2012

Harvest Date Influence on Dry Matter Yield and Moisture of Corn and Stover

Haibo Huang
University of Illinois at Urbana-Champaign

Dan B. Faulkner
University of Illinois at Urbana-Champaign, dfaulkner@email.arizona.edu

Larry L. Berger
University of Nebraska-Lincoln, lberger2@unl.edu

Steven R. Eckhoff
University of Illinois at Urbana-Champaign, seckhoff@illinois.edu

HARVEST DATE INFLUENCE ON DRY MATTER YIELD AND MOISTURE OF CORN AND STOVER

H. Huang, D. B. Faulkner, L. L. Berger, S. R. Eckhoff

ABSTRACT. *Harvest date greatly affects the biomass yield, moisture, and quality of corn and stover. Traditionally, corn and stover have been harvested at lower moisture levels. However, corn stover and grain can be more effectively utilized as animal feed and biomass-ethanol feedstock if they are collected before in-field dry down. This study determined dry matter yield, moisture content, and quality of corn and stover before, during, and after grain maturity in central Illinois. The two-year average kernel moisture was 37.4% (w.b.) when reaching physiological maturity. At the same time, the average stover moisture was 67.7% (w.b.). The dry matter yield of grain increased rapidly until reaching grain maturity and remained relatively stable after grain maturity, with an average yield of 11.2 t ha-1 over the two-year study. For corn stover, the two-year average dry matter yield was 14.7 t ha-1 at the beginning of the study (filling stage), and it decreased to 13.2 t ha-1 at grain physiological maturity and further decreased to 11.0 t ha-1 throughout grain dry down. During grain dry down, the moldy kernel percentage increased from 2.1% to 4.1% and the stalk lodging percentage increased from 1.2% to 3.6%. The results of this study showed that early harvest of corn and stover at grain maturity has several advantages: higher dry matter yield of stover, lower moldy kernel percentage, and fewer plant lodgings.*

Keywords. *Corn, Dry matter yield, Early harvest, Lodging, Moisture content, Mold, Stover.*

Rapid growth in the corn-ethanol industry has dramatically increased the demand for corn and helped push the price of corn to an all-time high. Efficient utilization of the non-grain portion of the corn plant for livestock and the grain for ethanol will allow the optimization of both food and fuel production. Sewell et al. (2009) reported that when the thermochemically treated corn stover (non-grain portion of the corn plant, including cob, husk, stalk and leaf) was mixed with dried distiller's grain with solubles (DDGS) from an ethanol plant, it could be as nutritious as corn alone in ruminant diets. Traditionally, corn and stover have been harvested after grain physiological maturity and at low kernel moisture levels (18% to 25% w.b.) due to the high cost of drying. There are several reasons why harvesting at higher moisture would be good. Stover harvested as soon as the grain reached physiological maturity would be less lignified, more responsive to chemical treatments to enhance digestibility (Weaver et al., 1978; Russell, 1986; Cone and Engles, 1993), and yield would be higher (Cummins, 1970; Pordesimo et al., 2004a, 2004b; Shinners and Binversie, 2007). Weather losses (early frost, storm, etc.) of grain would be lower, and grain quality losses due to mold and insect invasion would be reduced with an earlier harvest. Early harvest of stover and grain has additional advantages, including better weather early in the harvest season, longer daylight length (so work can be done more efficiently and safely), and a longer harvest window. In addition, the early removal of corn from the field may allow production of a second crop that is nitrogen fixing. For example, hairy vetch has been shown to fix nitrogen over winter, producing about 50 to 200 kg N ha^{-1} (Smith et al., 1987; Dabney et al., 2001). This cover crop would also reduce soil erosion and increase soil organic matter, which would allow a higher fraction of corn stover to be removed from the field.

Corn with moisture content greater than 35% spoils readily and is a safety and health hazard when moldy. Most corn drying systems today are designed to dry from the mid-20% moisture range to 14.5%. Increasing the average initial moisture content from 25% to 35% more than doubles the amount of moisture that needs to be removed, which leads to longer drying time and higher energy cost. To solve this problem, Eckhoff (2010) proposed freezing high-moisture corn instead of drying it. The corn would be flash frozen and then put in a large insulated pile for long-term storage. Compared with drying, this method would consume less energy and have lower storage cost. The frozen corn can be delivered to the ethanol plant, where it can be used as an energy sink for fermentation. This could potentially eliminate the need for cooling towers and chillers, and most importantly could reduce process water usage.

