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HARVEST AND STORAGE OF WET CORN STOVER BIOMASS

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Abstract. *Stover moisture was dependent on growing conditions, stover component, timing of grain harvest and length of time between grain and stover harvest. The ratio of stover mass harvested to total stover DM yield averaged about 55, 50 and 37% for chopping, wet baling, and dry baling, respectively. Harvesting wet stover as chopped material and ensiling in a bag was successful with average DM matter loss of 10.9% after 7 to 8 months storage. Harvesting wet stover by baling and tube wrapping was also successful with average DM loss of 2.9%. Dry stover bales stored indoors and outdoors had average DM losses of 3.3 and 18.1%, respectively. Stover harvested and stored as wet material had fewer weather related delays, greater harvesting efficiency, lower storage losses, more uniform moisture, and in some situations lower moisture after storage than dry stover stored outdoors.*

Keywords. Biomass, corn stover, harvesting, silage, storage.

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Abstract

The moisture in the total stover fraction was between 65 and 58% (2002-typical conditions) and between 58 and 39% (2003-dry conditions) when grain moisture was between 30 and 20%. Stover was successfully preserved by ensiling in this moisture range, indicating direct harvest of stover at grain harvest is possible. The ratio of stover mass harvested to total stover DM yield, i.e. the harvesting efficiency, averaged about 55, 50 and 37% for chopping, wet baling and dry baling, respectively. Harvesting wet stover as chopped material and ensiling in a silo bag was successful with DM matter loss at 10.9% after seven to eight months storage. Harvesting wet stover by baling and tube wrapping was also successful with DM loss of 2.9%. Dry stover bales stored indoors and outdoors had average DM losses of 3.3 and 18.1%, respectively. Average DM loss for bales stored outdoors was 10.0, 14.0 and 30.3% for bales wrapped with net wrap, plastic twine and sisal twine, respectively. Average outdoor storage was 15.0 and 21.2% when precipitation during the storage period was 235 and 734 mm (9.3 and 28.9 in.), respectively. Independent of wrap type, the average DM loss was 21.0 and 15.2% for bales stored outdoors on the ground and outdoors on a well drained surface, respectively. Stover harvested and stored as wet material had fewer weather related delays, greater harvesting efficiency, lower storage losses, more uniform moisture, and in some cases lower moisture after storage than dry stover stored outdoors

Background

There is increased emphasis on renewable energy and environmental sustainability by the conversion of biomass to transportation fuel, electricity, and industrial products. The Biomass Research and Development Board (2001) projected a three-fold increase in bio-ethanol, bio-diesel, bio-electricity, and emerging bio-based products over the next decade. It is estimated that in 2020 over 500 million tons of bio-based feedstock will be required annually to meet the energy needs of the US without increases in imported energy (Sokhansanj and Wright, 2002). Alternative feedstocks such as crop residues could help meet the increased demand for renewable resources

Corn stover is residue left on the soil surface after corn grain has been harvested. It consists of stalk, leaf, cob and husk fractions. Based on reported corn grain production, it has been estimated that approximately 220 million dry tons of corn stover could potentially be harvested annually (Glassner et al., 1998). Compared to other biomass commodities such as switchgrass, hybrid poplars, and small-grain straw, corn stover has considerable advantages in that the grain fraction is a high value co-product, and the yield of corn stover is quite high. Among many possible uses, corn stover has been proposed as a feedstock for enzymatic hydrolysis of cellulose to fermentable sugars to produce fuel ethanol, direct combustion or gasification to produce electricity, and processing of specific fractions into a supplemental fiber source for paper pulp.

Corn stover has been harvested as supplemental feed for beef and non-lactating dairy animals for decades. Typically it is harvested as a dry product packaged and stored in round bales. Because corn stover availability typically greatly exceeds on-farm demand, there has not been much economic incentive to understand and improve stover harvesting systems. However, knowledge of the mass, moisture and constituent distribution of the various stover fractions, as well as the stover drying rate after grain harvest and storage characteristics, are critical when considering corn stover as a widely harvested marketable commodity.

Like forage for ruminant animals, corn stover can be harvested and stored as a dry or ensiled product. The dry system typically involves the following steps beyond grain harvesting: shredding with flail shredder, field drying, raking into a windrow, and baling. Shredding and windrowing can be combined, but this can slow drying during an already difficult drying period, so most producers shred and lay the stover as wide as possible. The time after grain harvest for stover to reach baling moisture has been reported to take from several days to weeks because of the low ambient temperatures and frequency of rain during the fall harvest season (Schechinger and Hettenhaus, 1999). Ensiling high-moisture stover virtually eliminates the field drying process, increasing the available harvest window. A single-pass grain and stover harvesting scheme would reduce costs and produce the highest-quality product and ensiling is the only reasonable storage method for direct harvested stover. Single-pass grain and stover harvesting was estimated to reduce stover delivered costs by roughly 25% compared to dry-bale stover systems (Shinners et al., 2003).

Fractional stover mass, fractional constituent yield, and fractional stover moisture in relation to grain physiological maturity are critical information because these relationships affect harvest timing, equipment selection and development, storage and transportation methods, and processing requirements; all of which ultimately affect the delivered cost of corn stover. This data needs to be collected in the Northern Corn Belt because the great majority of potential stover yield resides above the 39th parallel (NASS, 2003). There is limited technical data concerning the harvesting and handling of corn stover on a large scale. Some research has been conducted in this area by Edens et al. (2002); Montross et al. (2002) and Pordesimo et al. (2002). Research is needed to address timeliness, productivity, drying rate, moisture, soil contamination, and storage losses under typical Upper Midwest conditions.

Objectives

The specific objectives of this research were:

- To determine the yield and moisture of the various fractions of the corn plant before grain harvest.
- To determine the drying rate of corn stover after grain harvest as affected by harvest date and conditioning treatment.
- To determine the field performance and storage characteristics of harvesting wet corn stover by chopping and storing in a bag silo or by baling and wrapping in plastic film.
- To determine the field performance and storage characteristics of harvesting dry corn stover and packaging in large round or square bales and storing inside or outdoors.

Procedures

Yield and Moisture Characteristics

Four different corn hybrids grown in five separate fields were evaluated for yield and moisture during a 50-day period from August 28th to October 16th, 2002 and during a 58-day period from August 22nd to October 20th, 2003 (table 1). The average field size was about 5 ha (13 ac) and the crop was grown on 76-cm (30-in.) row spacing. Target plant population was about 79,000 seeds/ha (32,000 seeds/ac) for all varieties and fields. Approximately every five days, five plants per field were harvested by hand cutting at about 10 cm (4 in.) from the ground. Plants were selected in an approximate “X” pattern in the field, i.e. one plant from the center and one each from the center of each quadrant. The five plants were pooled together each day to form a representative sample of each field. The plants were transported to a laboratory and hand separated into five fractions: grain, cob, husk, leaf and stalk. The leaf sheath was assumed to be part of the stalk. The stalk was further subdivided into quarters by length and identified as top, mid-top, mid-bottom, and bottom fractions. All sub-fractions, except the grain, were size-reduced by chopping with a laboratory-scale cutterhead set to a TLC of 12 mm (½ in.) The mass of the entire contents of all sub-fractions was determined before and after oven drying at 103ºC (217ºF) for 24 h in accordance with ASAE Standard S318.2 (ASAE, 2002). Plant population was determined by counting the number of plants in several random 30 m (100 ft.) rows in each field. The yield of each fraction was determined by multiplying the mass by the measured plant population.

Table 1. Corn crop information concerning the five fields used in the stover yield and moisture studies conducted in 2002 and 2003.

Variety	CRM* days	Dates		Final Population	
		Planting	Harvest	plants/ha	(plants/ac)
2002					
Pioneer 35R58	105	5/3	10/17	62,165	25,170
Kaltenberg 6789	108	4/23	"	79,380	32,140
" "	"	"	10/8	74,600	30,200
Agri-Gold 6382	102	4/26	10/19	77,830	31,510
DeKalb 570RR	101	"	10/11	61,690	24,970
2003					
Pioneer 35R58	105	4/25	10/10	75,075	30,395
" "	"	5/13	10/30	75,195	30,444
Kaltenberg 6789	108	4/24	10/29	79,020	31,992
Agri-Gold 6333	109	4/23	11/6	75,555	30,589
AsGrow 601RR	104	4/25	10/30	63,479	25,700

* Wisconsin Comparative Relative Maturity Index (Lauer, 1998)

Stover Field Drying Characteristics After Harvesting

Two drying trials were conducted in the fall of 2002: one that commenced on 10/9 and another on 10/21. Three drying trials were conducted in the fall of 2003 commencing on 10/2, 10/10 and 11/6, respectively. Within a few hours of harvest of the grain fraction with a conventional combine harvester in all trials, a portion of a field was subdivided into blocks and the following three treatments applied to each block: untreated; shredded and laid full-width; and shredded and windrowed. In 2003, a fourth treatment was added consisting of a shredded and doubled windrow (i.e. two single windrows merged into one). Each treatment was replicated with four blocks at each trial and the treatments were randomly assigned within each block. The formed single windrow was about 1 m (3 ft.) wide by 100 m (300 ft.) long. The only wheel traffic allowed in the field during harvest was that of the harvester. In 2002, shredding was accomplished with a 4.6 m (15 ft.) wide Buffalo model 4915 flail shredder equipped with windrow forming shields. In 2003, shredding was accomplished with a 4.6 m (15 ft.) wide Balzer model 1500 flail shredder which could not form a windrow. Therefore, single or double rotary rakes were used to form the subsequent single or double windrows, respectively. In both years, the shredder was operated at about 10 cm (4 in.) above the soil surface at a speed of about 6.5 km/h (4.0 mi/h).

Samples for moisture determination were collected the day the sub-plots were formed and daily for three days after that. Samples were collected sporadically after that as weather permitted, but typically samples were collected every two or three days for up to 20 days after grain harvest. One sub-sample was collected from each sub-plot by gathering by hand all the material in an area about 0.5 m^2 (6 $ft.^2$) that spanned across two rows. Samples were placed in plastic bags, transported to a laboratory, sized reduced as described above, and the entire sub-sample oven dried at 103ºC (217ºF) for 24-h in accordance with ASAE Standard S318.2 (ASAE, 2002). Weather data such as temperature and precipitation were recorded during the drying periods on an automated weather station.

Harvesting and Storing Wet Stover – Chopped and Bagged

One field in 2002 and two fields in 2003 were first harvested using a conventional combine harvester. Typical field size was about 6 ha (15 ac). Harvesting took place on 10/08/02, 10/13/03 and 10/30/03. No other traffic was allowed on the field prior to shredding. Within several hours of grain harvesting the stover was shredded and windrowed using a 6 m (20 ft.) wide Hiniker model 5600 flail shredder set to operate at about 15 cm (6 in.) from the soil. The shredder had an attachment that allowed a windrow to be formed on the far right-hand side of the machine. On the subsequent pass in the opposite direction, another windrow was placed immediately adjacent to the first. This doubling of windrows was performed to match the capacity needs of the forage harvester. In 2002, the shredded and windrowed stover was allowed to sit overnight and harvesting commenced the next day. In 2003, the windrowed stover was harvested within 1-2 h of grain harvest. A John Deere model 6950 self-propelled forage harvester equipped with a 4.5 m (15 ft.) wide model 645 windrow pick-up was used to gather and chop the stover. The harvested material was collected in a Miller Pro model 4012 side-dumping forage container specially equipped with load cells to determine harvested mass. The material was dumped into straight-axle trucks, the load leveled by hand and the height from the top of the truck measured to determine volume occupied by the stover. The harvested mass and transport volume were used to calculate chopped stover density. The forage harvester was used to harvest roughly 15 loads per field, five each at 6.4, 12.7 and 19.1 mm (0.25, 0.50 and 0.75 in.) TLC. The total time and distance required to harvest a load was also recorded so that harvesting rate and yield could be determined. The material was then unloaded into a Kelly Ryan silo bagger and placed in a 2.4 m (8 ft.) diameter plastic silo bag. The location of each load was marked on the bag and later the length and diameter of the bag at each load was determined so that silo density could be calculated. Prior to placing in storage, sub-samples were collected for moisture and particle-size determination. Moisture was determined on three sub-samples per load by oven drying at 103ºC (217ºF) for 24 h in accordance with ASAE Standard S318.2 (ASAE, 2002). Particle-size was determined on three sub-samples per TLC in accordance with ASAE Standard S424.1 (ASAE, 2002). In addition, particle-size was determined on two or three sub-samples of the untreated and shredded stover prior to chopping.

