1. of October. From second cut only the species Tall Fescue was used for the ensiling and storage experiments. After a storage period of 6 months losses and methane yield were measured. The mass loss was about 2 % and the dry matter loss was about 29 %. No significant differences in losses were found between batches with additives and the batches without additives. Probably due to a pour grass quality the ensiling process was not quit satisfactorily, and substantial increased moisture content after storage was seen. The initial moisture content was 68.2 % and after storage the average moisture content for al batches was 75.3 %.

The methane yield determined in batch anaerobic digestion tests of the silage is shown in figure 3.

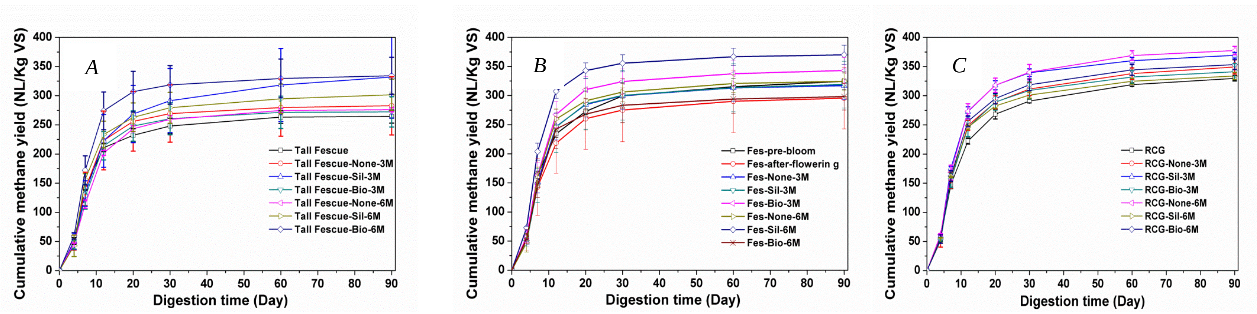

Figure 3. Methane yield determined in batch anaerobic digestion test for fresh grass, silage stored 3 month and silage stored 6 month. *A* Tall Fescue, *B* Festulolium and *C* Reed Canary Grass.

Only results for 2 storages periods for each grass species are shown as the tests on silage stored for 10 months still are ongoing. Cumulative methane yield in the batch test on 10 month stored silage show after 20 days about 300 Nl $kg(VS)^{-1}$ for Tall Fescue and Festulolium and about 250 Nl $kg(VS)^{-1}$ for Reed Canary Grass.

Methane formation in the tests was affected by the ensiling process. Methane yields in the fresh grass (cumulative yield after 90 days) ranged between 264 and 330 Nl $kg(VS)^{-1}$. For silage without additive methane yields ranged between

282 and 377 Nl kg(VS)$^{-1}$. For silage with additive Sill-All Fireguard methane yields ranged between 332 and 370 Nl kg(VS)$^{-1}$. For silage with additive Biotal Axcool Gold methane yields ranged between 334 and 353 Nl kg(VS)$^{-1}$. Generally, ensiling resulted in increased methane yield of 0 to 26%. Increased methane yields in silage when dry matter content determination - as in this study – is based on own drying method may be slightly overestimated. When dry matter in silage is determined by drying, volatile components e.g. alcohols and organic acids are evaporated although these components contribute to the formation of methane in the batch tests. However, the corrections fond in similar studies are small compared to the increased methane yields found is this study.

The extruding was made on Tall Fescue harvested in June 2015. Results on capacity and energy consumption of the process are stated in the table 4.

Table 4. Extruding of meadow grass. Grass specie: Tall Fescue. Moisture content of the grass: 74.0%

	Capacity ton/h	Power kW	Energyconsumption kWh/ton
Extruder	3.37	47.5	14.2
Shredder and feeding system	3.37	35.7	10.6
Extruder incl. shredder and feeding system	3.37	83.2	24.8

The total energy consumption for the extruding process was 24.8 kWh per ton (WB). The effect of this pre-treatment on the methane yield determined in batch anaerobic digestion tests of the extruded grass is shown in figure 4.

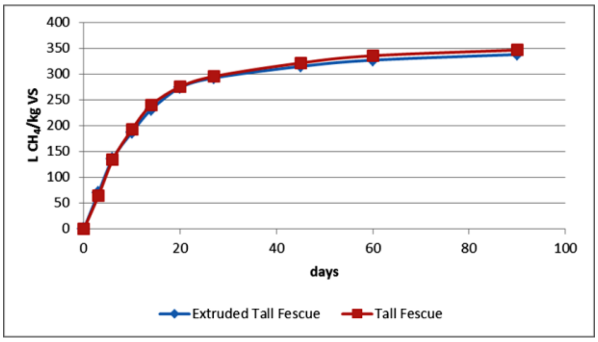

Figure 4. Methane yield determined in batch anaerobic digestion test for fresh grass and extruded grass (Tall Fescue).

