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An ASABE Meeting Presentation
Paper Number: 095654

AEROBIC AND ANAEROBIC STORAGE OF SINGLE-PASS, CHOPPED CORN STOVER

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Written for presentation at the
2009 ASABE Annual International Meeting
Sponsored by ASABE
Grand Sierra Resort and Casino
Reno, Nevada
June 21 – June 24, 2009

Abstract. *Corn stover has great potential as a biomass feedstock due its widespread availability. However, storage characteristics of moist corn stover harvested from single-pass harvesters have not been well quantified. In 2007, moist whole-plant corn stover at 19.1 to 40.3 % (w.b.) moisture content was stored for 237 days in aerobic piles, one covered and one uncovered, as well an anaerobic silo bag. In 2008, two moist stover materials – whole-plant and cob/husk from 31.7 to 58.1% (w.b.) moisture - were stored for 183 or 204 days in covered and uncovered anaerobic piles, ventilated bags, or anaerobic silo bags. Stover stored in uncovered piles was rehydrated from precipitation, which increased biological activity and produced DM losses from 8.2% to 39.1% with an average of 21.5%. Stover in covered piles was successfully conserved when the average moisture was less than 25% (w.b.) with DM losses of 3.3%. Stover above 36% (w.b.) and piled under a plastic cover had DM losses from 6.4% to 20.2% with an average of 11.9%. Localized heating to temperatures where spontaneous combustion might be a concern (i.e. > 70°C) occurred in the aerobic piles when moisture was above 45% (w.b.). Ambient air blown through a center tube in the ventilated bag dried stover near the tube to an average of 24.2% (w.b.), but the remainder of the bag averaged 46.8% (w.b.) at removal. Loss of DM ranged from 7.4% to 22.0% with an average of 11.8%. Stover was most successfully conserved in the bags where anaerobic conditions were maintained. Under anaerobic conditions DM losses ranged from 0.2% to 0.9%. When anaerobic conditions were not maintained in the silo bag DM losses averaged 6.1% of DM. Anaerobic storage is the best solution for conserving the value of moist corn stover.*

Keywords. *Biomass; chemical composition; corn stover; density; feedstock; losses; particle-size; storage.*

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ABSTRACT

Corn stover has great potential as a biomass feedstock due its widespread availability. However, storage characteristics of moist corn stover harvested from single-pass harvesters have not been well quantified. In 2007, whole-plant corn stover at 19.1 to 40.3 % (w.b.) moisture content was stored for 237 days in aerobic piles, one covered and one uncovered, as well an anaerobic silo bag. In 2008, two stover materials – whole-plant and cob/husk from 31.7 to 58.1% (w.b.) moisture – were stored for 183 or 204 days in covered and uncovered anaerobic piles, ventilated bags, or anaerobic silo bags. Stover stored in uncovered piles was rehydrated by precipitation, which increased biological activity and produced DM losses from 8.2% to 39.1% with an average of 21.5%. Stover in covered piles was successfully conserved when the average moisture was less than 25% (w.b.) with DM losses of 3.3%. Stover above 36% (w.b.) moisture and piled under a plastic cover had DM losses from 6.4% to 20.2% with an average of 11.9%. Localized heating to temperatures where spontaneous combustion might be a concern (i.e. > 70°C) occurred in the aerobic piles when moisture was above 45% (w.b.). Ambient air blown through a center tube in the ventilated bag dried stover near the tube to an average of 24.2% (w.b.), but the remainder of the bag averaged 46.8% (w.b.) at removal. Loss of DM ranged from 7.4% to 22.0% with an average of 11.8% with this storage method. Stover was most successfully conserved in the bags where anaerobic conditions were maintained. Under anaerobic conditions DM losses ranged from 0.2% to 0.9%. When anaerobic conditions were not maintained in the silo bag DM losses averaged 6.1% of DM. Anaerobic storage is the best solution for conserving the value of moist corn stover.

INTRODUCTION

With approximately 32 million ha of corn (*Zea mays* L.) grown in the United States (USDA, 2009), the non-grain, above ground portion of the plant known as corn stover deserves the attention as a possible biomass feedstock for cellulosic ethanol. Much of the available corn stover in the US goes unused after the grain harvest (Kadam and McMillin, 2003); so it is logical to pursue research to discover the worth of recovering this resource as a potential replacement for fossil generated fuel.

In the past, corn stover (stalk, leaf, cob and husk) has been collected through various methods for on-farm use as animal bedding or as high-fiber feed for ruminant animals. One collection method involved a machine called a stacker wagon, which formed a moderately densified cube by flail chopping the stover into a wagon where it was compressed (Ayers and Buchele, 1971). Although this was a workable two-pass harvesting system, most producers abandoned this practice because the harvesting rate was too slow, stack density too low, and storage losses too high.

Another harvesting option involves shredding and then merging the material into a windrow. After field drying, the stover windrow is baled with a round or square baler. The bales would typically be stored outdoors or under a tarp. Another option is chop the stover with a forage harvester and preserve the material by ensiling. Productivity was greater and storage losses lower with the chopped and ensiled system compared to storing round bales outdoors (Shinners et al., 2007a).

One of the major challenges facing corn stover and other biomass is conserving the feedstock during storage. The storage system must also fit efficiently between harvest and transportation to a biorefinery. Rigorous material specifications for successful storage, such as a narrow range of moisture or particle-size, may complicate and delay the harvest. Grain harvest is usually dependent on the grain moisture content, which is approximately half the moisture content of the stover (Shinners and Binversie, 2007). Certain storage systems, such as dry bales stored outdoors, not only may have high storage losses, but may require excessive handling and extra processing at a biorefinery.

There are three storage options that can be considered: on-farm, regional satellite or centralized at the conversion facility. The latter system is not considered practical due to land area required, transportation bottlenecks at harvest and fire hazards. On-farm and satellite storage are considered viable options at this time, with each system having potential advantages over the other.

A major challenge with either system is the required moisture for stable storage. If sufficient moisture and air is available, microorganisms begin breaking down the feedstock leading to heating, mold growth and undesirable product degradation. Mold is very undesirable in any feedstock. Corn silage with mold produced lower DM intake and digestibility within beef cattle (Whitlock et al., 2000). Ethanol producers also want as little mold as possible because the molds may be lethal to microorganisms used in downstream conversion processes. Microbial activity may also consume desirable elements of the feedstock leaving a higher proportion of lignin, decreasing theoretical ethanol yield.

The objective of the research was to quantify the storage characteristics of moist corn stover (i.e. > 25% w.b. moisture) as affected by initial moisture, stover fractions, and type of storage scheme.

MATERIALS AND METHODS

Harvest and Storage – 2007

Two schemes were used to harvest stover in 2007. The initial material was harvested with a John Deere 9750 STS combine modified to harvest grain and whole-plant stover (stalk, leaf, cob and husk) in a single-pass (Shinners et al., 2007b, 2009a). The theoretical-length-of-cut (TLC) of the stover processor was 11 mm. Cut height was between the second and third nodes and ground speed was about 3 km/h. Later material was harvested in two-passes, first by forming a windrow of stover at grain harvest (Shinners et al., 2009b) and then chopping with a John Deere 7800 forage harvester at 5 mm TLC. All trials were conducted at the University of Wisconsin Arlington Agricultural Research Station (AARS) using a single field of Renk 689 YGP corn variety. The single-pass harvesting was done on October 29-30 and November 3, 2007. Two-pass harvesting took place on November 11, 2007. Hand separation after harvest indicated an average of 4% of the harvested stover dry mass was grain. The mass of material harvested and placed into storage was determined to the nearest 2 kg with a weighed container forage wagon. Random samples of material were taken throughout the filling process for later particle-size analysis using ABSAE Standard S424.1 (ASABE, 2008).

Three treatments were considered: stored aerobically both with and without cover and stored anaerobically in a silo bag. The two aerobic treatments were not compacted, merely piled directly on the ground. The piles were roughly 3 m high, 5 m wide and 15 m long. The piles averaged roughly 7000 kg DM of stover. The covered pile was covered with a 200 micron plastic sheet and the sheet secured at the edges with weights. The three structures were placed on sod with a gentle slope for drainage. The silo bag was 2.74 m diameter and also 200 microns thick. The silo bag was filled and sealed on October 29th while the piles were formed on the October 30th, and November 3rd and 11th.

As material was placed into all structures, polypropylene mesh bags (55 x 80 cm with 7 mm mesh) were placed throughout the structures to quantify storage performance. Between 1.5 and 2.0 kg DM of stover was placed in each bag and the weight determined to the nearest 5 g. Three replicate sub-samples each for moisture and chemical compositional analysis were collected from the mesh bags prior to weighing. Moisture samples were oven dried at 103ºC for 24 h and composition samples at 60ºC for 72 h (ASABE Standard S358.2, 2008). Twelve mesh bags were placed into both aerobic piles, eight with the single-pass material and four with the two-pass material. Four mesh bags were placed in the silo bag. These bags were buried as deeply into the bag as safely possible after the bagger had been removed. It was not possible to place mesh bags in the silo bag prior to this time because the bagger rotor would have destroyed the mesh sample bags.