Harvesting and Storing Wet Stover – Baled and Wrapped

One field in 2002 and two fields in 2003 were first harvested using a conventional combine harvester. Typical field size was about 3 ha (7 ac). Harvesting took place on 10/11/02, 10/24/03 and 10/30/03. No other traffic was allowed on the field prior to shredding. Within an hour of grain harvesting the stover was shredded and windrowed using a 4.6 m (15 ft.) wide flail shredder set to operate at about 10 cm (4 in.) from the soil. A Kuhn model GA7301 twin-rotor rotary rake was then used to merge two windrows into one to match the capacity needs of the balers. In 2002, large square bales were formed with a Case IH model 8575 baler (80-cm W x 88-cm H; 31.5-in. W x 34.5-in. H) set to deliver bales about 150-cm (60 in.) in length. In 2002, large round bales were formed with a John Deere model 566 (150-cm W x 180-cm ϕ; 60-in. W x 72-in. ϕ) using sisal twine on 15-cm (6-in.) spacing plus six end wraps. In 2003, the same round baler was used but either plastic twine on 15-cm (6-in.) spacing plus six end wraps or 2½ layers of to-edge mesh wrap were used to secure the bales. All bales were weighed in the field to the nearest 0.5 kg (1 lb.) using a 1,800 kg (4,000 lb.) capacity platform scale. All bales were bored once on each side to a depth of about 50-cm (20-in.) using a 5-cm (2-in.) diameter boring tube to collect material for moisture determination. Moisture samples were oven dried at 103ºC (217ºF) for 24-h in accordance with ASAE Standard S318.2 (ASAE, 2002). Relevant bale dimensions were measured in the field to allow calculation of bale density. Bales were then wrapped in eight layers of 1-mil white plastic film using an H & S model LW2 tube line wrapper. Large square bales were placed with their longitudinal axis perpendicular to the longitudinal axis of the tube. In 2002, a total of 16 large round and 16 large square bales were formed and wrapped. In 2003, a total of 8 net and twine wrapped bales each were formed each day. Total time to form each bale and distance covered to form each bale were determined during formation in order to calculate yield and harvesting rate.

Harvesting and Storing Dry Stover – Baled

One field each in 2002 and 2003 were first harvested using a conventional combine harvester. Typical field size was about 4 ha (10 ac). Grain harvesting took place on 10/17/02 and 10/10/03. No other traffic was allowed on the field prior to shredding. The stover was allowed to sit for a few days and then was shredded and windrowed using a 4.6 m (15 ft.) wide flail shredder set to operate at about 10 cm (4 in.) from the soil. In 2002, several rain events prevented baling until 11/27/02. The day before baling, a Kuhn model GA7301 twin-rotor rotary rake was used to invert and merge two windrows into one to aid in final drying and to match the capacity needs of the balers. In 2003, the field was raked similarly on 10/22/03. In both years, large square bales were formed (10 bales in 2002; 5 bales in 2003) with a Case IH model 8575 baler (80 cm W x 88 cm H; 31.5 in. W x 34.5 in. H) set to deliver bales about 200 cm (80 in.) in length. In 2002, large round bales were formed with a John Deere model 456 (117 cm W x 152 cm ϕ; 46 in. W x 60 in. ϕ) using either plastic twine (8 bales) or sisal twine (4 bales) on 15 cm (6 in.) spacing plus six end wraps or 2½ layers of to-edge mesh wrap (16 bales). In 2003, round bales were formed with a John Deere model 566 (150 cm W x 180 cm ϕ; 60 in. W x 72 in. ϕ) using plastic twine (12 bales) or sisal twine (12 bales) on 15 cm (6 in.) spacing plus six end wraps or 2½ layers of to-edge mesh wrap (18 bales). All bales were weighed in the field to the nearest 0.5 kg (1 lb.) using a 1,800 kg (4,000 lb.) capacity platform scale. All bales were bored once on each side to a depth of about 50 cm (20 in.) using a 5 cm (2 in.) diameter boring tube to collect material for moisture determination. Moisture samples were oven dried at 103ºC (217ºF) for 24-h in accordance with ASAE Standard S318.2 (ASAE, 2002). Relevant bale dimensions were measured in the field to allow calculation of bale density. Total time and distance to form each bale were determined during formation in order to calculate yield and harvesting rate. All large square bales and eight (2002) or six (2003) net wrapped round bales were stored inside an open front hay shed. The remaining round bales were stored outdoors with half of each wrap type stored directly on the soil and half on a raised, well-drained surface (wooden pallets). The rows of round bales were placed on a level surface in a line running north-south with the ends butted tightly together and no obstruction to shade the surfaces.

Bales were removed from storage on June 19th and 20th, 2003 (2002 bales) or June 28th and 29th, 2004 (2003 bales). Bales were weighed and bored for moisture samples using the same equipment and procedures described above. Before the bale was weighed, the maximum width, height and bottom length in contact with the soil was measured on both ends of the bale. Bore samples from several locations were collected from round bales stored outdoors to accurately assess the average bale moisture. Four samples were taken to a depth of about 30 cm (12 in.), one from each side and two from the bottom of the bale. The two side and bottom moistures were averaged and defined as the rind and bottom moistures, respectively. Two additional bore samples, one from each side, were taken from a depth of 30 to 50 cm (12 to 20 in.) and average moisture defined as the core moisture. The overall volume adjusted bale moisture was calculated using these moistures and the bale dimensions explained above.

Results and Discussion

Yield and Field Drying Characteristics

Average growing conditions were similar in 2002 and 2003, with total precipitation of 437 and 419 mm, respectively. However, in the reproductive and grain filling stages (roughly 7/15 to 9/15), total precipitation was 145 and 44 mm for 2002 and 2003, respectively, so the plants were under moisture stress in 2003 which negatively affected grain yield. Stover DM yield was greatest at the beginning of the study and declined throughout the early study period before leveling off near grain harvest (fig. 1). The loss of stover mass occurred primarily because leaves, husk and the upper stalk senesced and were lost by abscission as they became dry and brittle (table 2). Dry matter loss in the cob was most likely due to respiration and microbiological activity. Stalk yield decreased slightly over time in 2002, but was somewhat reduced in 2003 when the crop was under moisture stress. Loss of stalk mass was primarily from the top half of the stalk as the plant weathered and deteriorated. However, mass was lost from the whole stalk in 2003 due to moisture stress and the resulting plant senescence (table 2). These results are similar to those found by Johnson et al. (1966) and Pordesimo et al. (2002). In both years of the study, roughly 43 and 84% of the stalk DM was found in the bottom one-quarter and one-half of the stalk, respectively (table 2). If stover yield is to be maximized, harvesting systems must be developed that allow the bottom half of the stalk to be completely harvested. At the time of grain harvest, about 16, 8, 18 and 58% of the total stover dry mass resides in the cob, husk, leaf and stalk fractions, respectively (table 2). Two single-pass stover/grain harvest scenarios have been proposed. One involves using a modified crop unit on the grain combine that chops and conveys a majority of the stalk and leaf fractions while passing the grain, cob, husk and some leaf and stalk fractions through the combine, depositing the non-grain fractions on the soil surface (Shinners et al, 2003).

Assuming that the modified crop unit would capture the entire bottom half of the stalks, 50% of the top half of the stalk and 50% of the leaves, then about 65% of the potential stover would be harvested, leaving 7.7 Mg DM/ha (3.4 ton DM/ac) for erosion control and fertilization (table 2). Another harvesting scenario involves capturing the non-grain fraction from the rear of the combine after grain separation. This would include all the cobs and husk and 50% each of the leaf and top stalk and would result in the harvest of about 35% of the potential stover (table 2).

Grain yield continued to increase until about two weeks before typical harvest date, results that were similar to those reported by Johnson et al. (1966) (fig. 1). Grain yield was significantly reduced in 2003 due to moisture stress during the reproductive and grain filling stages. The ratio of grain to total dry mass is important when estimates of stover potential yield are made based on grain yield. Research reported by Leask and Dynard (1973), Preston and Schwinn (1973), Lipinsky et al. (1977), Nielson (1995), Linden et al. (2000) and others indicated a grain mass fraction of 45 to 55% of total corn crop DM yield. A common rule of thumb used when considering biomass feedstock potential from corn stover is that the mass of stover will be about equal to the mass of grain harvested (Smil, 1983). In 2002 when rainfall was adequate during grain formation, this was true only for a short period early in the fall, much earlier than typical corn grain harvesting dates (fig. 2 and 3). Historically, grain harvest in Wisconsin begins on or about October 1st and is most active from October 15th through November 15th (USDA, 1996). Stover represented less than 45% of the total crop mass when grain moisture was less than 30% and ready for harvest. These results are similar to those found by Pordesimo et al. (2002). In 2003, when moisture stress depressed grain yield, stover represented 45 to 50% of the crop mass when grain moisture was less than 30%. The ratio of stover to total crop mass was hybrid dependent and ranged from 41 to 46% and 46 to 54% at the typical outset of the grain harvest in 2002 and 2003, respectively (fig. 3). Under typical growing conditions when moisture deficiencies do not retard grain yield, stover yield can be expected to yield less than 45% of total crop dry mass at grain harvest.

Although there were some differences in moisture of the different hybrids, the data were pooled to provide a representative measure as the fall progressed. In both years of the study, the decline of moisture over time was greatest for the grain, leaf and husk fractions while the stalk remained relatively wet (fig. 4). The leaf and husk lost moisture because of senescence, and their large surface area and thin cross-section. After the grain reached "black layer" maturity, it was essentially sealed off from the rest of the plant and lost moisture through evaporation to the atmosphere. In 2002, the bottom half of the stalk was greater than 60% (w.b.) moisture throughout the fall harvest period (fig. 5). Under moisture stress in 2003, this was the case only for the bottom quarter of the stalk (fig. 5). The rind of the stalk is physiologically structured to maintain the moisture in the plant as a drought defense mechanism and this makes it difficult for moisture to leave the plant in the fall. Until the plant is truly dead, some evapotranspiration continues to take place even as the grain dries, so water will continue to move into the stalk from the root structure. Some sort of mechanical conditioning is needed after grain harvest to split the stalk to allow an egress for the moisture contained in the stalk pith.

Table 2. Dry matter yield of corn plant fractions near the beginning and end of study period.

