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Farm-scale anaerobic storage and aerobic stability of high dry matter perennial grasses as biomass feedstocks

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ABSTRACT

Research was conducted to determine the feasibility of using a chopped harvest and anaerobic storage system to conserve mature, high dry matter (DM) switchgrass and reed canarygrass intended as cellulosic biomass feedstocks. The grasses were anaerobically stored in farm-scale silo bags for over 220 days. Switchgrass DM content was either 459 or 566 g kg^{-1} and reed canarygrass DM content was 525 g kg^{-1}. Average storage losses were 27 and 22 g kg^{-1} of DM for switchgrass and reed canarygrass, respectively. Additional DM loss after two- and seven-day aerobic exposure was 16 and 23 g kg^{-1} or 11 and 19 g kg^{-1} for switchgrass and reed canarygrass, respectively. On-harvester inoculation with a combination of homofermentative (*Pediococcus pentosaceus*) and heterofermentative (*Lactobacillus buchneri*) bacterium increased the production of both lactic and acetic acid during storage and in some situations produced lower yeast and mold populations during aerobic exposure. Inoculation improved aerobic stability in reed canarygrass and the high DM switchgrass. Fermentation products were less than 25 g kg^{-1} for both grasses. Average recovery of cellulose and hemicellulose was 97% of initial mass. Anaerobic storage of chopped, inoculated, high DM, mature perennial grasses was shown to be a viable cellulosic biomass feedstock logistics system.

1. Introduction

Perennial grasses intended as cellulosic biomass feedstocks are typically stored aerobically as dry bales. When dry bales will be made, the mass fraction of water must be less than 20% to reduce the risk of detrimental biological activity in the stored bales [1,2]. Although perennial grasses like switchgrass (SWG) and reed canarygrass (RCG) dry more readily than typical forage crops [1], field drying of perennial grasses harvested late in the season can still be difficult because of high yields and poor ambient conditions at harvest [1]. Field drying is costly in terms of weather risks, energy inputs, and harvest timeliness. Drying of cellulose microfibrils results in the irreversible shrinking of the pore space and reduces the accessible surface area resulting in a feedstock that is more resistant to enzymatic degradation [3]. Alternatively, harvesting moist perennial grasses by chopping and preserving by ensiling can reduce field wilting time and associated weather risks; produce a size-reduced flowable material at harvest; achieve greater productivity than baled systems; reduce negative consequences of cell wall hornification; and

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reduce biorefinery water requirements. Direct-cut harvest may also be possible with this system, which would further improve timeliness, reduce weather risk and decrease chances for soil contamination. The above listed attributes must more than offset the added cost of transporting material with low-bulk density and high-moisture, both of which reduces the mass of dry matter (DM) shipped per truckload.

By size-reducing and processing grasses in the field with existing forage harvesting equipment and sending a uniform product to the storage site or biorefinery, the complexities associated with processing dry bales are eliminated [4]. Moist feedstocks can be harvested over a longer period and the machinery can be used to harvest many other crops, so the greater fixed costs of high capacity forage harvesting equipment can be diluted across more land area and time compared to dry bale equipment [5–7].

When the reduction in value from storage losses of outdoor stored bales is considered, the total cost of bales stored outdoors may be more than other more capital intensive systems [5–7]. Greater material degradation and DM loss occurs as the bales are stored longer. However, feedstocks will be needed during months outside of their seasonal availability; so long storage periods will be required [8]. DM losses of SWG ranged from 50 to 130 g kg^{-1} for bales stored outdoors over 12 months in Pennsylvania [9]. Dry bales of SWG and RCG stored outdoors for 9–11 months averaged 75, 87 and 149 g kg^{-1} DM loss for bales wrapped with net wrap, plastic twine, and sisal twine, respectively [1].