Submitted for review in November 2010 as manuscript number FPE 8934; approved for publication by the Food & Process Engineering Institute Division of ASABE in January 2012.

The authors are **Haibo Huang, ASABE Member,** Graduate Research Assistant, Department of Agricultural and Biological Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois; **Dan B. Faulkner,** Professor, Department of Animal Science, University of Illinois at Urbana-Champaign, Urbana, Illinois; **Larry L. Berger,** Professor and Head, Department of Animal Science, University of Nebraska-Lincoln, Lincoln, Nebraska; and **Steven R. Eckhoff, ASABE Member,** Professor, Department of Agricultural and Biological Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois. **Corresponding author:** Steven R. Eckhoff, Department of Agricultural and Biological Engineering, 360B AESB, University of Illinois at Urbana-Champaign MC-644, 1304 W. Pennsylvania Avenue, Urbana, IL 61801; phone: 217-244-4022; fax: 217-244-0323; e-mail: seckhoff@illinois.edu.

  ISSN 2151-0032

Moisture content in stover is much higher than in the corn kernels. Pordesimo et al. (2004a) showed that the total stover-to-moisture ratio was 2 to 2.5 with grain moisture between 18% and 31% (w.b.) in Tennessee. Shinners and Binversie (2007) reported that the total stover-to-grain moisture ratio averaged 2.15 during the typical harvest period in Wisconsin. The relatively high moisture in stover makes artificial drying uneconomical (Kaminsky, 1989). Nielsen (1995) suggested that the stover moisture should not exceed 30% (w.b.) for optimum harvesting and needs to be 20% (w.b.) or less for dry storage. Field drying of corn stover is common; however, it has several disadvantages, such as low collection efficiency, high soil contamination, and insect invasion. Harvesting corn stover as a wet product and ensiling it is an alternative. Shinners et al. (2007, 2011) found that storing wet stover by ensiling resulted in lower dry matter losses and more uniform product moisture compared to dry stover bales stored outdoors.

Purdue University had a long-term study on the loss of corn yield with delayed harvesting after physiological maturity and estimated that harvest yield decreased 1% to 2% per week during the dry-down period. Drought-induced stalk lodging, European corn borer damage, and other insect problems reduced the yield potential if harvesting is delayed beyond maturity. The objectives of this study were: (1) to determine dry matter yield and moisture content of corn and stover before, during, and after corn maturity; and (2) to ascertain the effect of the dry-down period after kernel physiological maturity on corn molding and yield loss due to stalk lodging.

MATERIALS AND METHODS

TEST SITE AND MATERIAL

The corn was grown at the Agricultural and Biological Engineering Farm of the University of Illinois at Urbana-Champaign, located in Urbana, Illinois. In 2009, Pioneer 32D78 was chosen due to its high potential yield and high total fermentables for dry grind ethanol. In 2010, Pioneer P0916XR was chosen for its high potential yield and suitability for corn-after-corn rotation. The comparative relative maturity (CRM) for Pioneer 32D78 and Pioneer P0916XR is 116 and 109, respectively. The growing-degree days (GDDs) required for these two hybrids to reach physiological maturity are 1572 and 1461, respectively. Both of these two hybrids are suitable for the central Illinois area and were recommended by the seed company. In 2009, the corn crops were planted on 22 May, which was late in central Illinois due to frequent rainfall and low temperature in April and May (figs. 1a and 1b). Delayed planting postpones the corn maturity and cool weather in the fall affects the corn in-field drying rate. In 2010, the corn crops were planted on 21 April. In both years, the corn crops were planted on 76 cm (30 in.) row spacing and 15.6 cm (6.125 in.) rank spacing in a 0.4 ha (1 acre) field. The target plant population for both years was 75,680 plants ha^{-1}.