Removal Procedure – 2007

Stover was removed on June 24, 2008. The uncovered pile had exhibited considerable volumetric loss by this date. A front-end loader was used to remove material. The removed material was placed in trucks and the contents weighed to the nearest 10 kg on a truck scale. Care was taken to minimize spillage losses at removal. Mesh bags were collected by hand, and the contents weighed and then sub-sampled for moisture and composition. Moisture and composition samples were oven dried as described above, except the moisture samples from the silo bag were dried at 60ºC for 72 h (ASABE Standard S358.2, 2008).

At a representative location in the aerobic piles, cross sectional pictures and samples for moisture distribution were collected. A total of 15 moisture sub-samples were collected in a grid pattern. Samples for fermentation analysis were taken from the silo bag at approximately 1 m intervals along the length of the bag. Samples were sealed in plastic bags and the frozen. Additional samples were taken from random locations throughout the silo bag for particle-size and moisture distribution analysis.

Dried compositional samples were ground in a mill using a 1 mm screen and then sent to Dairyland Laboratories Inc. (Arcadia, WI) for analysis of neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin (ADL), and ash using wet laboratory techniques. Fermentation samples were also analyzed by Dairyland Laboratories for common fermentation products using high performance liquid chromatography techniques. Cellulose and hemicellulose content were estimated by differences between ADF and ADL and between NDF and ADF, respectively. Theoretical ethanol yield (TEY) was predicted using the NREL theoretical yield calculator (USDOE, 2008) and assuming that the C6 sugars were the cellulose content multiplied by 0.86 and the C5 sugars were the hemicellulose content multiplied by 0.71 (Lorenz et al., 2009).

Harvest and Storage – 2008

Stover storage structures were constructed at AARS in early fall of 2008. There were four major differences between the storage trials conducted in 2008 compared to 2007. First, actual structures were built to hold the aerobically stored material rather than relying on piles as used in 2007. The structures were meant to simulate a section of a large pile. In 2008, two types of stover material were investigated: whole-plant and cob/husk. Four storage treatments were considered: covered and uncovered aerobic piles, anaerobic silo bag, and a ventilated bag. The latter treatment is similar to that used to compost organic material (Garvin et al., 1995). Finally, two moisture ranges were targeted in 2008. Therefore, 16 different treatments were investigated: four storage schemes by two material types by two moisture ranges.

Each aerobic structure measured 6 m square with a center wall splitting the structure into two halves. The structure was constructed using fence posts and square mesh high density polyethylene fencing. The center wall was constructed with 2.5 m tall fence posts and the outside wall with 1.2 m posts. This allowed the stover to be heaped in the center simulating a pile. The mesh fencing was secured to the perimeter and center wall posts. Molded expanded polystyrene insulation (50 mm) was placed on the end walls of the structures prior to filling. One half of each structure was filled whole-plant or cob/husk stover, respectively. Four structures were built – two each for covered and uncovered stover at two moisture ranges (fig. 1).

Figure 1. Looking west, silo and aerated bags in the foreground with covered piles and uncovered piles farther back.

An Ag-Bag model CT-5 bagger was used to make the ventilated and anaerobic bags using 1.5 m diameter bag of 125 micron thickness. While forming the aerated bag, a 90 mm diameter perforated tube was placed at the bottom center along the full length of the bag. After filling, ventilation slits were cut into the bag every 5 m at the 2 and 10 clock positions. A centrifugal fan forced air through perforated tube. Within one to two minutes after the fan was turned on, the bag was inflated and air could be felt exiting the ventilation slits. The CT-5 bagger was also used to form the silo bags. In this case neither the perforated tube or ventilation slits were used. On a particular harvest date, about half the bag volume was filled first with one stover material and then the remaining volume filled with the other so there were a total of four bags required for the eight bagged treatments.

Whole-plant material was harvested by using the single-pass harvester described above configured with a whole-plant head from a forage harvester (Shinners et al., 2009a,b). The stover consisted of the stalk, leaf, cob and husk. The stover processor TLC was 11 mm, the cut height between the second and third nodes, and ground speed was about 4 km/h. The cob/husk material was harvested with the same single-pass harvester, except the whole-plant head was replaced with an ear-snapper head so the stover was primarily cob and husk, with a small fraction of upper stalk and leaves.

The high moisture range material was harvested on October 27th – 31st, 2008 using Pioneer 34A20 hybrid. The low moisture range was harvested on November 18th – 21st, 2008. In field grain and stover moisture was monitored prior to harvest to determine when the desired moisture range had been met. Random samples of both stover materials were taken throughout the filling process for later particle-size analysis using ASABE Standard S424.1 (ASABE, 2008).

A side-dumping forage wagon was used to fill one side of the split aerobic structures about half full. The material was leveled by hand and then 10 mesh bags of material were buried throughout the structure. Bags were not placed within 1 m of the exposed side of the structure. The sampling and weighing techniques used with the mesh bags were similar to procedures used in 2007. Five probes with three thermocouples each spaced 30 cm apart were randomly placed around the center of the structures. The thermocouples were attached to a multiplexer and datalogger which recorded the temperatures at one hour intervals. The second load of stover was placed in the structure and the top manipulated by hand to have roughly a 20° slope with a peak in the center (fig. 1). The dimensions of the structure were measured to estimate material density. The covered structures were covered with the same material used in 2007 and restrained by weights.

The Ag-Bag CT-5 bagger used a telescoping hydraulic cylinder to force material from the loading chamber into the tunnel and bag rather than a compacting rotor used on conventional baggers. This system allowed mesh bags to be placed throughout the ventilated and anaerobic bags. Ten mesh bags of each of the two stover materials were placed in each bag. Thermocouple probes similar to those described above were placed into the material at the ventilation slits of the ventilated bags. Individual thermocouples were forced into the anaerobic bag at random locations and then the holes sealed with tape and sealant. A total of 15 thermocouples were distributed through both material types for each of the four bag structures. The cross-sectional dimensions of the bags were measured to determine material density.

The fan in the ventilated bags was operated continuously until December 6th in an attempt to dry the stover for preservation. After this time, the fan was operated only when internal temperatures in the bag increased rapidly. Several different strategies for maintaining bag temperature were attempted, but the method used for most of the winter months involved turning the fan on for 12 hours during the night for two consecutive nights each week. After May 2nd, the fan was operated continuously until the material was removed on May 20th.

Removal Procedure – 2008

The material was removed from storage on May 20 and 21, 2009. The procedures for removing material, collecting the mesh bags and sampling for moisture, constituents and fermentation products were the same as used in 2007. Roughly halfway through removing a particular treatment, a vertical face was created by hand for cross-sectional moisture distribution sampling. Sub-samples were oven dried and analyzed using the same procedures as used in 2007.

Statistical Analysis

Statistical analysis was performed using SAS (SAS, 2008). The significance of storage structure was determined through single factor analysis of variance (ANOVA). Least significant difference (LSD), as calculated by SAS, was used to describe significant statistical differences between means. ANOVA was done on initial samples to determine if there were differences in composition between materials at the time of harvest. ANOVA was also done on the changes in a parameter (initial – final) to determine the effect of storage treatment on the material. The LSD for the changes is a parameter was also used to determine if the material had changed significantly during the storage period.

RESULTS

Particle Size and Density – 2007

The average particle-size of sub-samples analyzed was 27 mm, more than twice that of the TLC of the processor. The particle-size of sub-samples collected from the silo bag was 18 mm, showing the additional size reduction caused by the packing rotor of the bagger. The density of the piles and silo bag was 75 and 140 kg DM/m^3, respectively.

Moisture Content – 2007

High ambient temperatures and low humidity in 2007 caused the corn plants to dry at a much faster rate than is typically experienced in south-central Wisconsin. These conditions also produced a wide range of stover moisture in the field and into the storage structures (table1). Although two harvesting schemes were used, no statistical difference was found between the one-pass and two-pass systems for the initial moisture content of this material. There was no significant change in the moisture of mesh bag samples during storage in the silo bag or covered pile. Since the material in these two structures was not exposed to precipitation, significant increases in moisture would have been evidence of respiration losses (Pitt, 1990). The material in the mesh bags in the uncovered pile had a significant change in moisture content during the storage period with average moisture content above 70% (w.b.) at removal. The total precipitation during the storage period was 660 mm, which is 230 mm more than the 25-year average. Although a crust formed on this pile shortly after storage, the high aggregate final moisture shows that this crust did not prevent precipitation from entering the pile. Large fissures opened on the top of the pile during the spring and summer months, allowing precipitation easy access to interior of the pile.