Storing biomass feedstocks anaerobically as silage is one way to ensure feedstock conservation for an extended period of time [1,2,10]. Average DM losses of 11 g kg^{-1} were achieved in ensiled bales of SWG and RCG between 530 and 660 g kg^{-1} DM content [1]. Low DM losses (between 10 and 50 g kg^{-1}) for ensiled, moist corn stover have been achieved at both lab- and farm-scale [2,10–12]. The addition of biological amendments to corn stover before ensiling improved conservation [11]. In addition to conserving feedstock value during storage, care needs to be taken to minimize aerobic degradation once the feedstock is removed from storage. Little research has been conducted on the aerobic stability of ensiled biomass feedstocks, however aerobic spoilage during feed-out has been known to represent up to 30–40% of total animal feed DM [13].

Biomass feedstocks must be transported off the farm and transportation costs can be reduced when the dry mass transported is maximized. From this standpoint, conserving biomass feedstocks by anaerobic storage at 500–700 g kg^{-1} DM content was shown to be economically desirable [7]. However, there is little published research concerning the on-farm conservation of chopped, mature SWG or RCG intended as a biomass feedstock at these DM contents. Research concerning conservation of perennial grasses intended as a biomass feedstock by ensiling has been limited, with most work using SWG or RCG at DM contents less than 500 g kg^{-1} [14–17].

The objectives of this research were to quantify the anaerobic storage characteristics of high DM content, mature SWG and RCG intended as biomass feedstocks; to conduct the research at the farm-scale; to investigate a biological amendment to improve conservation and aerobic stability; and to quantify the aerobic stability of the perennial grass feedstocks at removal from storage.

2. Materials and methods

2.1. Harvest

The two perennial grasses were used (RCG – *Phalaris arundinacea* – Palaton variety and SWG – *Panicum virgatum* L. – Shawnee variety) which were established in 2005 [1]. Two DM contents were targeted at harvest: approximately 600 and 500 g kg^{-1} (high and low DM content). The RCG and SWG were cut and swathed using a John Deere model 4990 windrower on August 31 and September 18, 2010, respectively. The grasses required one day of field wilting to achieve the target DM contents. After field wilting, the crop was harvested the day after cutting with a John Deere model 7800 self-propelled forage harvester (SPFH) equipped with a windrow pick-up. A heavy rainstorm prevented the harvest of the high DM RCG. The harvester theoretical-length-of-cut (TLC) was 12 mm. Crop yield averaged 7.4 and 8.5 Mg DM ha^{-1} for the RCG and SWG, respectively. Both grasses were mature at harvest and were in the seed ripening stage [18].

In addition to the two DM content treatments, a biological amendment was investigated. Biotal 500 (Lallmand Animal Nutrition Biotal 500 containing *Lactobacillus buchneri* 40788 (LB) and *Pediococcus pentosaceus* 12455 (PP)) was applied at harvest. The bacterial inoculants were applied using an on-harvester Dohrmann model DE-1000 inoculant applicator. The applicator was set to deliver approximately 100,000 cfu/g PP and 400,000 cfu/g LB. Untreated control treatments were also harvested. Random chopped samples of all treatments were taken for later analysis of particle-size following ASABE Standard S424.1 [19].

2.2. Storage and removal

The silo bags for this research were made using a modified Ag Bag model CT-5 bagger [20]. Harvested material was transported to the storage location, and randomly collected subsamples of about 2 kg were placed into polypropylene mesh bags measuring 53 cm by 80 cm with 10 mm mesh (McMaster-Carr part no. 9883T53). Before placing these replicate subsample parcels into the silo bag to quantify storage characteristics, four subsamples were collected from each parcel. Two subsamples were oven dried for moisture content determination at 103 °C for 24 h and two subsamples dried at 60 °C for 72 h for constituent determination, following ASABE Standard S358.2 [21]. Wireless temperature data loggers (Onset model UA-001-08) were placed in every other parcel to monitor temperature at a sampling rate of four times per day. Before the subsample parcels were placed in the silo bag, they were weighed to the nearest 0.005 kg. Six replicate parcels were used in each treatment.

Two silo bags were made, one each for the RCG and SWG. The RCG silo bag contained only the low DM content material with LB + PP treated material and the untreated control. The SWG bag had these two treatments at the two targeted DM contents. In either bag, each of the treatments were split into thirds and placed in three replicate locations in the silo bag. Sacrificial material was placed in the beginning and end of the bag and between treatments to reduce edge effects.