	2002#					2003*				
	Aug 28th		Oct 14th		Change	Aug 29th		Oct 20th		Change
	Mg/ha	(ton/ac)	Mg/ha	(ton/ac)	%	Mg/ha	(ton/ac)	Mg/ha	(ton/ac)	%
Whole-plant	19.21	8.59	22.36	9.98	16.2	19.95	8.90	21.21	9.47	6.4
Grain	7.23	3.23	13.08	5.84	80.8	6.77	3.02	11.22	5.01	65.7
Cob	2.28	1.02	1.54	0.69	-32.6	1.84	0.82	1.52	0.68	-17.4
Husk	1.22	0.55	0.65	0.29	-46.5	1.30	0.58	0.92	0.41	-29.2
Leaf	2.89	1.29	1.53	0.68	-47.0	3.29	1.47	1.99	0.89	-39.5
Total stalk	5.59	2.50	5.56	2.48	-0.8	6.75	3.01	5.56	2.48	-18.6
Bottom stalk	2.52	1.13	2.52	1.13	0.0	2.72	1.22	2.29	1.02	-15.8
Mid-bottom stalk	1.99	0.89	2.08	0.93	4.5	2.57	1.15	2.41	1.08	- 6.2
Mid-top stalk	0.80	0.36	0.74	0.33	-7.5	1.11	0.49	0.84	0.38	-24.3
Top stalk	0.28	0.13	0.22	0.10	-23.4	0.35	0.16	0.15	0.07	-57.1

- Average of Pioneer, Kaltenberg and Agri-Gold hybrids (table 1). * - Average of all hybrids (table 1).

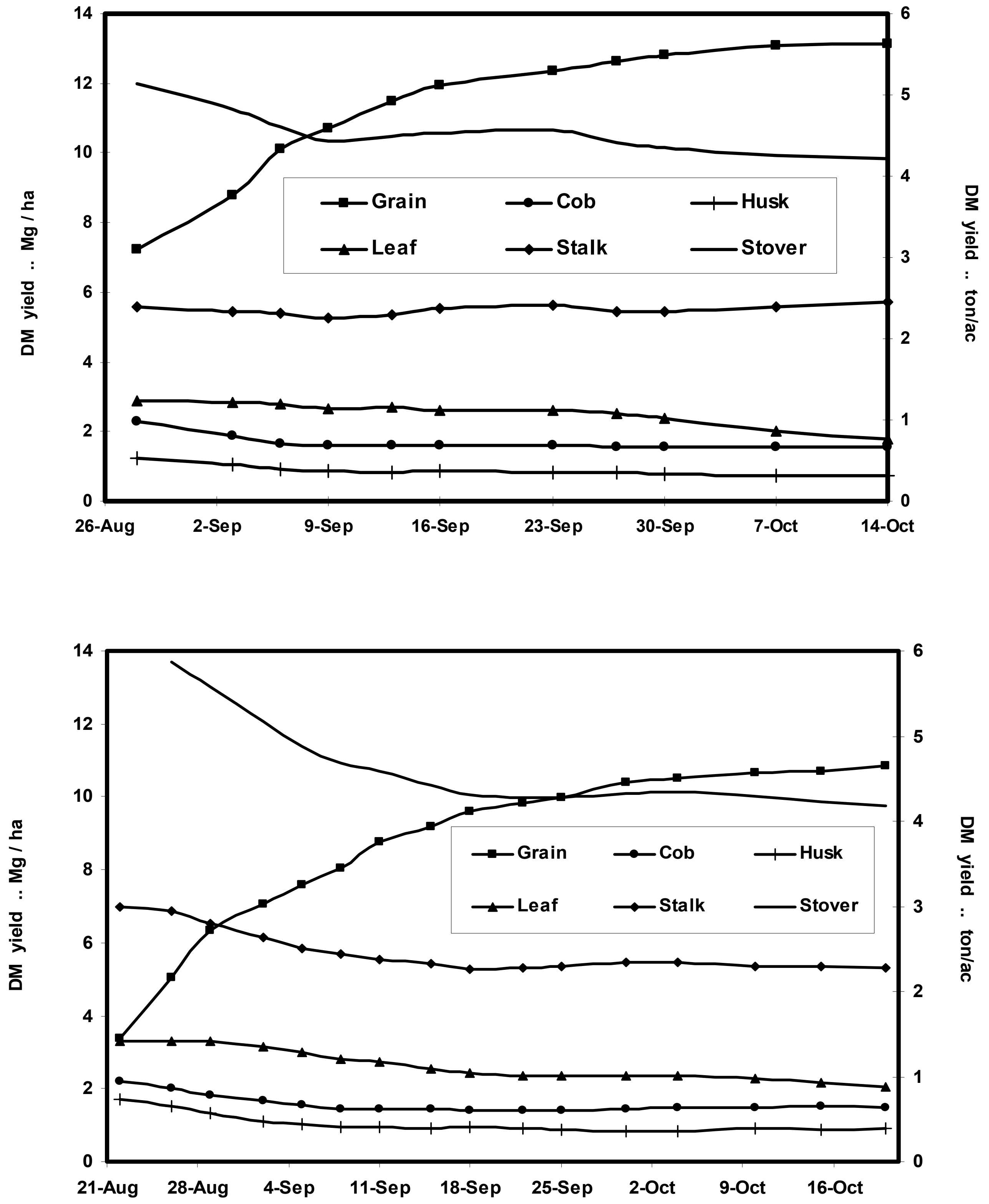


Figure 1. Dry matter yield of grain and stover fractions as fall progressed for 2002 (top – average of Pioneer, Kaltenberg and Agri-Gold hybrids) and 2003 (bottom – average of all hybrids).

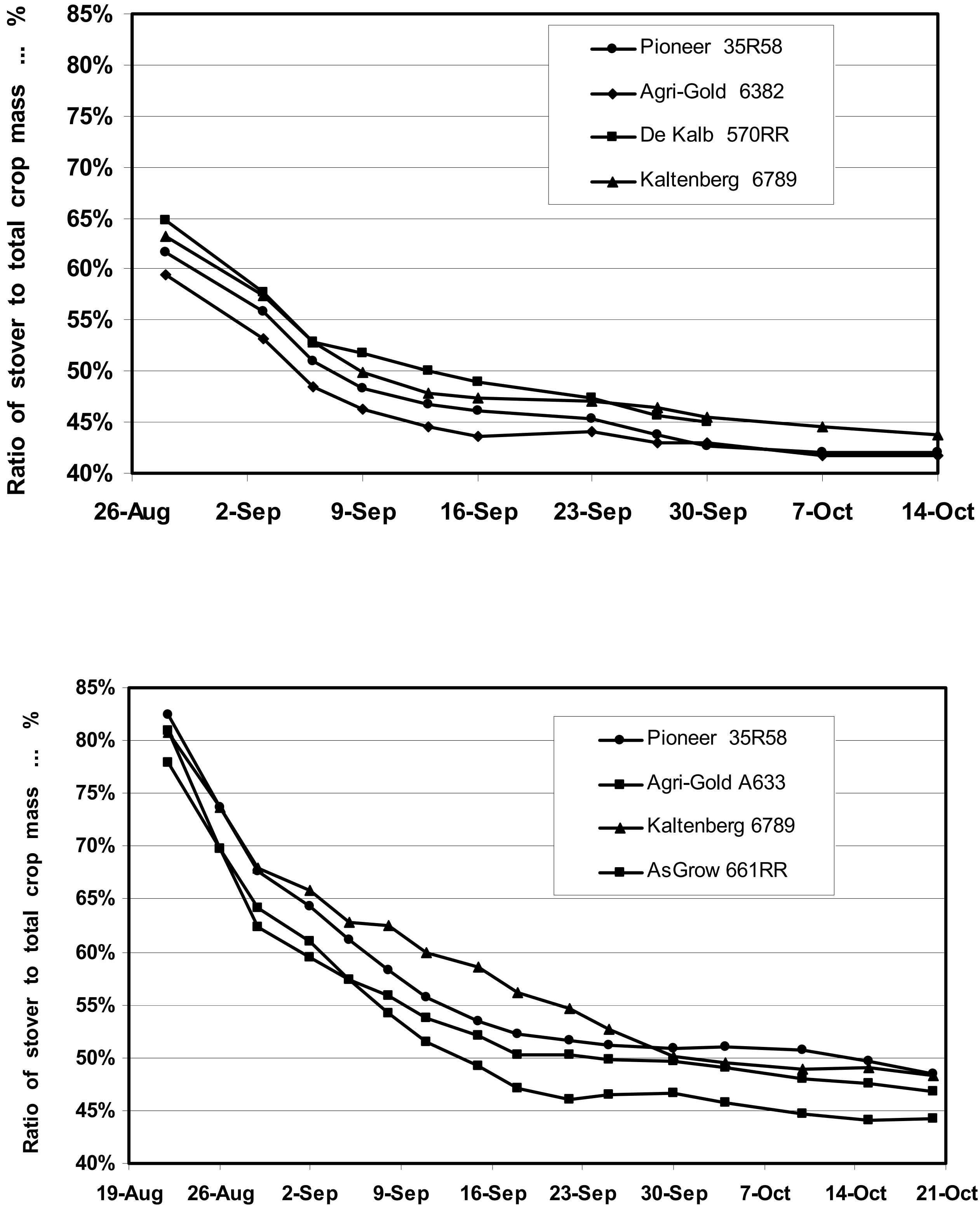
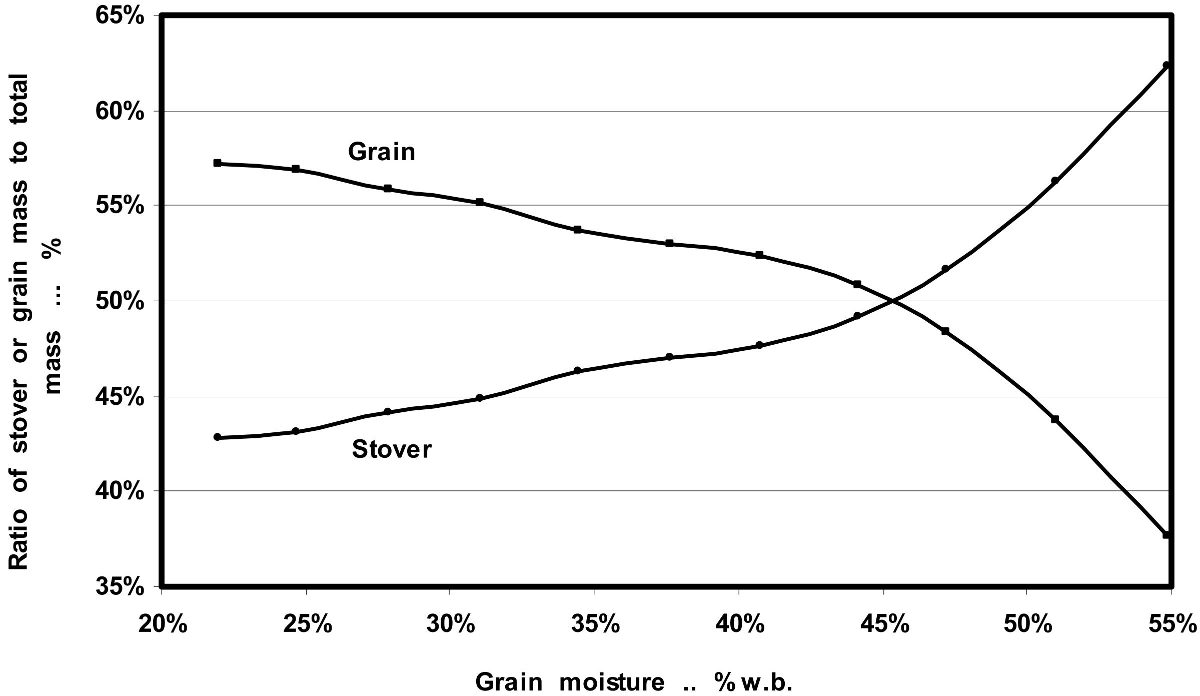


Figure 2. Ratio of dry stover mass to total crop dry mass for four different corn hybrids as fall progressed: 2002 (top) and 2003 (bottom).