The cross-sectional moisture distribution of the two piles showed that outer areas of the uncovered pile had greater moisture than the core (table 1). The covered pile had more uniform moisture. The range of moisture from the anaerobic silo bag at removal was similar to that when stored.

Table 1. Moisture content (% w.b.) of whole-plant corn stover as affected by three different storage methods. Samples collected from each load into storage, from mesh bags placed throughout the storage structures or from sub-sampling in three different zones at removal.

Storage Method	Into Storage			At Removal		
	Max	Min	Average	Max	Min	Average
Covered Pile	31.3	17.9	22.9	43.3	17.7	22.2
Uncovered Pile	30.7	19.6	23.8	83.8	56.8	71.1
Silo Bag	40.3	19.1	29.8	38.8	19.9	28.7

	Material in Mesh Bags			Moisture Distribution at Removal		
	Into Storage	At Removal	Change	Top[a]	Side[b]	Core[c]
Covered Pile	21.1	19.5 a	1.6 b	20.7	25.5	18.5
Uncovered Pile	20.9	73.4 b	-52.5 a *	59.7	68.6	48.5
Silo Bag	19.5	22.5 a	-3.1 b	--	--	--
LSD[d]	2.5	13.6	13.0			
P[e]	0.47	<0.0001	<0.0001			

[a] Average of three samples collected from the top portion of pile.
[b] Average of three samples collected from the side of pile.
[c] Average of four samples collected from the core of pile.
[d] Mean values followed by different letters in the same column are significantly different at 95% confidence
[e] Results of ANOVA tests, effect is significant if $P < 0.05$
* Indicates a statistically significant change in moisture during storage, $P = 0.05$

Chemical Composition - 2007

The material placed into the uncovered pile had slightly greater NDF, ADF, and ash than the stover used in the other two treatments, so the material had a slightly greater TEY into storage, although the difference was less than 4% (table 2). There were very few statistically significant changes in most of the compositional parameters measured from the mesh bag samples stored in the silo bag or covered pile (table 2). There were several significant changes in composition of the material in the uncovered pile. There was a slight loss of NDF, but significant apparent gains in CP, ADF, ADL, and ash that indicated loss of water soluble carbohydrates. These changes led to a significant loss in TEY. Coupled with the loss of DM (table 3), the potential ethanol yield from one Mg of DM placed into storage in the uncovered pile was significantly less than for the other two treatments (table 3).

Storage Losses

Loss of DM during storage was quantified in two ways: by changes in mass of the replicated mesh bags and by loss of mass in the entire structure. There was very good agreement between the two methods, showing that the mesh bag method is a good surrogate for estimated DM loss in the entire structure (table 3). This method also has the advantage of replication which allows for statistical analysis.

Losses of DM were very low for the silo bag despite the low initial moisture (table 3). The pH of this material at removal was 6.7, and lactic, acetic, and total acids were 0.2%, 0.3% and 0.5% of total DM, respectively, indicating very little fermentation took place. Despite this, DM losses were very low because anaerobic storage conditions were maintained until removal. These results were consistent with those reported by Shinners et al. (2007a,b; 2009a). Losses of DM would be expected to be quite high for whole-plant corn silage ensiled with low moisture (Pitt, 1990; Muck, 1988). Whole-plant corn silage also exhibited low levels of fermentation products when ensiled at low moisture content (McDonald et al., 1991; Hoglund, 1964). Ensiled animal feed would be removed daily from bunker or bag silos in relatively small quantities compared to biomass feedstock which would be removed in very large quantities. In this research the entire silo bag contents were removed in a single day. Pitt and Muck (1993) modeled DM loss due to aerobic deterioration at feed out as inversely proportional to the feed out rate. DM losses of whole-plant corn silage at 65% DM due to aerobic deterioration decreased dramatically at feed out rates greater than 10 cm/day.

Losses of DM were also low for the covered pile (table 3). The average initial moisture of the material was below 23% (w.b.) (table 1). Round bales of stover stored under cover in this moisture range had DM loss from 1.1% to 4.9% (Shinners et al., 2007a). There was very little evidence of mold at removal, although there was some slight mold at the interface between the stover and the plastic cover, likely due to moisture condensation. Losses of DM in the uncovered pile were very high (table 3). Since there was no barrier to prevent precipitation from entering the pile, high moisture in the pile caused considerable biological degradation. The material was observed to have a great deal of mold at removal. It was observed that the volume of the pile started to decrease within a few weeks of storage and by the end of the storage period the pile was less than half its original volume. No statistical difference was found between the DM loss of the material harvested with the one-pass or two-pass systems.

Table 2. Composition (% of DM) of whole-plant corn stover into storage and change in composition after 237 days of storage as affected by three different storage methods.

Storage Method	NDF	ADF	ADL	Ash	TEY[b]
			Into Storage[a]		
Covered Pile	79.4 a	50.9 a	6.0	4.5 ab	410 a
Uncovered Pile	81.8 b	53.0 b	5.7	5.2 b	426 b
Silo Bag	79.7 ab	51.1 ab	5.9	4.2 a	412 a
LSD[c]	2.4	1.9	0.4	1.0	13
P[d]	0.03	0.02	0.38	0.07	0.008
			Change During Storage[e]		
Storage Method	NDF	ADF	ADL	Ash	TEY Loss[f]
Covered Pile	-2.8 a	-2.7 ab *	0.0 b	0.2 b	-17 a
Uncovered Pile	1.4 b	-4.8 a *	-8.1 a *	-2.2 a *	49 b *
Silo Bag	-2.5 a	-1.5 b	0.7 b	0.2 b	-18 a
LSD[c]	3.7	2.6	3.1	0.9	32
P[d]	0.02	0.03	<0.0001	<0.0001	<0.0001

[a] Stover harvested on October 27, 30 and November 3, 11 2007.
[b] Theoretical ethanol potential, L/Mg DM into storage.
[c] Different markers within the column group are statistically different at P = 0.05.
[d] Results of ANOVA tests - effect is significant if P < 0.05.
[e] Change = Initial - Final, stover removed from storage structures on June 24, 2008.
[f] TEY Loss = Initial TEY - ((1 - DM Loss) * Removal TEY; L/Mg DM into storage.
* Indicates a statistically significant change in constituent during storage (P = 0.05)

Table 3. DM loss as measured by replicated mesh bag technique or change in dry mass of entire contents of structure and estimated mold score.

Storage Method	Moisture Into Storage (% w.b.)	DM loss .. % of total Mesh Bags	Whole Structure	Mold Score [a]
Covered Pile	22.9	3.3 a	3.7	1
Uncovered Pile	23.8	39.1 b	33.3	4
Silo Bag	29.8	0.2 a	0.1	1
LSD[b]		12.6		
P[c]		<0.0001		

[a] 1 - Little or no mold present, no mold odor; 2 - Mold present in some locations, some mold odor; 3 - Mold visible throughout, heavy mold odor; 4 - High degree of mold, decomposed stover
[b] Different markers in the same column group are statistically different (P = 0.05)
[c] Results of ANOVA tests, effect is significant if P < 0.05

Particle Size, Density, Temperature – 2008

The mean particle-size for the early harvest stover was 44 and 56 mm for the whole-plant and cob/husk stover, respectively (table 4). The mean particle-size was 59 and 67 mm for whole-plant and cob/husk stover, respectively, for the later harvest (table 4). The densities did not decrease remarkably in the later harvest as might be expected with lower moisture content and increased particle size.

Grain moisture was 33% (w.b.) when harvested in late October, unusually high for south-central Wisconsin. The average moisture was 57% and 46% w.b. for the whole-plant and cob/husk stover, respectively. By November 18, the grain moisture had decreased to 25% (w.b) while the stover moisture were 41% and 35% (w.b.), respectively.

The covered and uncovered aerobic pile treatments harvested in late October heated immediately for both stover materials (figs. 2 and 3). Peak temperatures reached 73°C and sustained that temperature for several days in some locations. The uncovered piles of both materials began to heat again after the spring thaw when precipitation could enter the pile and restart biological activity.

The silo bag formed in late October with both stover materials followed the ambient temperature closely for the duration of the storage period. Temperatures rose quickly during the aerobic and lag phases of fermentation, and then temperatures were very stable throughout storage. There was an initial temperature spike with the aerated bag, but internal temperatures dropped quickly following ventilation and followed ambient trends for most of the winter months. After ambient temperatures started to consistently reach above freezing, temperatures within the ventilated bag started to rise. Operating the fan for 12 hours over each of two consecutive nights helped temporarily reduce stover temperature, but heating from biological activity would resume a few days later.