WEATHER CONDITIONS

Corn plant growth, yield, and drying rate are largely dependent on accumulated heat input and precipitation during the growing and harvest season. Ambient air temperature and precipitation at the experimental location were recorded by a local weather station (data source: www.noaa.gov). Growing-degree days were calculated using equation 1:

$$\text{GDDs} = \left[\frac{T_{\max} + T_{\min}}{2}\right] - 10°\text{C} \tag{1}$$

where $T_{\max}$ is the daily maximum temperature (with an upper limit of 30°C), and $T_{\min}$ is the daily minimum temperature (with a lower limit of 10°C) (McMaster and Wilhem, 1997; Darby and Lauer, 2002).

SAMPLE COLLECTION

In 2009, the delayed planting date and lower heat input (compared with a normal year; fig. 1a) postponed the corn maturity date to September. Therefore, corn plants were harvested between 21 August and 23 November, representing corn filling, mature, and dry-down stages. In 2010, corn reached maturity in August, and corn plants were harvested between 29 July and 10 September. In 2009, corn plants were harvested biweekly. In 2010, corn plants were harvested at one-week intervals due to the higher in-field drying rate of grain (figs. 3a and 3b).

For each harvest, corn plants were collected in a 3.05 m × 1.33 m (10 ft × 4.25 ft) square plot. The number of lodged plants in the plot was recorded. All plants from the plot were pooled together to form a representative sample. Three replications at different (southwest, southeast, and north) sections of the experimental field were done for each harvest. The plants were cut by hand at about 10 cm (4 in.) above ground and transported to the laboratory for processing. The ears were carefully separated from the plants, followed by separation of the grains from the ears by hand, yielding three fractions: grain, cob, and stalk and leaf. The husk was added to the fraction of stalk and leaf. It was observed that the moisture content of leaves was different from that of stalks and husks. Therefore, to get a uniform moisture content sample of the entire stalk and leaf fraction, the whole stalk with leaves was chopped with a laboratory-scale chipper/shredder (model 410, Troy-Bilt, Cleveland, Ohio). The cobs were chopped separately to get a uniform sample for moisture content determination. The fractions of grain, chopped cob, and chopped stalk and leaf were weighed separately. Finally, kernels that had visible mold were separated by hand and weighed. The fraction of grain with mold (moldy kernel percentage) was calculated as a percentage of total grain dry mass.

MOISTURE AND DRY MASS DETERMINATION

Due to the high moisture contents of the corn and forage harvested before grain maturity, AACC two-stage methods were used for the moisture measurement of unground grain (AACC, 1984a) and for the moisture measurement of chopped forage (AACC, 1984b). The grain was dried for 24 h at 49°C in a convection oven, followed by 72 h at 103°C. The chopped cob and chopped stalk and leaf were dried for 24 h at 49°C in a convection oven, followed by 2 h at 135°C. The moisture contents (w.b.) and dry matter contents of all sub-fractions were then calculated.

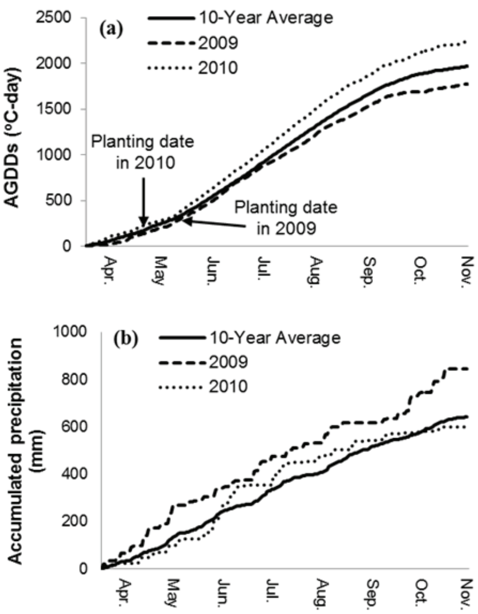

Figure 1. (a) Accumulated growing-degree days (AGDDs) and (b) accumulated precipitation during corn growing and harvest period for 2009, 2010, and the ten-year average.