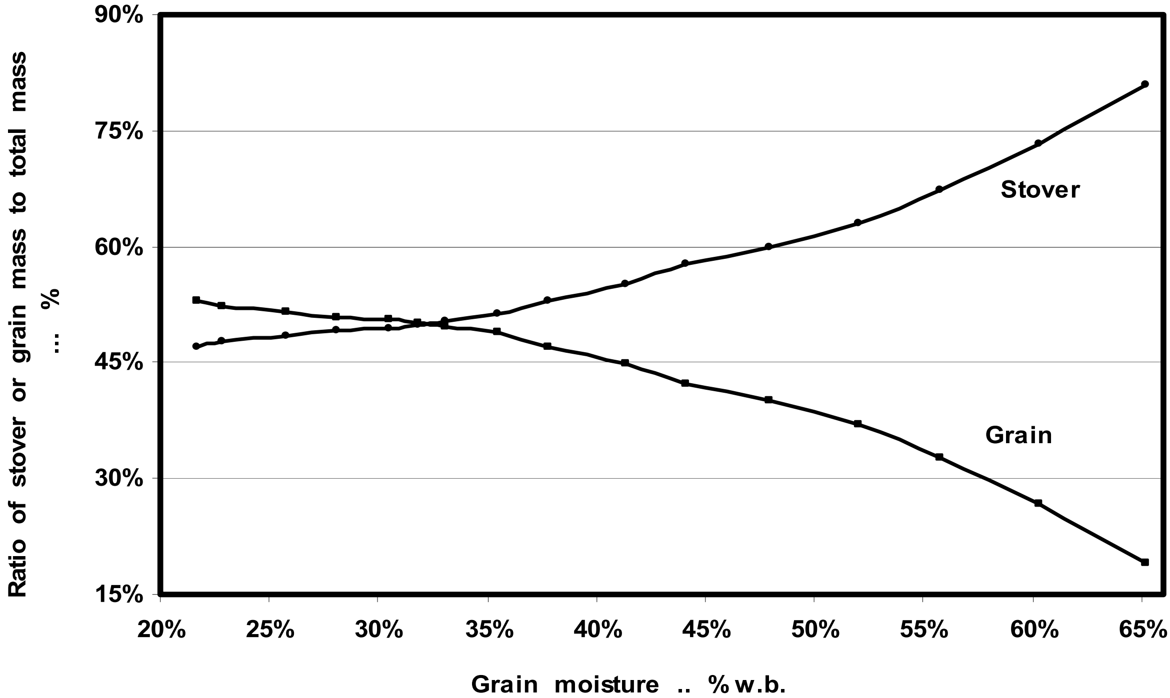
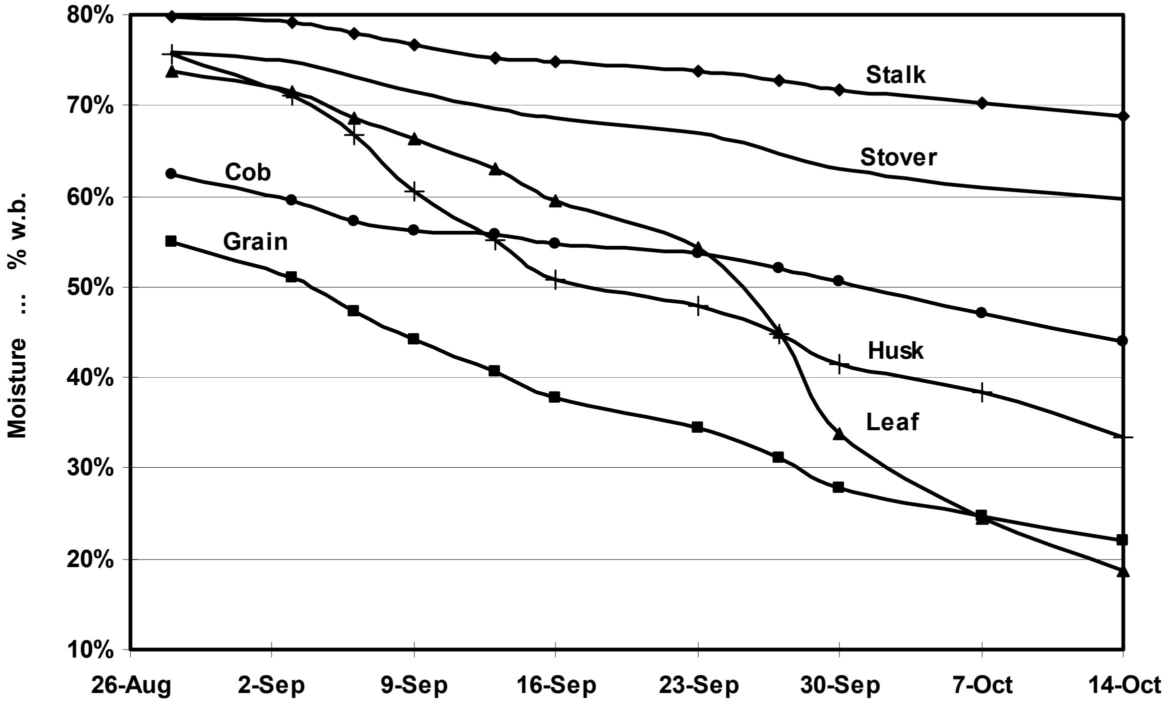


Figure 3. Ratio of stover or grain dry mass to total dry crop mass as a function of grain moisture (average of four hybrids): 2002 (top) and 2003 (bottom).



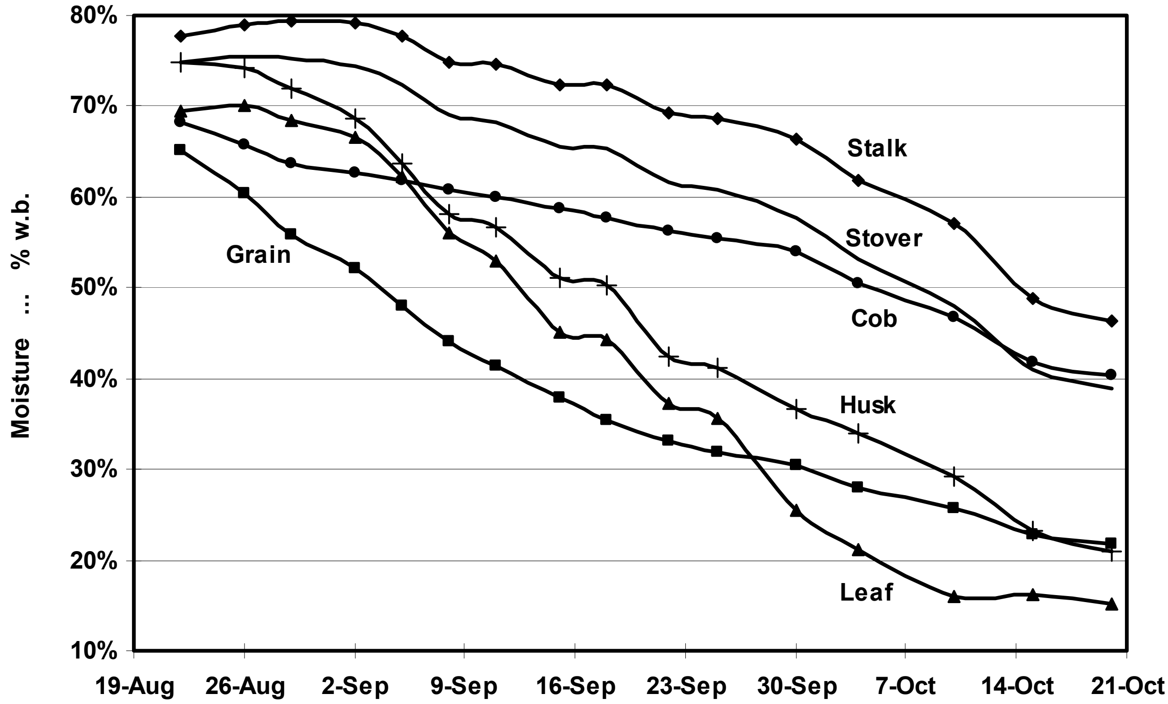
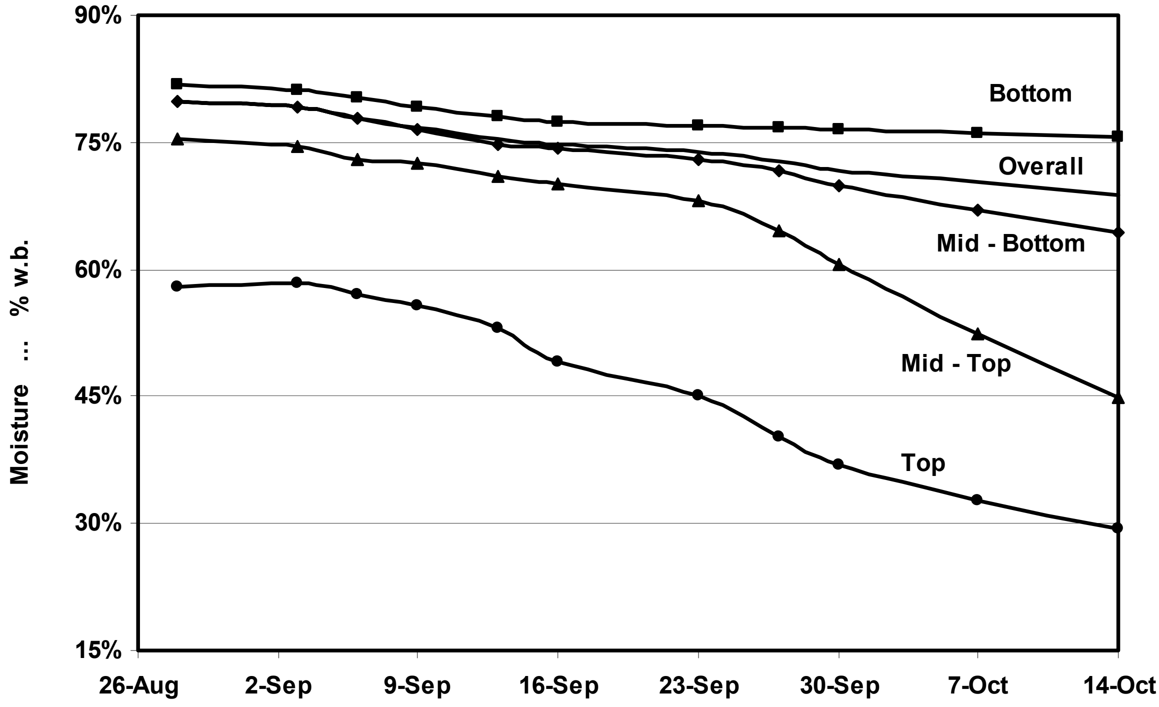


Figure 4. Moisture of corn plant fractions as the fall progressed for 2002 (top – average of Pioneer, Kaltenberg and Agri-Gold hybrids) and 2003 (bottom – average of all hybrids).



