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High dry matter whole-plant corn as a biomass feedstock



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ABSTRACT

This research investigated the harvest, ambient pre-treatment, and storage of whole-plant corn as an alternative to conventional systems where corn grain and stover are fractionated at harvest. Harvesting the whole-plant, both grain and most of the above ground stover, after physiological maturity can reduce the intense logistics challenges typically associated with corn harvest and expand the harvest window. To determine the feasibility of the proposed system, corn was harvested at 350–840 g kg⁻¹ whole-plant dry matter (DM) using a forage harvester and then ensiled in pilot-scale silos. Ambient pretreatment during storage was investigated using both dilute acid and lime. Both pretreated and control whole-plant silages were very well conserved during anaerobic storage with DM losses generally less than 40 g kg⁻¹. Hydrodynamic separation of the grain and stover fractions after storage was found to be more effective at fractionating starch and fiber than conventional dry grain harvest, and both fractions had desirable composition. The effects of pretreatment on the silage were very pronounced at 30 and 100 g (kg DM)⁻¹ sulfuric acid loading with less than 100 g (kg DM)⁻¹ of the hemicellulose still bound in the cell wall at DM contents greater than 500 g kg⁻¹. The whole-plant harvest and storage system was shown to be a viable alternative to conventional corn grain and stover systems for producing feedstocks for biochemical conversion.

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1. Introduction

A new corn harvest and storage system is proposed which intends to lower the cost of both the starch and cellulose fractions destined for ethanol production. This “single-pass; whole-plant” system eliminates many non-value added operations and simplifies the traditional fractionated systems into these major operations: whole-plant harvest with a forage harvester; anaerobic storage; co-transport of grain and stover; and grain and stover separation at the biorefinery. A recent study suggests

that whole-plant (starch plus cellulosic) bioprocessing could also eliminate the need for separation of the grain and stover fractions, further reducing costs [1]. The whole-plant method attains these desirable goals: single-pass harvest; low soil contamination; weight limiting transport; size-reduction at harvest; reduced system energy inputs; and high yields. Due to the harvest of a moist crop, the grain and stover must be stored anaerobically and conserved in a non-neutral pH environment created by fermentation or chemical application.

Grain and stover are currently harvested well after crop maturity to reduce drying required for stable aerobic storage.

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However, field drying is costly in terms of weather risks; delayed harvest timeliness; and pre-conversion rehydration. Additionally, the grain fraction is often finish dried using fossil fuel, compromising its energy balance. Finally, drying of cellulose microfibrils results in the irreversible shrinking of the pore space, reducing the accessible surface area and conversion efficiency [2]. Transportation of the combined grain and stover fractions is advantageous over a fractionated crop transport because of the balancing of weight and volume limitations of each; grain is significantly weight limited, while stover is significantly volume limited. By balancing these two, the monetary and energy costs of biomass densification can be avoided.

Our primary objective was to investigate the feasibility of co-harvest and storage of both grain and stover to achieve an overall lower cost system for both fractions. Toward this goal we investigated the effect of whole-plant moisture content and ambient pretreatment on conservation at the pilot-scale. Compositional analysis was used to quantify the effectiveness of the proposed system on feedstock conservation and potential for biochemical conversion.

2. Materials and methods

2.1. Substrate

Whole-plant corn was harvested from plots in 2009 and 2010 near Arlington, WI (43.30; 89.35). In 2009, DeKalb 6169, a 111-day comparative relative maturity (CRM) corn, was planted on 6-May and in 2010, Dekalb 57-79, a 107-day CRM corn, was planted on 27-May. Harvesting was done with a pull-type forage harvester. In 2009, three different theoretical-length-of-cut (TLC) were utilized: 19, 25, and 38 mm. The results from 2009 indicated no significant differences in storage characteristics between the different TLC, so in 2010 only the 19 mm TLC was used. Composition results from 2009 were pooled, one replicate from each TLC were combined to result in three replicates. From each harvest or treatment where TLC was varied, three sub-samples were taken for particle-size analysis using ASABE Standard S424.1 [3] and kernel damage assessment [4]. In 2010 hand shelled grain served as control to compare against the ensiled control grain.