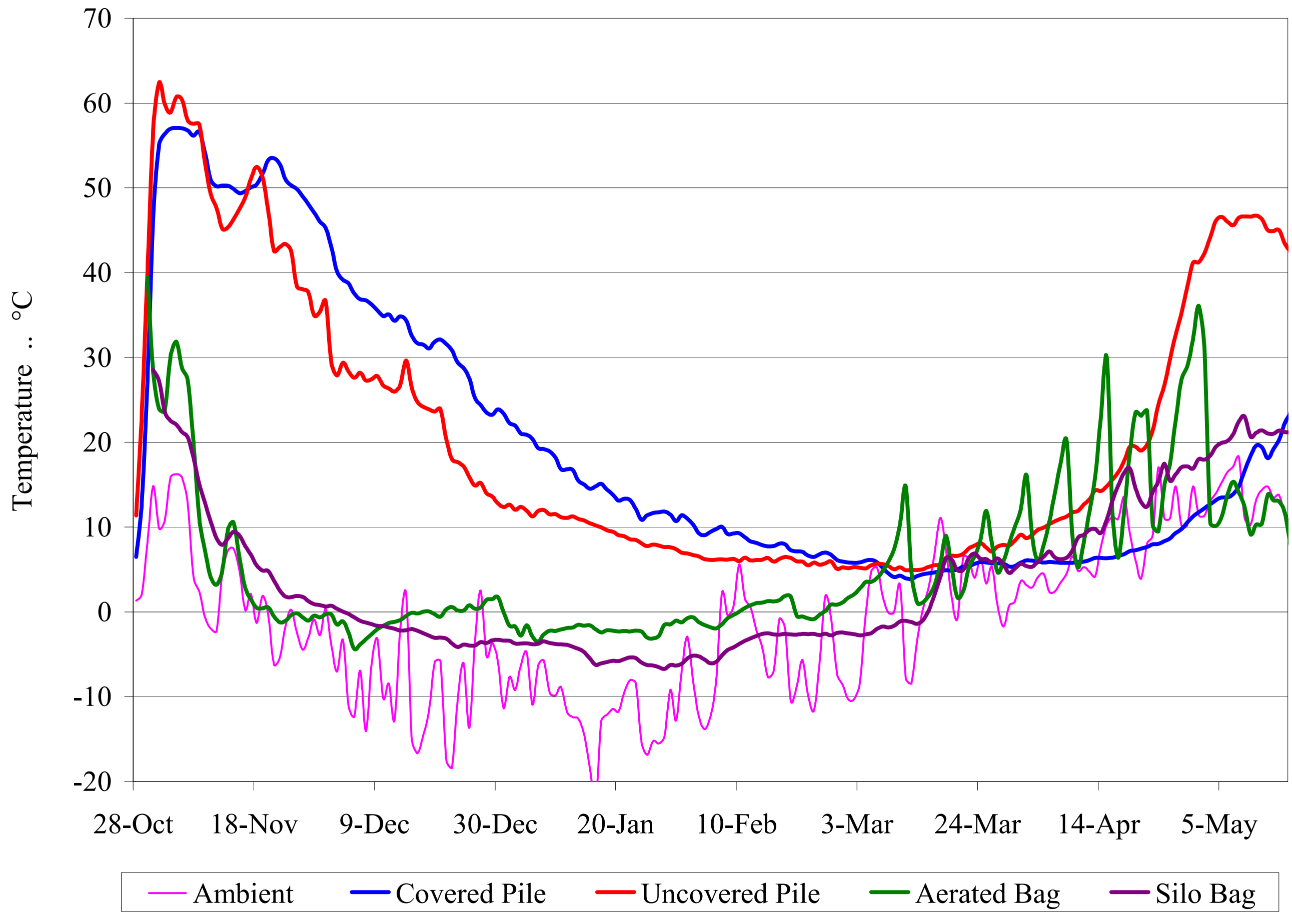

Figure 2. Average daily temperatures from 15 thermocouples per structure for whole-plant stover harvested on October 27-31, 2008 and stored in four different storage structures. Average stover moisture was 57.7% (w.b.).

Table 4. Physical properties of two stover materials harvested and placed into storage at two different periods in the fall of 2008.

Storage Method	Harvested October 27-31			Harvested November 18-21		
	Moisture % w.b.	Density[a] kg/m^3 DM	GMPS[b] mm	Moisture % w.b.	Density kg/m^3 DM	GMPS[a] mm
	Whole-Plant Stover					
Covered	35.7	73	55	57	70	41
Uncovered	48.3	63	57	58.1	74	38
Compost bag	36.2	86	65	57.6	96	48
Silo bag	44.4	176	--	54.1	88	49
	Cob/Husk Stover					
Covered	37.2	90	59	45.8	111	47
Uncovered	35.2	93	60	47.1	106	59
Compost bag	37.8	129	59	46.6	166	55
Silo bag	31.7	160	92	44.7	169	62

[a] Density of stover in respective storage structure
[b] Geometric mean particle size as determined by ASABE Standard S242.1

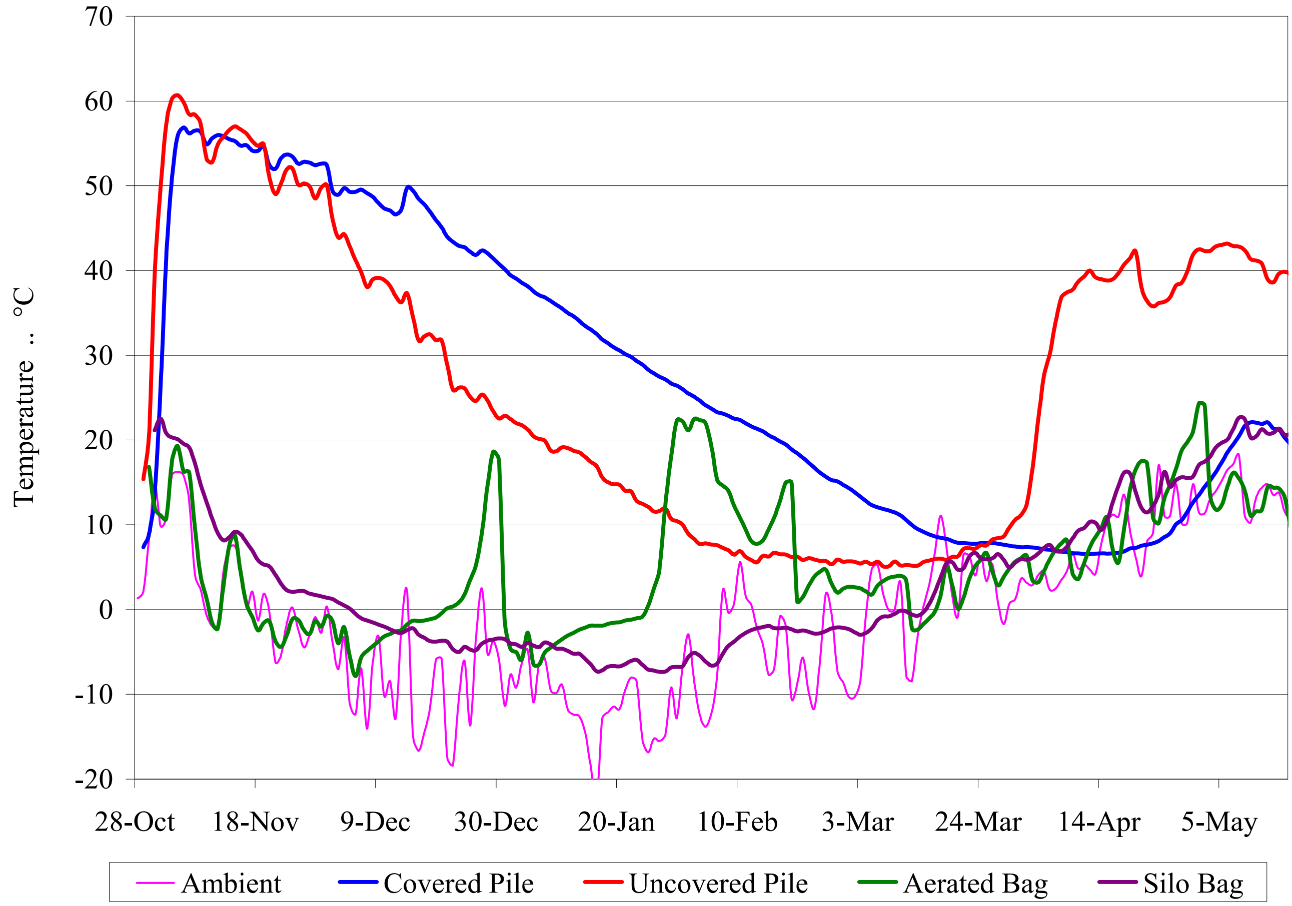

Figure 3. Average daily temperatures from 15 thermocouples per structure for cob/husk stover harvested on October 27-31, 2008 and stored in four different storage structures. Average stover moisture was 46.1% (w.b.).