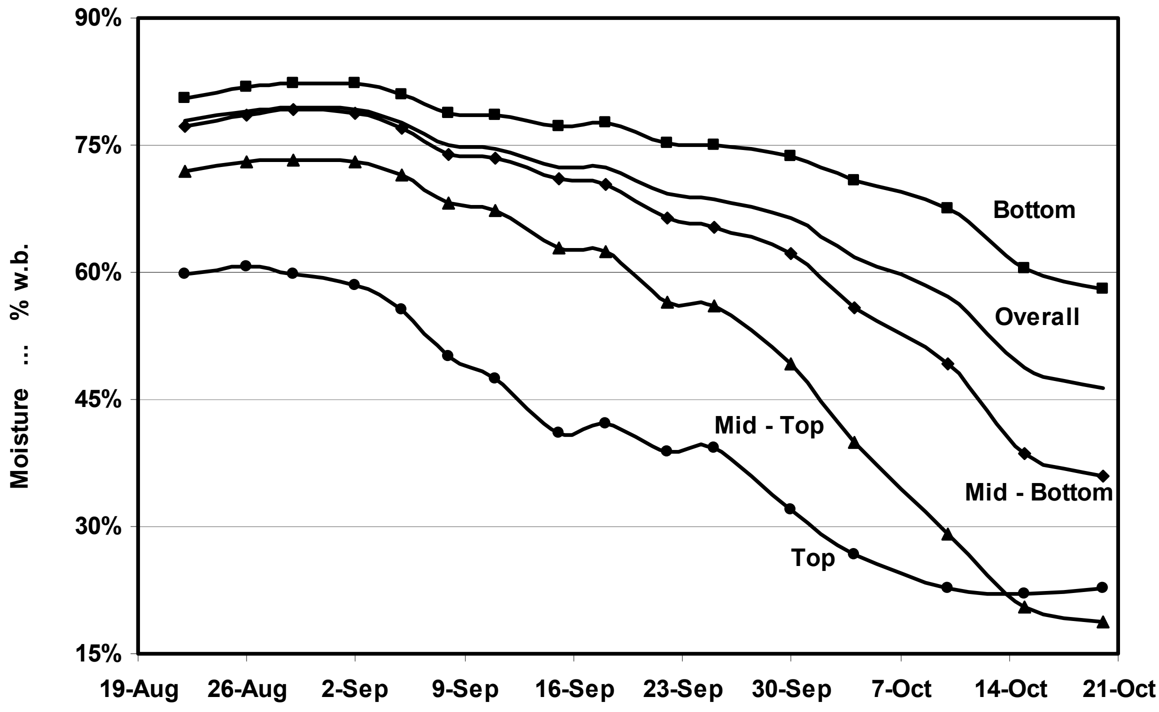
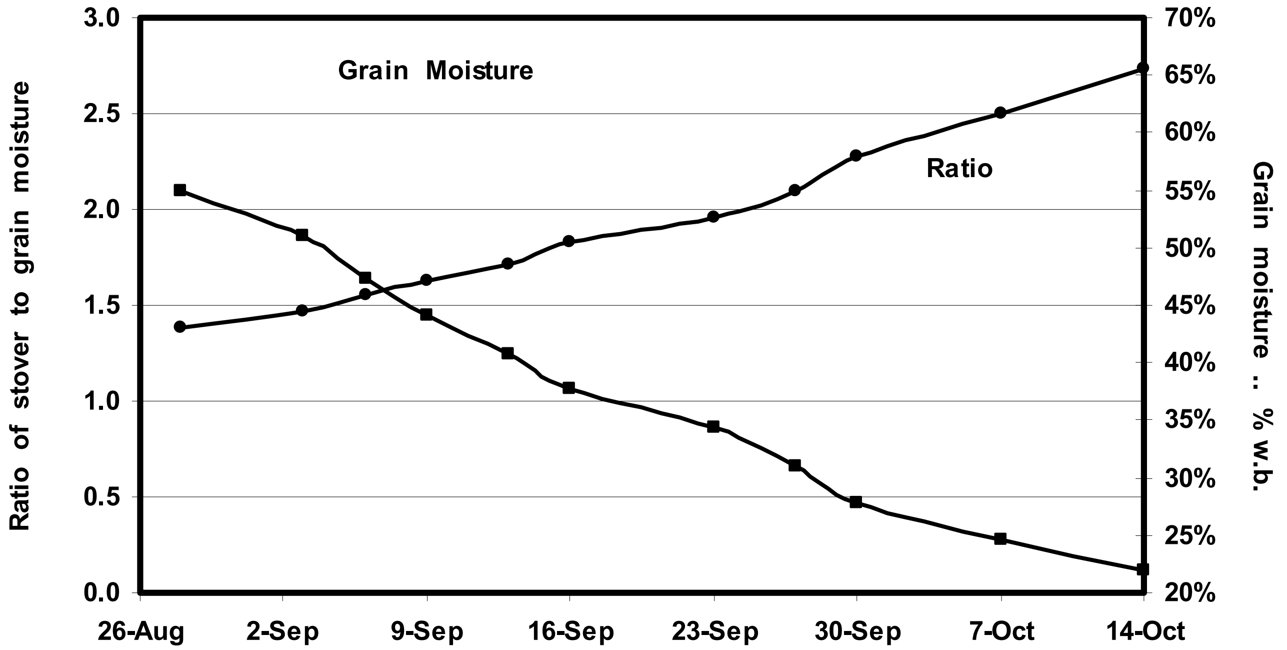
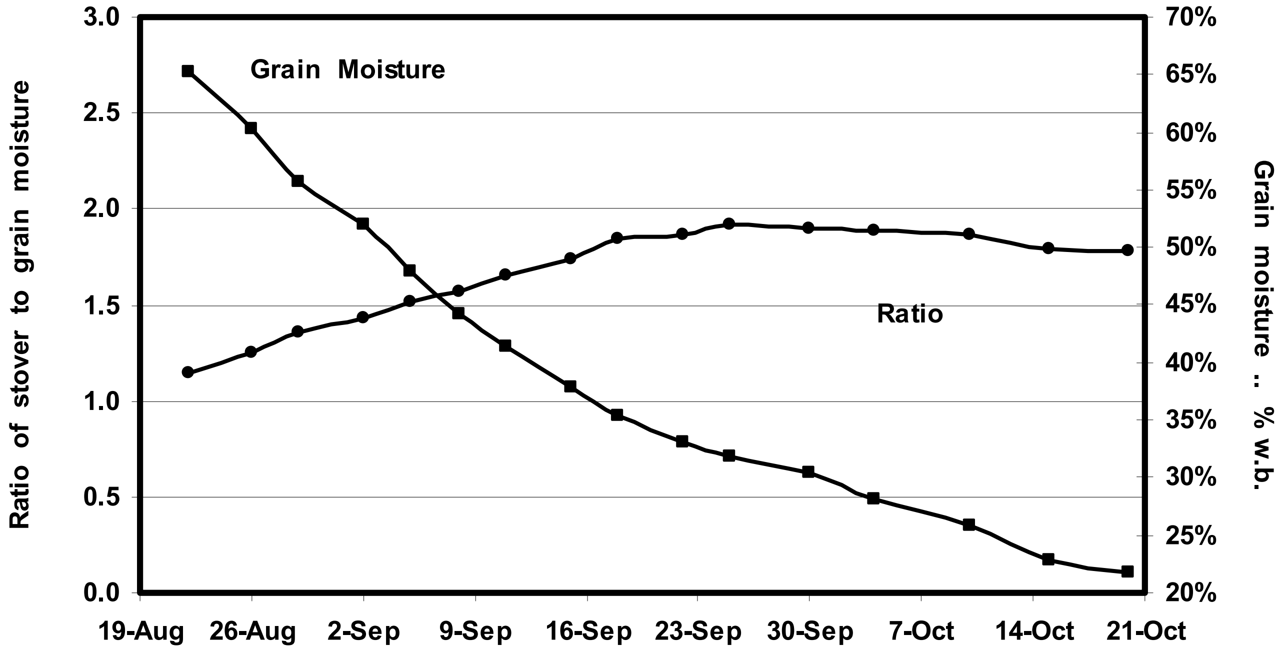


Figure 5. Moisture of various stalk fractions as the fall progressed for 2002 (top – average of Pioneer, Kaltenberg and Agri-Gold hybrids) and 2003 (bottom – average of all hybrids).





<u>Figure 6.</u> Ratio of stover to grain moisture as the fall progressed for 2002 (top: average of Pioneer, Kaltenberg and Agri-Gold hybrids) and 2003 (bottom: average of all hybrids).

Using one single-pass harvesting scenario which harvests the bottom half of the stalks, 50% of the top half of the stalk and 50% of the leaves, then stover moisture at grain harvest ranged from 69 to 65% under typical conditions in 2002 and 65 to 37% under moisture stress in 2003. This moisture range would be considered about ideal for adequate preservation by ensiling. The other single-pass harvesting scenario involves capturing the non-grain fraction from the rear of the combine and includes cobs and husk and 50% each of the leaf and top stalk, then stover moisture at grain harvest ranged from 45 to 33% under typical conditions in 2002 and 46 to 26% under moisture stress in 2003. This moisture range would generally be considered too low for adequate preservation by ensiling in a bunker or bag silo, although ensiling in wrapped bales at this moisture range could be accomplished (see below).

The moisture of the total stover fraction during the typical grain harvest moisture period (30 to 20%) ranged from about 65 to 58% in 2002 and 59 to 34% in 2003. The results in 2003 when moisture stress prevailed were similar to those reported by Edens et al. (2002). In their work, stover moisture ranged from 60 to 40% during the same period the grain was 30 to 20%. Their work was conducted in Tennessee where ambient conditions would favor more rapid dry down of the stalk, similar to those conditions experienced in the Upper Midwest in 2003. The results of 2002 show the difficulty that will be faced in the Upper Midwest when stover is to be dried under typical growing conditions for harvest as dry material because the initial stover moisture at grain harvest would be quite high. Another common rule of thumb is that stover moisture is roughly twice that of the grain (Buchele, 1975; Nielson, 1995). In 2002, this was only the case when the grain moisture was about 35% (fig. 6). Under typical conditions in 2002, the grain fraction lost moisture at a considerably faster rate then the stalk fraction so the overall stover:grain moisture ratio was much higher than 2:1 for most of the grain harvest period.

<u>Stover Field Drying Characteristics After Harvesting</u>

In 2002, field drying conditions were very challenging during the three weeks after grain harvest. There were small rain showers on 8 of the 23 days and two more significant rain events on day 9 and 16 of the drying period. A total of 25 mm (1in.) of rain fell during the 23 day drying period. The average temperature during the drying study was 4.8ºC (40ºF). These were about average conditions for Madison, Wisconsin during mid to late October (40 mm or 1.6-in precipitation and 9ºC or 48ºF). Only during one brief period did the moisture of two of the treatments reach the low 20% moisture range acceptable for baling (fig. 7) and that occurred seven days after grain harvest. In the second study, none of the treatments approached the desired moisture range during the 10 day drying period (fig. 7). In 2003, field drying conditioners were initially quite good and stover was dried to less than 20% moisture in about four days (fig 8). When several rain events occurred after shredding, none of the treatments reached this moisture after 10 days (fig. 8). Edens et al. (2002) reported that stover moisture was less than 20% within two weeks after grain harvest in Tennessee.