Extrusion is an energy intensive pre-treatment, like the extruder equipment is costly. As it is evident from figure 4, in this study there could not be documented an increased methane production by the process. Increased methane yield of 1 to 16% after 90 days have been found by other similar studies (Wahid et al., 2015). The applied fresh grass was of a good quality in respect to biogas production even without any pre-treatment. Grass having lower degradability might be more affected by the extruding.

Results from the experiments on briquetting are shown in the table 5.

Table 5. Briquetting of meadow grass. Grass dried on swath in the field and balled in square big bales. Moisture content of the grass: 14.4%

	Capacity ton/h	Power kW	Energy consumption kWh/ton
Briquette press	0.63	24.4	38.8
Shredder and hammer mill	0.57	33.8	59.4
Briquetting incl. shredder and hammer mill		58.2	98.2

Briquetting is in the same way as extruding an energy intensive method for pre-treatment. The method can only be used for dry material. The total energy consumption for the whole process including shedding of balled grass, milling by means of a hammer mill and the briquetting was 98.2 kWh per ton (WB). Compared to briquetting of wheat straw the obtained capacity was low. On average a capacity of 0.6 ton per hour were measured on briquetting of balled meadow grass. The bulk density of the produced briquette was 275 kg per m^3. Wet spots in the bales will block the milling or transport system. No test on methane or biogas potential of the briquettes was made. From similar studies a 3-5 percent surplus methane yield have been reported on briquetting of organic plant material (Xavier et al., 2015).

4. Conclusions

Continuous operation of a biogas plant requires regular in-take of feedstock, - biomass or other organic material. When the feedstock is crops, energy crops or grass from extensive lowland areas the crops are only harvested one or a few times a year. Storage for a shorter or longer period is thus necessary. Ensiling is found to be an appropriate method for storing of meadow grass for from extensive lowland areas. Comparing fresh grass, hay and silage, the highest methane yields were obtained from the silage.

The ensiling process and storage of the silage will cause dry matter losses. Storage of silage based on the grass species, Tall Fescue, Festulolium and Reed Canary Grass grown on a wet peat soil reveals dry matter losses similar to what is seen when traditional cultivated grass for cattle feed is being ensiled. Dry matter loss at 2.3 up to 6.5 percent occurs. Silage additives might increase the ensiling process and secure stable silage conditions. However, this study gives no clear significant documentation of reduced losses by use of additives.

Briquetting and extruding is energy intensive methods for pre-treatment. The technique can be used for meadow grass from extensive lowland areas. The energy consumption for extruding moist meadow grass is 24.8 kWh per ton at a capacity of 3.37 $tonh^{-1}$. The energy consumption for briquetting dry meadow grass is 98.2 kWh per ton at a capacity of 0.6 $tonh^{-1}$. For extruded grass no significant differences in methane yield could be seen from this study.

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References

Blokhina, Y.N; Prochnow, A; Plöchl, M, Luckhaus, C; Heiermann, M, 2011. Concepts and profitability of biogas production from landscape management grass. Bioresource Technology, 102 (2011), pp. 2086–2092

Herrmann, C ; Heiermann, M; Idler, C, 2011. Effects of ensiling, silage additives and storage period on methane formation of biogas crops. BIORESOURCE TECHNOLOGY . Volume: 102. Issue: 8. Pages: 5153-5161

Menardo, S; Balsari, P; Tabacco, E; Borreani, G, 2015. Effect of Conservation Time and the Addition of Lactic Acid Bacteria on the Biogas and Methane Production of Corn Stalk Silage. BIOENERGY RESEARCH Volume: 8 Issue: 4 Pages: 1810-1823

Kristensen, N.B, 2010. Ensilering af majs og græs. Aarhus universitet. Det jordbrugsvidenskabelige fakultet, institut for Husdyrbiologi og Sundhed. Intern Rapport, Husdyrbrug nr 21.

Lin, T., Rodríguez, L.F., Davis, S., Khanna, M., Shastri, Y., Grift, T., Long, S., Ting, K,C. 2015. Biomass feedstock preprocessing and long-distance transportation logistics. Global change biology. Bioenergy (1757-1693), 8 (1), p. 160.

Moset, V; Neves, X.C.A; Moller, H.B, 2015. Optimization of methane yield by using straw briquettes- influence of additives and mold size. INDUSTRIAL CROPS AND PRODUCTS Volume: 74 Pages: 925-932

Wahid, R; Hjorth, M; Kristensen, Simon; Moller, H.B, 2015. Extrusion as Pretreatment for Boosting Methane Production: Effect of Screw Configurations. ENERGY & FUELS Volume: 29 Issue: 7 Pages: 4030-4037

Xavier, C.A.N; Moset, V; Wahid, R; Moller, H.B., 2015.The efficiency of shredded and briquetted wheat straw in anaerobic co-digestion with dairy cattle manure. BIOSYSTEMS ENGINEERING Volume: 139 Pages: 16-24