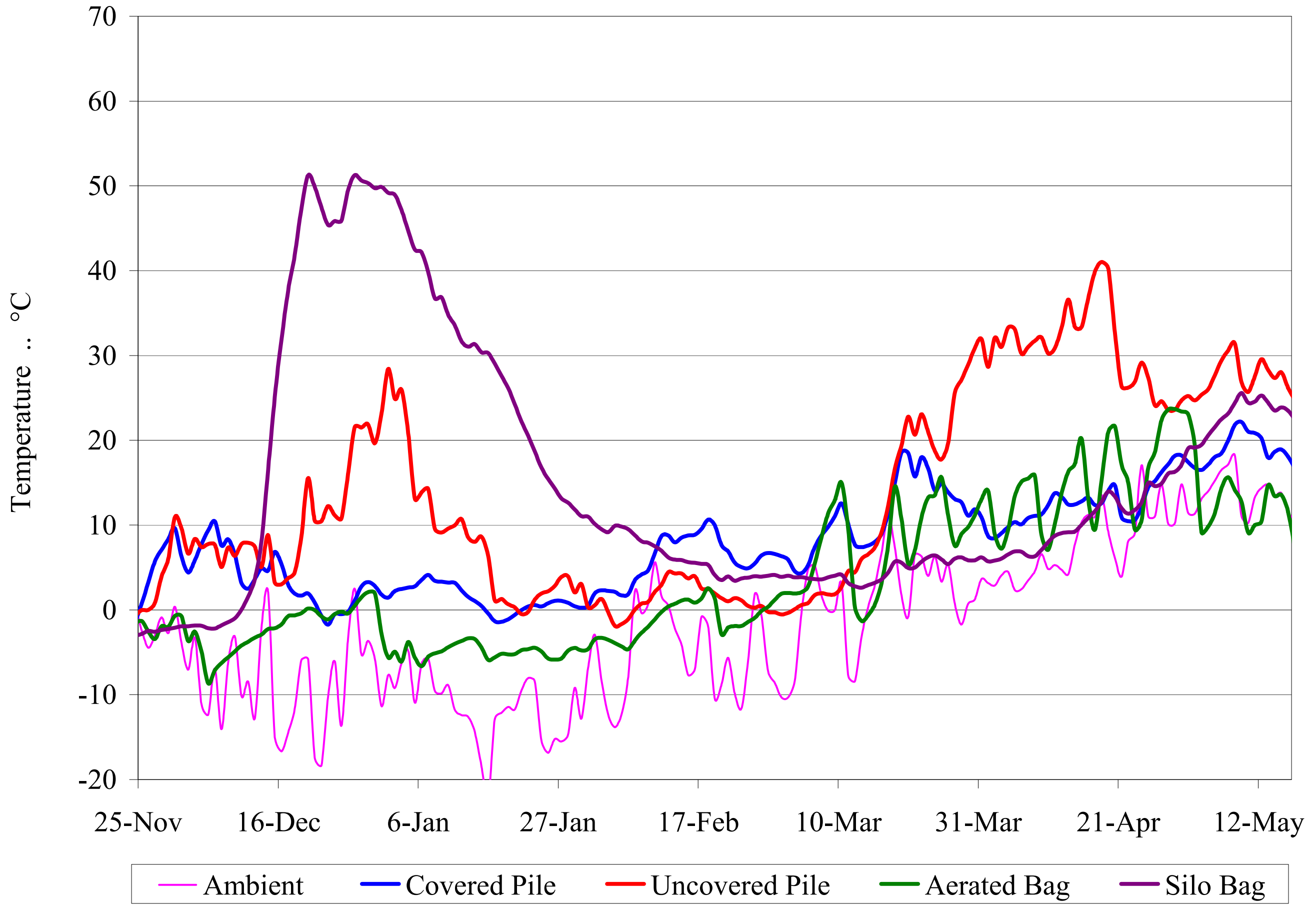

Figure 4. Average daily temperatures from 15 thermocouples per structure for whole-plant stover harvested on November 18-21, 2008 and stored in four different storage structures. Average stover moisture was 41.2% (w.b.).

There was less initial heating of the aerobic plies of stover harvested in mid-November, possibly because all the stover entered storage at or near freezing temperatures (figs. 4 and 5). The maximum average temperature was also less for the later harvest date. The heating in the ventilated bag generally followed the same pattern as with the earlier harvest date, although the whole-plant material did start heating during the winter months.

The silo bag formed at the later harvest date began heating after about one month in storage. It was observed that the seal around the thermocouples in this bag had become compromised. The tape and sealant used to seal the holes were stiff due to low temperatures when the thermocouples were placed in the bag. This problem became worse with time as the stiff thermocouple wires were moved by the wind, snow and ice. Attempts were made to reseal the holes around the thermocouples, but the low temperatures made these repairs ineffectual and anaerobic conditions could not be maintained. The density of the whole-plant section of the silo bag was one half that obtained in the earlier harvest date (table 4). The high porosity of this section of the bag created further difficulty maintaining an anaerobic environment.

The covered piles had the least amount of heating, except for a brief spike early in the storage of the cob/husk material. Heating occurred again after the spring thaw in the uncovered treatments when precipitation increased moisture in the piles.

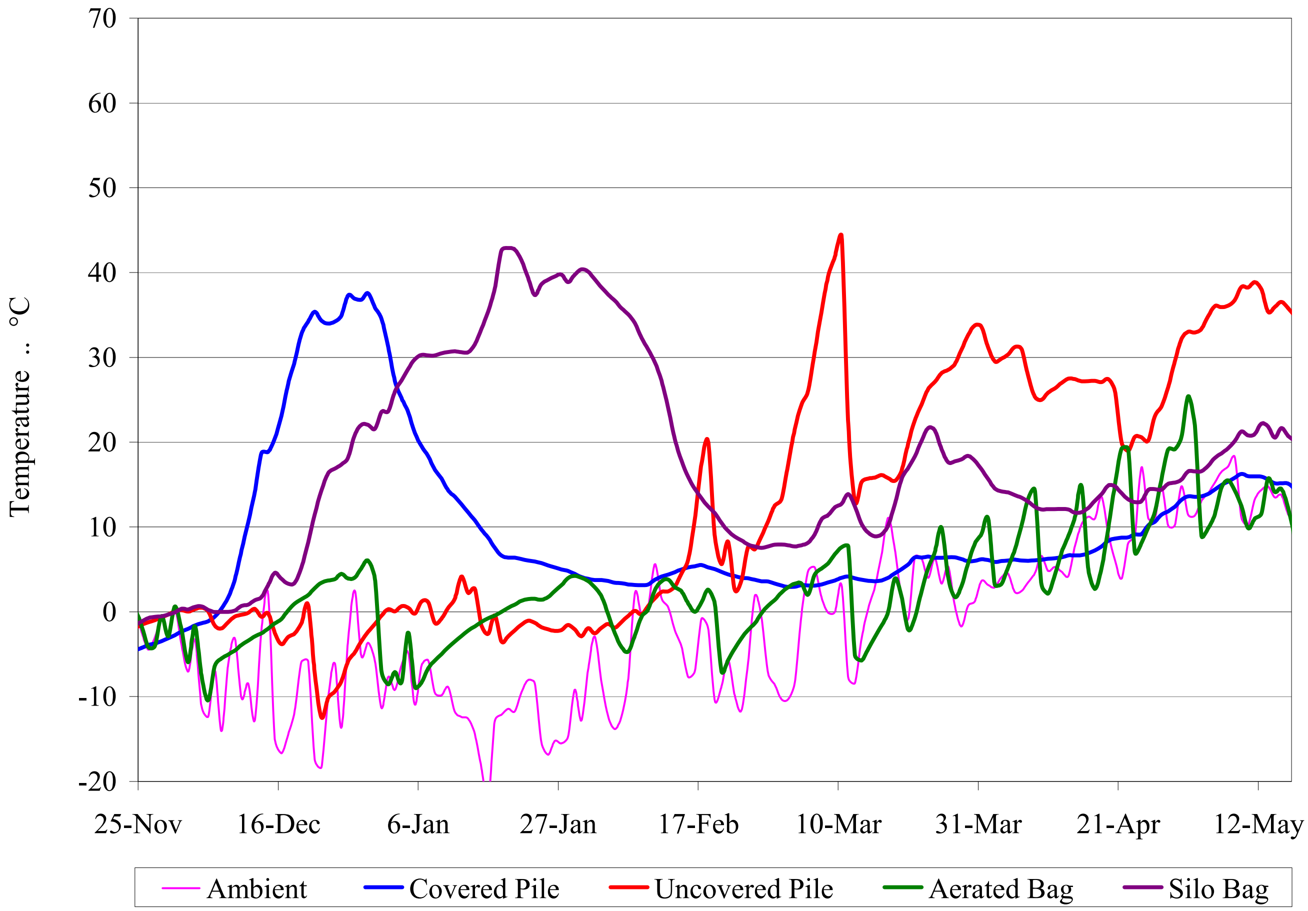

Figure 5. **A**verage daily temperatures from 15 thermocouples per structure for cob/husk stover harvested on November 18-21, 2008 and stored in four different storage structures. Average stover moisture was 35.5% (w.b.).