Mechanical conditioning in the form of flail shredding significantly improved the drying rate when the crop was placed in a wide swath behind the shredder (fig. 7 and 8). This occurred because the flail shredder worked well to split the stem open, allowing for the trapped moisture in the pith to more readily escape. Placing the shredded material in a narrow windrow at shredding is desirable because it could eliminate the need for raking prior to baling. Raking not only adds another field operation, but also increases the chance of soil and rock contamination. However, windrowing at shredding significantly reduced the drying

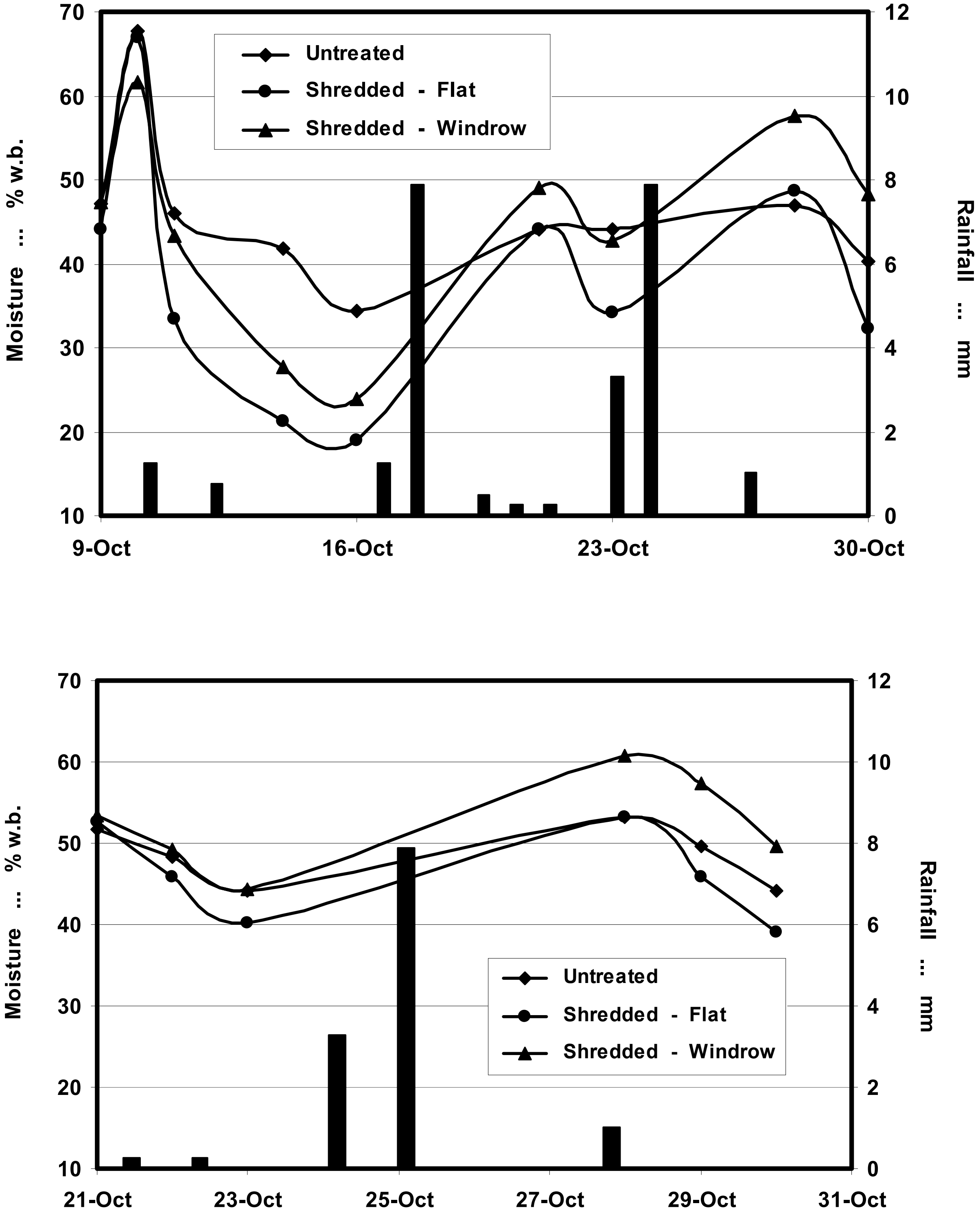


Figure 7. Drying rate of stover after grain harvest as affected by three conditioning treatments in 2002 (magnitude of rainfall events indicated by vertical bar).

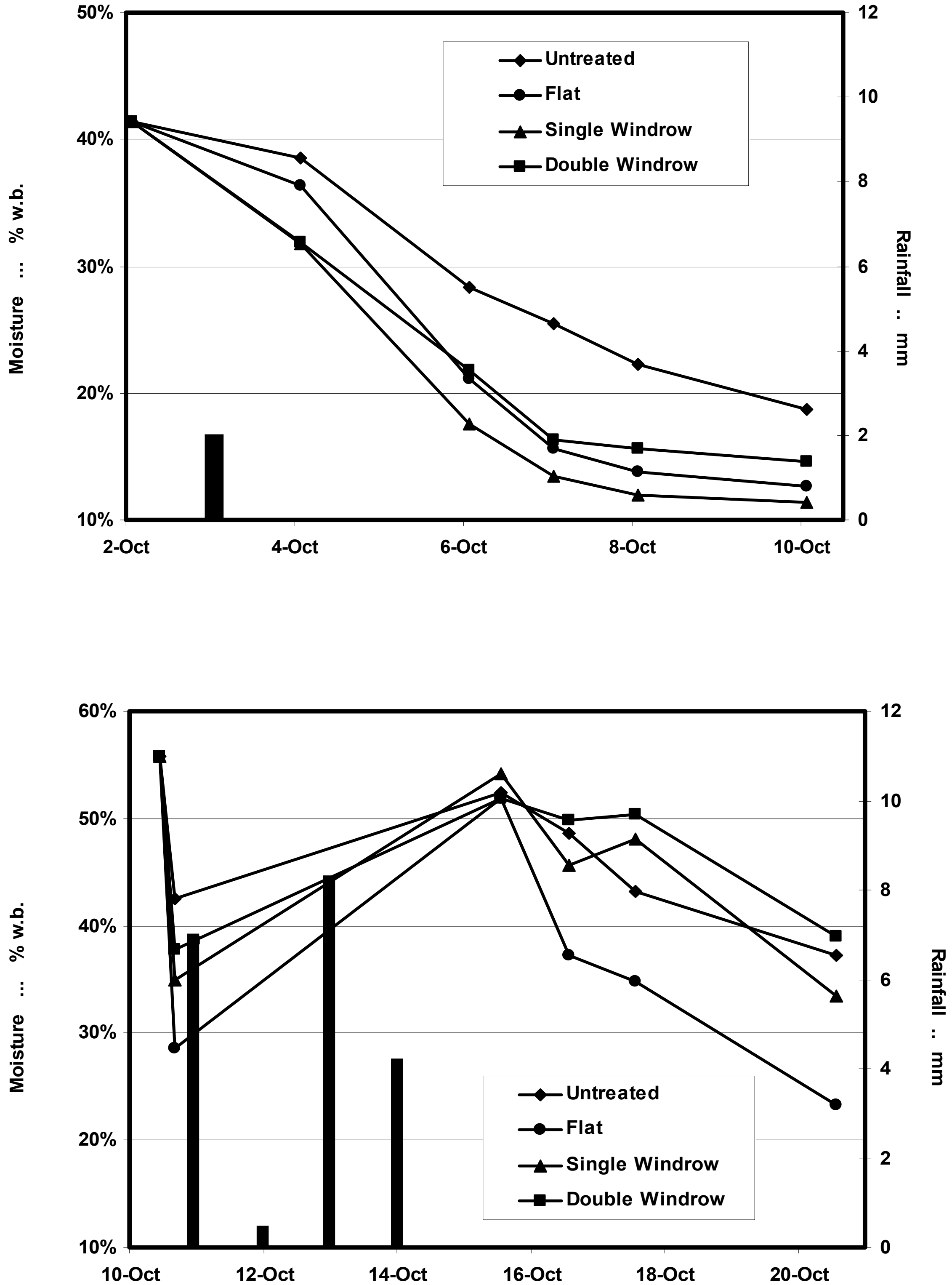


Figure 8. Drying rate of stover after grain harvest as affected by four conditioning treatments in 2003 (magnitude of rainfall events indicated by vertical bar).

rate, retarding it to the extent that the unconditioned control actually dried at a faster rate, especially when a double-density windrow was formed (figs. 7 and 8). The windrow density was such that air movement was probably restricted and the impact of the incoming solar radiation was minimized. When rain events occurred, the shredded treatments were more affected than the untreated treatments (figs. 7 and 8). This was presumably because the shredded treatments were laying close to the ground in a generally horizontal manner that promoted water sitting on the stover while a great majority of the untreated stover was still upright and allowed water to shed more easily. The results suggest that a device on the combine harvester that conditions the stalk but allows it to remain upright might enhance drying prior to a shredding operation that directly precedes baling. These results also suggest that delaying shredding until there is an anticipated stretch of good weather might enhance the possibility of achieving the desired moisture range

Harvesting and Storing Wet Stover – Chopped and Bagged

In 2002, the stover fraction was shredded and windrowed within an hour of grain harvest and then allowed to sit in the field until late the next morning. The ambient conditions during that period were quite warm (11ºC or 52ºF) and very windy, so stover moisture dropped from 63% (w.b.) at grain harvest to 47% (w.b.) at chopping. In 2003, shredding and chopping took place within an hour or so of grain harvest and stover moisture dropped only about 5 percentage units from grain harvest to chopping (60 to 55% on 10/13 and 45 to 41% on 10/30). In all cases, doubled windrows were formed at shredding.

The windrow proved to be quite difficult to pick-up with the harvester's windrow pick-up, which is used for gathering alfalfa and grasses. These crops are intertwined and feed continuously into the pick-up and feedrolls. The shredded stover was not intertwined, so the pick-up teeth had difficulty gathering it and often kicked it ahead rather than gathering it. The only way to overcome these difficulties was to slow forward speed to about 4.0 to 5.6 km/h (2.5 to 3.5 mi/h), so harvesting capacity was limited not by available power but by the gathering difficulties. The harvesting efficiency of shredding, windrowing and chopping was roughly 55% in both years (see footnote in table 3), meaning that just over half the available stover mass was collected. Shredding more than halved the particle-size of the stover (table 3). The density of the material in the truck was negatively correlated to particle-size but TLC did not significantly affect wet-mass-flow-rate (table 3).

Storing chopped wet stover in a bag silo was successful. The chopped material was removed from the bag after about eight months of storage. The chopped stover had excellent appearance and color and had a familiar, pleasant ensiled odor. However, pockets of mold were observed frequently at the surface where the bag was not held tightly against the stover. Dry matter loss was 10.9% of total DM in 2002 (table 4). It is unknown how much of this loss was due to respiration and biological activity and how much was due to lost material during loading and unloading. The 4.4 percentage unit rise in moisture during storage shows that some biological respiration did occur (table 4). In 2003, DM loss was quite low with initial and final moisture similar (table 4). When moisture was above 50% (w.b.), silage fermentation was quite good, with low pH and acceptable levels of lactic and acetic acid.