2.2. Experimental design

In 2009 a 4×2 replicated experimental design was used to investigate the effect of plant DM content (i.e. harvest date) and acid pretreatment (0 or 100 g sulfuric acid $(\text{kg DM})^{-1}$). Harvest dates and DM contents were Oct. 9 (350 g kg^{-1}); Oct. 27 (440 g kg^{-1}); Nov. 12 (600 g kg^{-1}); and Dec. 14 (660 g kg^{-1}). In 2010 a 3×4 experimental design was used to investigate the effect of plant DM content and pretreatment. Harvest dates and DM contents (whole plant and grain, respectively) were Sept. 28 (550 and 710 g kg^{-1}); Oct. 7 (660 and 810 g kg^{-1}); and Oct. 19 (840 and 840 g kg^{-1}). Pretreatments were 0, 10, or 30 g sulfuric acid $(\text{kg DM})^{-1}$ and the fourth pretreatment was 10 g calcium hydroxide $(\text{kg DM})^{-1}$. In both years, all treatments were replicated three times at each harvest date.

2.3. Pilot-scale silos

Prior to treatment and storage, the substrate was sub-sampled and analyzed for DM content using a microwave oven according to ASABE Standard S358.2 [3] so that amendments, if any, were applied on a DM basis. From each replicate pilot-scale silo, one sub-sample was taken for later separation of the grain and stover fractions and two sub-samples each were taken for determination of DM content and constituent analysis. Constituent and DM sub-samples were dried at 60 °C for 72 h in a forced air oven [3]. All substrates were homogenized in a Hobart model 1401 mixer and pretreated, if applicable. Pretreatment amendments of dry pulverized calcium hydroxide (98% $\text{Ca}(\text{OH})_2$ – Standard Hydrated Lime – Mississippi Lime Co., St. Louis, MO) or 18M liquid sulfuric acid (Sigma–Aldrich St. Louis, MO) were applied by top dressing over the course of the two min the substrate was in the mixer. After mixing, 4.3 kg OM of the substrate either with and without pretreatment was then placed into 19 l plastic containers, compacted using a hydraulic cylinder to a target density of 225 kg OM $(\text{m})^{-3}$, sealed, and then weighed to the nearest 0.01 kg. The container had a locking lid with a neoprene gasket to tightly seal the container. The containers were filled to the top so the locking lid maintained achieved density. Gas was manually released one week after filling by partially opening the lid. The containers then remained sealed during the remainder of the storage period. The silos were stored indoors at approximately 20 °C for 120 days in 2009 and 60 days in 2010.

2.4. Fraction separation

In 2009, sub-samples used for fractionating the grain and stover were taken prior to pretreatment and dried in a forced air oven at 60 °C for 72 h. The sub-samples were separated by hand into grain or stover fractions for later constituent analysis. In 2010, the fractionation sub-samples (~200 g DM) taken prior to pretreatment were fractionated on the basis of differences in specific gravity, using a previously developed hydrodynamic technique using a single flotation step [5]. All material that floated was considered the “stover fraction” and all material that sank was considered the “grain fraction”. A sample of the water was taken to evaluate any dissociated solids and solubles.

2.5. Removal procedure

Each pilot-scale silo and its contents were first weighed to the nearest 0.01 kg, then the contents were removed and homogenized prior to sub-sampling. Two sub-samples from each silo were taken for DM content determination at 60 °C for 72 h [3]. In 2009, a sub-sample of about 300 g DM was frozen at –20 °C for fractionation and subsequent constituent analysis of the grain and stover fractions at a later date. Fractions were separated using hydrodynamic method described above. The remainder of the silage was size-reduced in a hammermill with a 32 mm screen, sub-sampled into plastic bags, and frozen for constituent analysis of the whole-plant silage.

In 2010 the removal technique was modified to reduce sampling error of the heterogeneous material that was too easily fractionated by mechanical handling. Upon removal, a sub-sample was taken to evaluate DM content, and the

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