Moisture Content

At the time of harvest, there was no significant difference in moisture between materials placed in the four storage treatments for either stover material harvested in October (table 5). There were significant differences for stover harvested in November, which were attributed to field variations. There was a significant loss of moisture during storage for both materials stored in the covered piles. This was attributed to the considerable heating that occurred. Also, the cover prevented precipitation from reaching the material. On cold days, water vapor could be seen exhausting from under the cover. Whole-plant stover stored in piles without cover gained moisture, although change in moisture during storage was not significant. Uncovered piles of cob/husk had a significant loss of moisture during storage, again attributed to heating. The cob/husk stover also formed a better thatch or crust than the whole-plant stover, which may have helped reduce the amount of precipitation entering the pile. Three of the four aerated bag treatments produced a significant loss of moisture. Since the aerated bags heated less than the other two aerobic treatments, the forced air ventilation probably helped dry the material. There was no significant change in moisture in the silo bag where anaerobic conditions were maintained. There was a loss of moisture in the silo bag where heating occurred due to air entering the bag.

Samples collected from a single cross-section near the top, sides and core of the structures at removal showed moisture was generally greater near the top of all storage treatments (table 6). This was attributed to precipitation in the uncovered treatment and water vapor condensation in the remaining treatments. The core tended to have the lowest moisture of all the treatments where individual thermocouples had shown the greatest temperature rise occurred. The silo bag where anaerobic conditions were maintained had the most uniform moisture distribution. Uniform properties are an important attribute for feedstocks that will be converted to bioproducts. Uniform moisture facilitates feeding bioreactors with the correct amount of DM and insures a more uniform treatment from chemical or biological amendments.

Table 5. Aggregate moisture content (% w.b.) from the material in the mesh bags used to quantify DM loss filled with two different stover materials harvested at two different periods and stored in four different structures.

Storage Method	Harvested October 27 - 31					
	Whole-Plant			Cob/Husk		
	Into Storage	At Removal[a]	Change	Into Storage	At Removal[a]	Change
Covered Pile	57.0	33.7 a	23.3 b *	45.8	24.6 a	21.2 b *
Uncovered Pile	58.1	62.8 b	-4.7 a	47.1	25.3 a	21.8 b *
Aerated Bag	57.6	53.2 b	4.4 a	46.6	24.5 a	22.1 b *
Silo Bag	54.1	57.4 b	-3.3 a	44.7	44.1 b	0.6 a
LSD[b]	3.6	13.7	14.8	3.1	4.3	5.4
P[c]	0.13	0.0008	0.001	0.43	<0.0001	<0.0001
	Harvested November 18 - 21					
	Whole-Plant			Cob/Husk		
	Into Storage	At Removal[a]	Change	Into Storage	At Removal[a]	Change
Covered Pile	35.7 a	24.2 a	11.5 b *	37.2 bc	24.2 ab	13.0 *
Uncovered Pile	48.3 c	50.5 b	-2.2 a	35.2 b	24.7 ab	10.5 *
Aerated Bag	36.2 a	25.8 a	10.4 b *	37.8 c	27.4 b	10.4 *
Silo Bag	44.5 b	22.9 a	21.5 c *	31.7 a	22.5 a	9.2 *
LSD[b]	3.7	8.2	8.2	2.2	3.4	3.9
P[c]	<0.0001	<0.0001	<0.0001	<0.0001	0.048	0.25

[a] Stover removed from storage structures on May 20 and 21, 2009.
[b] Mean values followed by different letters in the same column are significantly different at 95% confidence
[c] Results of ANOVA tests, effect is significant if $P < 0.05$
* Indicates a statistically significant change from initial to final moisture, $P = 0.05$.

Table 6. Aggregate moisture content (% w.b.) of samples collected at removal from storage from the three locations at a single cross-section for two different stover materials harvested at two different periods and stored in four different structures.

	Harvested October 27-31					
	Whole-Plant			Cob/Husk		
Storage Method	Top[a]	Side[b]	Core[c]	Top[a]	Side[b]	Core[c]
Covered Pile	62.9	41.7	27.6	49.7	42.4	25.7
Uncovered Pile	84.8	84.4	71.6	76.5	80.2	39.0
Aerated Bag	58.4	49.3	30.9	45.9	30.5	21.0
Silo Bag	59.1	55.1	51.0	51.5	44.7	46.4
	Harvested November 18-21					
	Whole-Plant			Cob/Husk		
	Top[a]	Side[b]	Core[c]	Top[a]	Side[b]	Core[c]
Covered Pile	45.6	40.4	24.1	44.2	30.8	25.1
Uncovered Pile	74.4	86.1	48.4	72.5	79.1	37.3
Aerated Bag	59.1	47.6	23.6	31.6	26.5	21.1
Silo Bag	66.8	37.0	27.2	52.4	31.8	20.2

[a] Average of three samples collected from the top portion of pile or bag structures.
[b] Average of three samples collected from the side of pile or sides of the bag.
[c] Average of four samples collected from the core or center area of pile or bags structures.

Storage Losses

All storage treatments except the anaerobic silo bag had greater than 10% loss of DM during storage for the material harvested on October 27-31 when the stover moisture content was 57.7% and 46.1% for the whole-plant and cob/husk materials, respectively (table 7). Losses were greater for the whole-plant material because this material had greater moisture. The temperature history for aerobic piles showed a prolonged period of heating from microbial metabolism which resulted in the large DM losses. Although the temperature history did not show as much heating in the aerated bag, DM losses of both materials was similar to the aerobic piles. The DM losses combined with the chemical changes in storage caused a large loss of TEY. All the aerobic treatments were observed to have significant visual evidence of molds at removal.

The DM losses were numerically less for most treatments placed into storage at the later harvest date because the low temperatures delayed heating and average moisture of the whole-plant and cob/husk material was less (41.2% and 35.5%, respectively). The temperature history indicated long periods of heating in the aerobic structures, corresponding to the DM losses that averaged 9.9% for the three aerobic structures. Mold was evident in all treatments when removed from storage. The losses in the silo bag were similar to most of the other treatments because the bag could not be kept anaerobic. The temperature history indicated long periods of heating in this structure, leading to the unexpectedly high DM losses.

The silo bag with the late harvested material did not ensile properly because it was not kept anaerobic. There was no fermentation products measured in the material. The pH of the whole plant and cob and husk materials were 8.2 and 7.4, respectively, which are much higher than would be expected from similar material that was maintained anaerobic. For the silo bag where anaerobic conditions were maintained, the pH levels were 4.7 and 4.8 and the fermentation products were 4.3% and 0.9% of DM for the whole plant and cob and husk materials, respectively. The fermentation products were almost entirely made up of lactic and acetic acids. These levels of total acid production and pH were consistent with ensiled stover reported previously (Shinners et al., 2007a,b; 2009a).

Composition

There were almost no statistical differences in constituents between materials placed into the four storage structures at harvest (tables 8 and 9). The average NDF, ADF, ADL and ash content was 80.6% and 82.7%; 49.3% and 45.6%; 4.7% and 4.6%; and 5.5% and 3.7%; for the whole-plant and cob/husk stover. The greater NDF and lower ADF values for the cob/husk materials are consistent with that found by others (Lorenz et al., 2009).

Most of the compositional changes in storage resulted in an apparent gain in NDF, ADF, ADL, and ash as a result of DM loss from biological respiration. Many of these changes were statistically significant. For most constituents, there was significantly less change in chemical composition in the anaerobically stored stover harvested on October 27-31 compared to the other three storage treatments (table 8). None of the remaining storage treatments produced a clear trend to have more or less change in composition than another.

Hemicellulose generally decreased for all early harvest treatments except the silo bag. Breaking down hemicellulose into monosaccharides is an indication there was respiration and hydrolysis occurring (Dewar et al., 1963; Melvin, 1965). The indigestible fraction of the hemicellulose remains and can lower NDF concentration (Muck, 1988). Break down of hemicellulose and DM loss also occur on a smaller scale in normal anaerobic storage (Miller and Rotz, 1995). The remaining indigestible fraction after loss of soluble carbohydrates usually increases the fiber concentration (Rotz and Muck, 1994), which may explain the general increase of ADL in treatments with high DM losses. When managed correctly, anaerobic storage should produce little change in NDF and ADF that correspond to carbohydrates consumed during the fermentation process (Miller and Rotz, 1995). There was significant gains in NDF and ADF for both stover materials stored in the anaerobic silo bag (table 8).

Table 7. Loss of stover DM using replicated mesh bag technique; loss of theoretical ethanol yield (TEY); and estimated mold content for two different stover materials harvested at two different periods in 2008 and stored in four different structures.