Table 3. Productivity and physical properties of corn stover harvest as chopped material using precision-cut forage harvester and ensiled in plastic silo bag.#

TLC	Moisture	Harvester mass-flow		Density in truck		Density in silo bag		Particle-size
		wet	dry	wet	dry	wet	dry	
SI Units	% w.b.	Mg/h		kg/m^3		kg/m^3		mm
2002								
6.4 mm	48.4	49.1	25.9	158_b	82_b	288	150	17.8
12.7 mm	47.9	53.7	28.0	134_a	69_a	301	157	25.4
19.1 mm	45.8	55.5	30.1	126_a	67_a	286	150	27.9
LSD* (P = 0.05)	4.1	14.3	9.1	18	5	91	43	
2003								
6.4 mm	49.6	40.8	20.2_a	136	67	261	130	20.3_a
12.7 mm	48.0	51.3	26.0_b	131	69	251	128	22.9_b
19.1 mm	45.8	51.3	26.8_b	128	69	240	122	27.9_b
LSD* (P = 0.05)	6.5	11.1	4.2	24	13	75	37	2.5
English Units	% w.b.	ton/h		$lb./ft^3$		$lb./ft^3$		in.
2002								
0.25 in.	48.4	54.2	28.6	9.9_b	5.1_b	18.0	9.4	0.7
0.50 in.	47.9	59.3	30.9	8.4_a	4.3_a	18.8	9.8	1.0
0.75 in.	45.8	61.2	33.2	7.9_a	4.2_a	17.9	9.4	1.1
LSD* (P = 0.05)	4.1	15.8	10.0	1.1	0.3	5.7	2.7	
2003								
0.25 in.	49.6	45.1	22.3_a	8.5	4.2	16.3	8.1	0.8_a
0.50 in.	48.0	56.6	28.7_b	8.2	4.3	15.7	8.0	0.9_a
0.75 in.	45.8	56.6	29.6_b	8.0	4.3	15.0	7.6	1.1_b
LSD* (P = 0.05)	6.5	12.2	4.2	1.5	0.8	4.7	2.3	0.1

– In 2002, particle-size of stover before shredding and chopping was 690-mm (27-in.) and after shredding but before chopping was 290 mm (11.5 in.). Stover yield was 9.2 Mg DM/ha (4.1 ton DM/ac) just preceding grain harvest. Average harvested yield after shredding, windrowing and chopping was 4.9 Mg DM/ha (2.2 ton DM/ac).

– In 2003, particle-size of stover before shredding and chopping was 610 mm (20 in.) and after shredding but before chopping was 172 mm (6.8 in.). Stover yield was 10.5 Mg DM/ha (4.9 ton DM/ac) just preceding grain harvest. Average harvested stover yield after shredding, windrowing and chopping was 5.8 Mg DM/ha (2.7 ton DM/ac).

* – Averages with different subscripts in the same column are significantly different at 95% confidence

Table 4. Final storage data for chopped wet stover stored in a plastic bag silo for roughly eight months.

	Initial moisture % w.b.	Final moisture % w.b.	DM loss % of total	pH	Fermentation products … % of DM			
					Lactic acid	Acetic acid	Butyric acid	Ethanol
2002	47.3	51.7	10.9	4.1	3.66	1.01	0	0.26
2003	55.4	55.7	3.8	4.1_a	3.29_b	0.91_b	0	0
"	41.7	39.9	1.4	4.5_b	1.69_a	0.57_a	0	0
LSD* (P = 0.05)				0.3	0.56	0.17	-	-

* – Averages with different subscripts in the same column are significantly different at 95% confidence. Statistical analysis only conducted for data collected in 2003.

Table 5. Fraction of total corn plant contained in each of the five parts prior to grain harvest, after grain harvest and after stover harvest.

	Standing crop prior to grain harvest	After grain harvest	After stover harvest
	% of total DM		
Grain	51.4	3.1	1.4
Cob	6.1	12.2	3.2
Husk	4.2	8.4	10.4
Leaf	9.3	18.5	36.1
Stalk	29.0	57.8	48.9

Several random grab samples of the stover were hand separated into the five plant fractions after storage and compared to the fractions found prior to and after grain harvest. The proportion of stalk in the stover was less after stover harvest because the flail shredder was set at a height that left about 15 cm (6 in.) of stalk standing (table 6). Harvesting at that height also left a considerable fraction of the cobs, which tended to fall to the soil surface when ejected from the combine.

Harvesting and Storing Wet Stover – Baled and Wrapped

In 2002, the stover fraction was shredded and windrowed within an hour or so of grain harvest and then raked into double windrows within a few hours of shredding. The ambient conditions during that period were quite warm (14ºC or 58ºF) and windy, so stover moisture dropped from 63% (w.b.) at grain harvest to 39% (w.b.) at baling. Stover moisture was 50.9% at grain harvest and 44.4% at baling in 2003.

The pick-up on both the round and square balers experienced the same difficulty in gathering the shredded stover as was experienced with the forage harvester (described above). Therefore, the capacity of the balers was not limited by power or baling ability but gathering limitations. In 2002, the harvesting efficiency of shredding, raking and baling was 50 and 63% for the large round and large square balers, respectively (see footnote table 6). Round baler harvesting efficiency was also about 50% in 2003 (table 6). The pick-up for the large square baler was wider than that for the round baler by 46 cm (18 in.). Both pick-ups tended to push material to the side when gathering difficulties were experienced. When this occurred, the narrower pick-up of the round baler created higher losses that led to the lower harvesting efficiency.

The shape and handling characteristics of the bales was very good. Both bale types were easily moved with conventional lifting equipment and no difficulties were experienced when wrapping either bale type with plastic film. The large square bales of stover had 37% greater dry density than round bales (2002 only). Shinners et al. (2002) reported densities of alfalfa at 35 to 45% moisture of 151 and 177 kg DM/m^3 (9.4 and 11.1 lb./ft^3) for large round and square bales, respectively, a 17% difference. The corn stover, even after shredding, had many large diameter, intact stalk sections that resisted the compression forces in either baler. Densities were therefore 28 to 16% less in stover than those reported in similar moisture alfalfa. Harvesting machines and systems that help to further break down the mechanical structure of the stover could enhance bale density using either baler type.

The productivity of the large square baler was almost double that of the round baler (2002 only). About 25% of the round baling time was spent at idle while wrapping with twine, which greatly reduced productivity. The square baler pick-up had faster tip speed and had greater width, so baler forward speed was slightly higher for this baler. Average ground speed during baling was 3.5 and 4.2 km/h (2.2 and 2.6 mi/h) for the large round and square balers, respectively (2002 only). Round baler productivity was improved 36% when net wrap was used instead of twine (table 6). Similar productivity improvements were reported when baling alfalfa (Shinners et al., 2002). There were no significant differences in bale density between the round bale wrap types (table 6).

Storing wet stover bales by wrapping and ensiling was quite successful. Bales were removed from the tube after about eight months of storage. In both years, the bales had excellent appearance and color and had a familiar, pleasant ensiled odor. Mold was observed very infrequently. There were no statistical differences in DM loss between large square and round bales or between twine or net wrapped round bales; however the large square bales had numerically higher DM loss (table 7). Shinners et al. (2002) reported that DM loss of alfalfa bales at 35 to 57% moisture wrapped in film tubes ranged from 2.2 to 6.8% with no trend over several trials for one bale type to have lower losses than the other. The average DM loss for ensiled stover bales was 2.9%, about the same as for dry stover bales stored indoors (table 9). Losses of chopped forage stored in tower, bunk or bag silos have been reported to range from 5 to 20% dependent upon such management factors as moisture, packing density and feed-out rate (Pitt, 1990; Muck and Rotz, 1996; Muck and Holmes, 2000). Losses with high-moisture bales of alfalfa or grass have been reported to be less than this, typically in the range of 3 to 12% (Huhnke et al., 1997; Shin, 1990; Kennedy, 1987, Shinners et al., 2002).

Table 6. Productivity and physical properties of wet corn stover harvested as baled material using large round or large square balers and ensiled in plastic film wrap.

	Moisture	Baler mass-flow		Bale density		Harvested yield#	
		wet	dry	wet	dry	wet	dry
SI Units	% w.b.	Mg/h		kg/m^3		Mg/ha	
2002							
LRB - Twine	37.9	18.0_a	11.2_a	176_a	109_a	6.7_a	4.3_a
LSB	39.9	34.7_b	20.9_b	248_b	149_b	9.0_b	5.4_b
LSD* (P = 0.05)	2.9	2.5	1.6	13	6	0.9	0.5
2003							
LRB – Net	36.8	21.9_b	13.6_b	186	117	9.0	5.7
LRB – Twine	36.8	16.1_a	10.2_a	190	118	8.5	5.4
LSD* (P = 0.05)	6.3	2.4	1.2	16	10	1.8	0.7
English Units	% w.b.	ton/h		$lb./ft^3$		ton/ac	
2002							
LRB - Twine	37.9	19.9_a	12.4_a	11.0_a	6.8_a	3.0_a	1.9_a
LSB	39.9	38.3_b	23.0_b	15.5_b	9.3_b	4.0_b	2.4_b
LSD* (P = 0.05)	2.9	2.8	1.8	0.8	0.4	0.4	0.2
2003							
LRB – Net	36.8	24.2_b	15.0_b	11.6	7.3	4.0	2.5
LRB – Twine	36.8	17.8_a	11.2_a	11.9	7.4	3.8	2.4
LSD* (P = 0.05)	6.3	2.7	1.3	1.0	0.6	0.8	0.3

– Stover yield of standing plant material was 8.6 Mg DM/ha (3.8 ton DM/ac) just preceding grain harvest in 2002 and 11.3 Mg DM/ha (5.0 ton DM/ac) in 2003.

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

Table 7. Final storage data for wet stover bales formed and wrapped in a tube of plastic film October 2002 and removed from storage June 2003.

	Initial moisture % w.b.	Final moisture % w.b.	DM loss % of total	pH	Fermentation products % of DM			
					Lactic acid	Acetic acid	Butyric acid	Ethanol
2002								
LRB - Twine	37.9	38.9	3.0	5.3	1.19	0.77	0	0.31
LSB	39.9	40.7	4.2	4.8	1.73	0.79	0	0.46
LSD* (P = 0.05)	2.9	3.7	2.7	0.8	0.82	0.14	-	0.25
2003								
10/24/04	29.4_a	29.5_a	1.2	5.1_b	0.48_a	0.39_a	0	0.15_b
10/30/04	44.3_b	45.6_b	2.9	4.4_a	2.29_b	0.78_b	0	0.00_b
LSD* (P = 0.05)	2.8	2.6	2.1	0.2	0.66	0.11	-	0.03

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

Fermentation products were lower and pH higher for the wrapped stover bales than would typically be expected of whole-plant corn silage (table 7). Typical whole-plant corn silage would have a pH of about 4.0 and acid levels of 2.0 and 7.5% of DM for acetic and lactic acids, respectively. The low levels of acids and relatively high pH of the wrapped stover bales indicate that very little fermentation actually took place. However, DM losses were quite low, indicating that low-moisture stover can be very well preserved with limited fermentation as long as the plastic film limits oxygen infiltration. There were no statistical differences in fermentation products between bale types but higher moisture bales produced significantly greater levels of fermentation products than low moisture bales (table 7).

Shinners et al. (2002) reported that large square bales required almost twice the mass of plastic film per kg DM compared to large round bales, primarily because the surface-to-volume ratio favors the latter bale configuration. So although the large square bale offers productivity and density advantages, wrapping strategies, such as stacking bales before wrapping or using larger bale cross-sections, need to be investigated to reduce plastic film requirements.

Harvesting and Storing Dry Stover

In 2002, bales were formed almost six weeks after grain harvest and shredding because of frequent rain or snow during the field drying period. Therefore, the physical condition of the stover had somewhat deteriorated by the time baling occurred. The problems with poor gathering with the baler pick-ups were even more in evidence with this stover, so baling speed was limited to 2.7 and 3.8 km/h (1.7 and 2.4 mi/h) for the large round and square balers, respectively (table 8). In 2003, stover was harvested within a week of grain harvest and shredding and the stover physical condition was excellent. Although gathering still limited baling speed, baler productivity in 2003 was similar for wet and dry stover (tables 6 and 8) and these values should be considered typical.