	Whole Plant			Cob and Husk		
	DM Loss	TEY Loss[a]	Mold	DM Loss	TEY Loss[a]	Mold
Storage Method	% of DM	L/Mg DM	Score[b]	% of DM	L/Mg DM	Score[b]
	Harvested October 27-31					
Covered Pile	20.2 b	92	3	13.2 b	56	3
Uncovered Pile	24.5 b	110	4	12.4 b	57	3
Aerated Bag	22.0 b	118	3	10.3 b	57	3
Silo Bag	0.9 a	11	1	0.7 a	-3	1
LSD[c]	7.2			3.9		
P[d]	<0.0001			<0.0001		
	Harvested November 18-21					
Covered Pile	7.9 a	11	2	6.4	-3	2
Uncovered Pile	23.3 b	88	4	8.2	11	3
Aerated Bag	7.4 a	9	3	7.4	6	3
Silo Bag	6.4 a	4	3	5.8	-4	3
LSD[c]	6.6			3.5		
P[d]	<0.0001			0.51		

[a] TEY Loss = Harvest TEY - ((1 - DM Loss) * Removal TEY)
[b] 1 - Little or no mold present, no mold odor; 2 - Mold present in some locations, some mold odor; 3 - Mold visible throughout, heavy mold odor; 4 - High degree of mold, decomposed stover
[c] Mean values followed by different letters in the same column are significantly different at 95% confidence
[d] Results of ANOVA tests, effect is significant if P < 0.05

Table 8. Chemical composition into storage and change in composition (% of DM) for two different stover materials harvested October 27-31, 2008 and stored in four different structures.

Storage Method	NDF	ADF	Lignin	Ash	TEY[b]
	Whole-Plant Stover Into Storage				
Covered Pile	80.5	48.8	4.2	7.2	423
Uncovered Pile	77.3	49.4	4.6	6.5	407
Aerated Bag	80.4	49.3	4.1	6.1	424
Silo Bag	78.3	48.6	5.0	6.0	407
LSD[c]	8.0	3.2	2.1	2.3	47
P[d]	0.64	0.87	0.68	0.55	0.63
	Change During Storage[d]				
Covered Pile	-0.4 b	-11.8 a *	-4.5 a *	-0.4 b	9 b
Uncovered Pile	0.3 b	-11.6 a *	-4.7 a *	-4.0 a *	14 b *
Aerated Bag	2.9 c *	-6.3 b *	-4.4 a *	-2.4 a *	32 c *
Silo Bag	-2.8 a *	-3.9 b *	-1.3 b *	-0.4 b	-11 a
LSD[c]	2.0	2.5	1.2	1.7	11
P[d]	0.0002	<0.0001	<0.0001	0.002	<0.0001
	Cob/Husk Stover Into Storage				
Covered Pile	80.6	43.8	3.2	4.1	423
Uncovered Pile	82.7	45.2	3.5	3.4	432
Aerated Bag	83.1	45.5	3.3	3.8	436
Silo Bag	80.2	44.6	5.7	4.3	407
LSD[c]	5.3	2.0	5.7	2.2	52.6
P[d]	0.44	0.25	0.61	0.71	0.49
	Change During Storage[d]				
Covered Pile	-1.7	-9.7 a *	-3.6 a *	-1.5 a *	1 ab
Uncovered Pile	-0.4	-8.7 a *	-3.0 a *	-1.6 a *	4 ab
Aerated Bag	0.2	-6.0 b *	-3.4 a *	-0.1 b	13 b
Silo Bag	-1.2	-3.1 c *	-0.1 b	0.5 b	-10 a
LSD[c]	2.6	1.3	1.0	0.8	14
P[d]	0.47	<0.0001	<0.0001	0.0001	0.0214

[a] L/Mg DM
[b] Mean values followed by different letters in the same column are significantly different at 95% confidence.
[c] Results of ANOVA tests, effect is significant if P < 0.05.
[d] Change is initial minus final constituent value.
* Indicates a statistically significant change in constituent during storage (P = 0.05).

Table 9. Chemical composition into storage and change in composition (% of DM) for two different stover materials harvested November 18-21, 2008 and stored in four different structures.

Storage Method	NDF	ADF	Lignin	Ash	TEY[b]
	Whole-Plant Stover Into Storage				
Covered Pile	84.5	49.0	4.1 a	4.7 b	442
Uncovered Pile	79.2	49.8	5.4 b	4.9 b	411
Aerated Bag	83.8	48.7	4.7 ab	4.0 a	436
Silo Bag	81.1	50.9	5.2 ab	4.5 ab	423
LSD[c]	5.3	2.5	1.2	0.5	30
P[d]	0.14	0.22	0.12	0.04	0.14
	Change During Storage[d]				
Covered Pile	-6.3 *	-6.3 b *	-2.1 b *	-0.7	-26
Uncovered Pile	-3.7	-11.9 a *	-4.0 a *	-3.3 *	-10
Aerated Bag	-5.5	-6.0 b *	-1.5 b *	-2.5	-25
Silo Bag	-5.8	-7.2 b *	-2.2 b *	-0.8	-24
LSD[c]	6.0	2.1	1.4	2.5	31
P[d]	0.80	<0.0001	0.01	0.09	0.64
	Cob/Husk Stover Into Storage				
Covered Pile	84.0	47.3	5.3	3.8	431
Uncovered Pile	84.4	46.6	5.3	3.4	432
Aerated Bag	83.2	46.0	5.3	3.2	425
Silo Bag	83.1	46.0	5.1	3.4	426
LSD[c]	7.2	2.2	2.3	1.6	35
P[d]	0.95	0.38	0.99	0.76	0.94
	Change During Storage[d]				
Covered Pile	-6.4 *	-5.0 bc *	-0.7	0.4 b	-33 *
Uncovered Pile	-4.7 *	-6.6 a *	-0.8	-0.4 a	-26 *
Aerated Bag	-5.5 *	-4.0 c *	-0.7	-0.9 a *	-28 *
Silo Bag	-5.9 *	-5.7 ab *	-0.9	-0.9 a *	-31 *
LSD[c]	2.5	1.3	1.0	0.7	14
P[d]	0.54	0.004	0.98	0.004	0.76

[a] L/Mg DM
[b] Mean values followed by different letters in the same column are significantly different at 95% confidence.
[c] Results of ANOVA tests, effect is significant if P < 0.05.
[d] Change is initial minus final constituent value.
* Indicates a statistically significant change in constituent during storage (P = 0.05).

DISCUSSION

The corn crop dried more rapidly than expected in 2007. By the time stover was harvested, the stover moisture content was generally less than 30% (w.b.). The whole-plant stover stored in the covered aerobic pile and anaerobic silo bag for over eight months conserved the stover quite well with small DM losses, minimal changes to the chemical composition and little or no mold present. The uncovered aerobic pile was subject to considerable rehydration from precipitation which promoted biological activity so DM losses were high and extensive mold growth was evident. Although there were a few low moisture locations in the uncovered pile at removal, mold was evident in these locations as well. Stover in the aerobic covered pile was well conserved because the initial moisture content averaged below 25% (w.b.) and the plastic cover kept precipitation from rehydrating the stover, limiting biological activity. The material in the silo bag was maintained under anaerobic conditions throughout the storage period, so preservation was excellent, despite the low initial moisture.

By the last week in October, 2008, the corn grain had only dried to 33% (w.b.), which is considerably greater moisture than typical for south-central Wisconsin (Shinners and Binversie, 2007). However, delaying grain harvest for further field-drying of the grain would not be an option because of the risk if snowfall. The stover moisture was at 57% and 46% (w.b.) for whole-plant and cob/husk materials, respectively. Stover at this range of moisture has been successfully conserved in anaerobic conditions (Shinners et al., 2007a,b; 2009) but no previous research was found to suggest successful preservation at this moisture range under aerobic conditions.

As expected the silo bag where anaerobic conditions were maintained preserved the material very well. There was considerable fermentation acid production which might be considered a loss if the acids could not be converted to a useful product at a biorefinery. None of the aerobic storage methods preserved the stover DM and there was rampant mold growth throughout all three aerobic structures. The heating in the covered and uncovered piles was prolonged and reached temperatures where spontaneous combustion was a concern, as peak temperatures of 73°C were measured in the piles. The whole-plant, uncovered pile was in the worst condition with precipitation penetrating deep into the pile because there was no visible thatch or crust to help shed moisture. The cob/husk uncovered pile was observed to have formed a better crust or thatch and was able to keep some precipitation from the interior of the pile, but losses and material decomposition were still unacceptable.

Ideally, forcing ambient temperature air through the stover in an enclosed bag would have dried the stover, helping with preservation. Drying did occur near the ventilation tube, but at removal from storage moisture away from the tube was still well above 30% (w.b.) in most cases. Although the material around the ventilation tube was dry and generally free of mold, the rest of the aerated bag was poorly preserved with considerable evidence of mold.