In 2002, large round and square bales were 13 and 10% less dense, respectively, on a DM basis than wet stover bales (tables 6 and 8). The reduction in bale density for both bale types might be due to the poor physical condition of the dry stalks at the time of baling. In 2003, bale density was similar for wet and dry stover (tables 6 and 8) and these values should be considered typical. Large square bales had about 9% greater density than round bales. The harvesting efficiency of shredding, raking and baling dry stover was roughly 33 and 41% for the 2002 and 2003, respectively, which was considerably lower than that for wet stover at 57 and 50%, respectively. One reason for this difference was that the dry stover was harvested well after grain harvest and losses from wind and biological degradation probably occurred. It was also observed that wet stover was more readily retrieved by the baler pick-up than dry stover. The results suggest that yield and harvesting efficiency decrease as the delay between grain and stover harvest increases. In 2002, the delay between grain harvest and wet or dry stover harvest was 1 and 42 days, respectively, and harvesting efficiency fell from 57 to 33%, respectively. In 2003, the delay between grain harvest and wet or dry stover harvest was 1 and 7 days, respectively, and harvesting efficiency dropped from 50 to 41%, respectively.

The historical average precipitation in Madison, WI during the storage period is 455 mm (17.9 in.) (NOAA, 2004). Total precipitation during storage period was 235 mm (9.3 in.) in 2002-03 and 734 mm (28.9 in.) in 2003-04, with 320 mm (12.5 in.) in the last six weeks of storage in 2004. Sisal twine wrapped bales had greater DM loss than bales wrapped with plastic twine or net wrap primarily because the sisal twine rotted away at the base of the bale (table 9). When sisal twine bales were lifted from storage, stover sloughed from the base of the bale was not recoverable. Material not recovered was considered part of the DM loss. In 2002-03, when precipitation was less, it was observed that the sisal twine had fewer tendencies to rot away when stored on pallets and that some bales maintained their integrity throughout storage, decreasing DM loss compared to storing on soil (table 9). However, in 2003-04, when precipitation was above normal, all the sisal twine rotted away at the base of the bale no matter if stored on the ground or pallets. Independent of storage method, net wrapped bales had about 62 and 31% (2002) or 70 and 25% (2003) lower DM losses than bales wrapped with sisal or plastic twine, respectively. Net wrapped bales almost always had significantly lower moisture in the rind than twine wrapped bales (tables 9), which contributed to lower DM loss. Storing bales on pallets reduced DM losses for all treatments because water was able to drain away from the bales resulting in lower moisture in the base of the bales. These results are very similar to those reported by Shinners et al. (2002) concerning bales of alfalfa or alfalfa/grass mixes.

Table 8. Productivity and physical properties of dry corn stover harvested as baled material using large round or large square balers and stored indoors and outdoors.

	Moisture	Baler mass-flow		Bale density		Harvested yield[#]	
		wet	dry	wet	dry	wet	dry
SI Units	% w.b.	Mg/h		kg/m^3		Mg/ha	
2002							
LRB – Twine	23.0	6.8_a	5.2_a	123_a	94_a	4.7_b	3.6_b
LRB – Net	23.5	7.3_a	5.5_a	138_b	106_b	2.9_a	2.2_a
LSB	24.0	17.2_b	13.1_b	178_c	134_c	4.3_b	3.1_b
LSD[*] (P = 0.05)	3.5	2.4	1.8	8	6	0.7	0.5
2003							
LRB – Twine	15.7_{ab}	11.2_a	9.5_a	139_a	118_a	5.4	4.7
LRB – Net	17.0_b	16.5_b	13.7_b	138_a	114_a	5.6	4.7
LSB	14.6_a	16.3_b	14.0.	150_b	128_b	5.4	4.7
LSD[*] (P = 0.05)	1.3	0.9	0.8	8	6	0.4	0.4
English Units	% w.b.	ton/h		$lb./ft^3$		ton/ac	
2002							
LRB – Twine	23.0	7.5_a	5.7_a	7.7_a	5.9_a	2.1_b	1.6_b
LRB – Net	23.5	8.0_a	6.1_a	8.6_b	6.6_b	1.3_a	1.0_a
LSB.	24.0	19.0_b	14.4_b	11.1_c	8.4_c	1.9_b	1.4_b
LSD[*] (P = 0.05)	3.5	2.6	2.0	0.5	0.4	0.3	0.2
2003							
LRB – Twine	15.7_{ab}	12.4_a	10.5_a	8.7_a	7.4_a	2.4	2.1
LRB – Net	17.0_b	18.2_b	15.1_b	8.6_a	7.1_a	2.5	2.1
LSB	14.6_a	18.0_b	15.4_b	9.4_b	8.0_b	2.4	2.1
LSD[*] (P = 0.05)	1.3	1.0	0.9	0.5	0.4	0.2	0.2

– In 2002, stover was harvested about one month after grain harvest and stover yield was 8.9 Mg DM/ha (4.0 ton DM/ac) just preceding grain harvest. In 2003, stover was harvested within one week of grain harvest and stover yield was 11.6 Mg DM/ha (5.2 ton DM/ac) just preceding grain harvest.

* – Averages with different subscripts in the same column are significantly different at 95% confidence.

Storing bales indoors significantly reduced DM loss compared to all other treatments (table 9). Average DM loss of large square and round bales stored inside was slightly less than 5% in 2002 and about 2% in 2003. The lower initial bale moisture in 2003 probably contributed to less biological activity in storage and the lower losses. There was no significant difference in losses between bale types stored indoors (table 9). The moisture of the bales stored indoors was significantly lower compared to all outdoor treatments, which contributed to the lower DM loss because biological activity was less. Bales stored indoors also were not subject to leaching losses during precipitation. The DM loss of net-wrapped round bales stored indoors was 45% less than the average DM loss of net wrapped bales stored outdoors.

Comparison of Wet and Dry Stover Harvest

Wet stover harvest occurred on a timelier basis because this harvesting scheme occurred right at grain harvest, avoiding the field drying time required of the dry stover process. Wet stover harvest produced a greater stover yield because wet stover was more readily retrieved by the harvesting equipment and less biological and weather related losses occurred than with dry stover harvest. Compared to storing dry bales outside, wet stover had considerably lower losses in storage, independent of ensiling scheme (chopped or baled). When precipitation during the storage period was above average, the dry stover was removed from storage at greater moisture than ensiled wet stover. Wet stover harvest and storage is the most appropriate scheme to consider because of these reasons.

Table 9. Storage characteristics of dry corn stover bales stored for approximately nine months[#].

Storage Location / Wrap Type / Bale Type	2002						2003					
	Moisture .. % wet basis					DM loss .. % of total	Moisture .. % wet basis					DM loss .. % of total
	Initial	Final					Initial	Final				
		Rind	Core	Base	Volume adjusted total			Rind	Core	Base	Volume adjusted total	
Inside												
Large round	25.9_{bc}				19.2_{a}	4.9_{a}	16.4_{bc}				13.6_{a}	2.2_{a}
Large square	23.9_{ab}				19.3_{a}	4.8_{a}	14.6_{a}				13.2_{a}	1.1_{a}
Outside on ground[@]												
Sisal twine	32.0_{d}	46.8_{b}	20.4_{bc}	48.0_{c}	37.7_{d}	29.1_{e}	15.6_{ab}	54.5_{a}	23.2_{a}	63.0_{c}	54.0_{c}	38.5_{d}
Plastic twine	24.4_{abc}	46.2_{b}	22.6_{c}	37.5_{bc}	36.4_{d}	14.3_{c}	16.6_{bc}	64.6_{b}	32.7_{b}	62.6_{bc}	59.1_{d}	19.0_{c}
Net wrap	22.2_{a}	35.8_{a}	18.9_{abc}	38.5_{c}	30.3_{c}	10.7_{bc}	16.4_{bc}	61.9_{b}	20.7_{a}	54.2_{a}	53.3_{c}	14.2_{c}
Outside on pallets[@]												
Sisal twine	27.5_{c}	45.3_{b}	16.7_{ab}	28.3_{ab}	30.9_{c}	17.7_{d}	15.4_{ab}	54.0_{a}	24.3_{a}	70.8_{d}	55.4_{c}	36.1_{d}
Plastic twine	23.0_{ab}	46.3_{b}	16.6_{a}	24.5_{a}	32.2_{c}	11.4_{c}	15.1_{ab}	61.4_{b}	22.5_{a}	56.4_{ab}	54.1_{c}	11.0_{b}
Net wrap	22.3_{a}	27.1_{a}	18.1_{ab}	24.2_{a}	23.5_{b}	7.0_{ab}	18.1_{c}	52.9_{a}	21.1_{a}	54.3_{a}	47.9_{b}	8.2_{b}
LSD* (P = 0.05)	3.5	9.3	3.7	11.2	3.3	4.3	1.7	5.1	5.8	6.4	3.0	5.6

– Total precipitation during storage period was 235-mm (9.3 in.) in 2002 and 734 mm (28.9 in.) with 320 mm (12.5 in.) in the last six weeks of storage in 2003.
@ – Only large round bales were stored outdoors. * – Averages with different subscripts in the same column are significantly different at 95% confidence.

Conclusions

- When corn grain moisture was in the typical harvest range of 30 to 20%, the ratio of stover dry mass to total crop dry mass averaged 43% in 2002 (typical conditions) and 47% in 2003 (dry conditions). At the time of grain harvest, grain and stover DM yields averaged 12.2 and 9.6 Mg/ha (5.5 and 4.3 ton/ac), respectively.

- The moisture in the total stover fraction was between 65 and 58% (2002-typical conditions) and between 58 and 39% (2003-dry conditions) when grain moisture was between 30 and 20%.

- If stover harvest consisted of the bottom half of the stalks, 50% of the top half of the stalk and 50% of the leaves, then stover moisture at grain harvest ranged from 69 to 65% under typical conditions in 2002 and 65 to 37% under moisture stress in 2003. If stover harvest consisted of cobs and husk and 50% each of the leaf and top stalk (i.e. non-grain fraction from the rear of the combine), then stover moisture at grain harvest ranged from 45 to 33% under typical conditions in 2002 and 46 to 26% under moisture stress in 2003.

- Mechanically conditioning the stover by shredding after grain harvest significantly improved the stover drying rate if the material was placed back on the surface in a swath about as wide as the shredder width. Placing the shredded material into a narrow windrow immediately after shredding significantly reduced drying rate.

- Harvesting efficiency, i.e. the ratio of stover mass actually harvested to mass in the field, averaged 55, 50 and 37%, respectively, for chopping, wet baling and dry baling. Harvesting by shredding tended to leave proportionally more cob and stalk on the field.

- Harvesting wet stover as chopped material and ensiling in a plastic bag was successful. Harvester capacity was limited to an average of 28.0 Mg DM/h (25.4 ton DM/h) by difficulty in gathering shredded stover at the pick-up. Density in the truck and silo were negatively affected by longer length-of-cut. After eight months in storage, losses were 1.4, 3.8 and 10.9% of total DM when stover moisture was 40, 56 and 52% (w.b.). The stover pH ranged from 4.1 to 4.5 with low levels of typical fermentation products.

- Harvesting wet stover as baled material and wrapping the bales for ensiling in a tube of stretch plastic film was successful. After eight months in storage, losses were 1.2, 3.0 and 2.9% of total DM when stover moisture was 30, 39 and 44% (w.b.). Stover pH averaged 4.9. Bale color and odor were excellent with very little evidence of mold growth.

- When precipitation during the eight month storage period was below normal, DM loss averaged 5 and 15% for bales stored indoors and outdoors, respectively. When precipitation during storage was above normal, DM loss averaged 2 and 21% for bales stored indoors and outdoors, respectively. Average DM loss for bales stored outdoors was 10.0, 13.9 and 30.4% for bales wrapped with net wrap, plastic twine and sisal twine, respectively. Net wrapped bales had significantly lower moisture when removed from storage than twine wrapped bales. Average bale moisture was 32 and 54% (w.b.) after eight months stored outdoors for 2002-03 (dry conditions) and 2003-04 (wet conditions), respectively.

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