The second harvest occurred in the third week of November when ambient temperatures were near freezing but the grain was 25% (w.b.), still well above typical (Shinners and Binversie, 2007). This harvest date would be quite late for south central Wisconsin due to concerns with snowfall. Despite the late harvest date, whole-plant and cob/husk moisture was 41% and 35%

(w.b.), respectively, so that successful preservation under aerobic conditions was still difficult. There was less heating and generally lower losses than when stover moisture was greater, but DM losses for all aerobic treatments still approached 10% and there was evidence of mold throughout each of the structures.

The difference in drying rate of the standing crop between the two years of this study shows year-to-year variations will cause the moisture of single-pass stover to vary considerably. What is needed are robust harvest and storage schemes that ensure excellent preservation no matter what the stover moisture. Successful stover conservation is quantified by low DM losses, minimal compositional changes and almost no mold growth. Only two storage methods met these criteria: stover stored in covered aerobic piles when stover moisture was less than 25% (w.b.) or stover stored anaerobically. The former system will likely not work for single-pass stover harvest except in those areas where the stover moisture can be expected to consistently reach 25% (w.b.) well before the winter weather ends the harvest season. In most of the US Corn Belt, this would not be the case, so a two-pass harvest system would be required where stover would be field wilted to the desired moisture prior to harvest. Anaerobic storage is the most robust method because it has been shown to produce excellent conservation over a wide variety of stover moisture. This is the only system that will provide the maximum flexibility with respect to weather and crop moisture.

A summary of previous research where stover was stored anaerobically shows DM loss averaged 3.3% across a wide range of moisture and ambient conditions (table 10). Fermentation products and pH were well correlated with initial stover moisture. Pitt (1990) suggested that bacteria will die when the silage enters the stable phase as the ensiled animal feed reaches 3.8 – 5.0 pH. Lactic and acetic acid are the most common acids formed during fermentation and the acidity (pKa) of these acids is 3.85 and 4.75, respectively, which limit the pH of most ensiled stover to 4.0 – 4.5 no matter the quantity of fermentation products. Conversion of cell wall contents to fermentation acids would considered a loss if these acids could not be converted to useful products at the biorefinery, so it would be appropriate to achieve the desired pH for stability while limiting the quantity of fermentation products. Individual samples of ensiled stover from silo bags stored in 2005 through 2008 were analyzed for pH and total fermentation acids and the data plotted versus wet basis moisture (fig. 6). If the goal is to achieve a pH of 4.0 to 4.5 but maintain reasonable production fermentation products, this plot indicates the desired moisture would be in the range of 35% to 45% (w.b.). This moisture requires considerably less water to be shipped compared to stover in the range of 45% to 60% (w.b.). For instance, if legal weight limits can be achieved, 44% more DM can be shipped when stover moisture is 35% (w.b.) compared to when it is 55% (w.b.). Low levels of fermentation products in ensiled animal feed would create concerns with aerobic stability at feed out, but feed out rate of biomass destined for a biorefinery would be comparatively much faster. Nonetheless, aerobic stability of ensiled biomass with low levels of fermentation products merits further research.

Table 13. Summary[a] of storage characteristics of whole-plant and cob/husk stover stored seven to nine months in anaerobic silo bags.

Year Into Storage	Material Type[b]	Into Storage Moisture (% w.b.)	DM Loss (% of total)	pH	Total Acids[c] (% DM)	Density .. kg / m^3 wet basis	Density .. kg / m^3 dry basis
2003	WP	41.7	1.4	4.1	5.0	227	131
2003	WP	55.4	3.8	4.1	4.2	275	122
2004	WP	42.2	6.0	4.8	2.4	170	96
2004	WP	42.8	4.2	4.8	3.6	224	128
2005	WP	51.3	4.1	4.2	5.9	390	194
2005	WP	50.1	3.5	4.2	5.3	245	120
2006	WP/CH	34.5	4.4	4.6	2.0	243	157
2007	WP	26.7	3.5	6.3	0.5	192	141
2008	WP	54.1	0.9	4.7	4.8	383	176
2008	CH	44.7	0.7	4.3	0.9	306	169

[a] – After Shinners et al., 2007a,b; 2009a.
[b] – Type of stover – WP - whole-plant stover, CH – cob/husk stover
[c] – Fermentation products consisted mainly of lactic and acetic acid

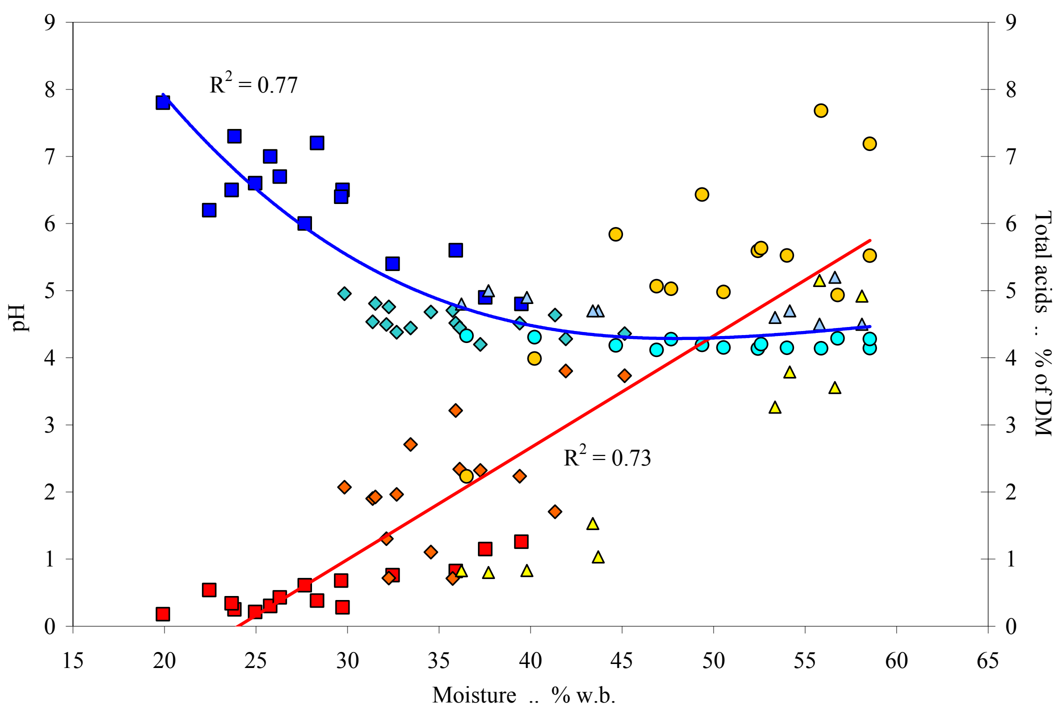

Figure 6. pH and total fermentation acids as a function of moisture for whole-plant stover stored at least seven months in anaerobic silo bags. Individual samples collected from silo bags at removal. Stover stored in 2005 (●), 2006 (◆), 2007 (■) and 2008 (▲).

SUMMARY

- Storage characteristics of two types of stover were investigated: whole-plant consisting of stalk, leaf, cob and husk (2007 and 2008) and cob/husk consisting of cob, husk and some top stalk (2008). Both materials were harvested using a single-pass harvester.

- In all cases, stover stored in uncovered piles was rehydrated from precipitation, which increased biological activity and produced DM losses from 8.2% to 39.1% with an average of 21.5%. When moisture content was greater than 46% (w.b.), temperatures in the structure averaged greater than 60ºC for prolonged periods.

- Stover in covered piles was successfully conserved when the average moisture was less than 25% (w.b.) with DM losses of 3.3% (2007). Stover above 36% (w.b.) and piled under a plastic cover heated during storage and had losses of DM from 6.4% to 20.2% with an average of 11.9%.

- The aerated bag was investigated as a method to use ambient air forced through the stover with a fan and perforated tube to dry the stover. Stover near the tube did dry, but the remainder of the bag did not. Loss of DM ranged from 7.4% to 22.0% with an average of 11.8%.

- Mold was evident throughout most the aerobic structures at removal and the stover moisture varied spatially in the structures. The exception was the material under the covered pile stored at less than 25% (w.b.) moisture.

- Stover was most successfully conserved in the anaerobic silo bag. In two of the three bags formed, anaerobic conditions were maintained and DM losses ranged from 0.2% to 0.9%. In one case, holes where thermocouples were placed through the plastic bags were poorly sealed and little fermentation took place, so DM losses averaged 6.1% of DM.

ACKNOWLEDGEMENTS

This research was partially sponsored by the University of Wisconsin College of Agriculture and Life Sciences, John Deere Harvester Works, John Deere Moline Technology and Innovation Center, and the DOE (Grant No. NRCS 68-3A75-4-137). This research could not have been completed without the assistance of the staff of the Arlington Agricultural Research Station.

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