RESULTS AND DISCUSSION

WEATHER CONDITIONS

Accumulative heat input (AGDDs) and precipitation information for 2009, 2010, and the ten-year average during the corn kernel filling, mature, and dry-down stages are shown in figures 1a and 1b. These weather parameters would affect not only stover and grain dry matter yield but also in-field drying rates. The AGDD value in 2009 is lower than the ten-year average; while the AGDD in 2010 is significantly higher than the ten-year average (fig. 1a). The inadequate accumulative heat input in 2009 postponed the grain maturity date and reduced the in-field drying rate of grain. From figure 1b shows that accumulated precipitation in 2009 was above the ten-year average; while in 2010, the accumulated precipitation was slightly below the ten-year average before mid-June and went above the ten-year average after mid-June, due to the frequent rainfalls in June.

GRAIN AND STOVER DRY MATTER YIELD AND DISTRIBUTION

The dry matter yields of the grain and stover fractions in seven harvests in 2009 and 2010 are shown in figures 2a and 2b. In 2009, the grain yield increased rapidly until reaching physiological maturity on 30 September, which in this study was 131 days after planting. At the same time, the dry matter yield of grain was 11.4 t ha^{-1}. After maturity, the grain dry matter yield became relatively stable until the end of the study, ranging between 11.4 and 11.9 t ha^{-1}, with an average of 11.5 t ha^{-1}. In 2010, the grain reached physiological maturity on 19 August, 120 days after planting. After grain maturity, the grain dry matter yield ranged between 10.6 and 11.1 t ha^{-1} with an average of 10.8 t ha^{-1}. Delayed planting and low accumulated heat input during the growing season (fig. 1a) in 2009 postponed corn physiological maturity despite adequate rainfall.

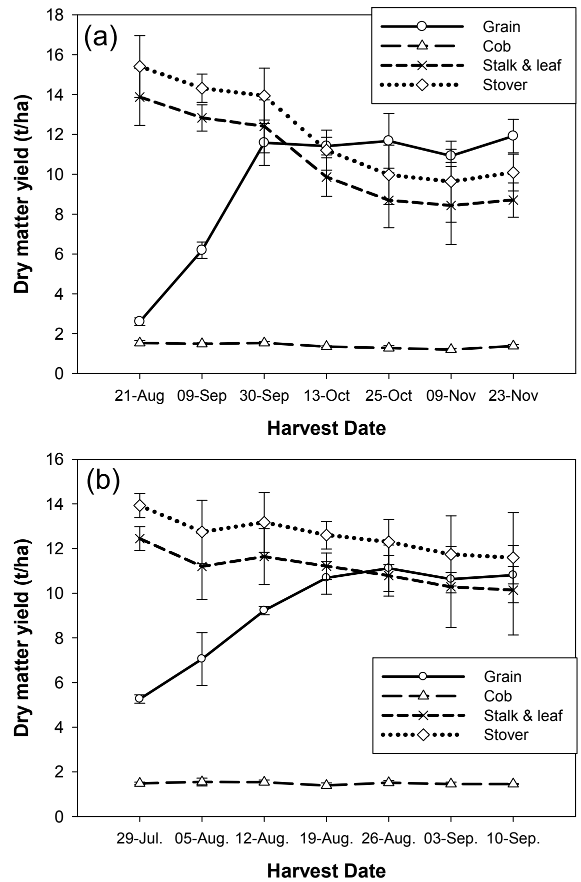

Figure 2. Dry matter yield of corn plant fractions in seven harvests in (a) 2009 and (b) 2010. The husk was added to the fraction of stalk and leaf.

In 2009 and 2010, the dry matter yields of stover were greatest at the beginning of the study and decreased throughout the whole study. In 2009, stover yield decreased by 34% from the beginning to the end of the study (from 15.4 to 10.1 t ha^{-1}) (fig. 2a). In 2010, stover yield decreased by 17% from the beginning to the end of the study (from 14.1 to 11.6 t ha^{-1}). The loss of biomass was mainly due to nutrient translocation from stover to grain before grain physiological maturity (Center et al., 1970) and physical loss of leaf and husk as they became dry and brittle after grain maturity. This phenomenon was also reported by other studies during different study period lengths. Cummins (1970) stated that the total dry matter yield of stover declined by 19% from 4 September to 26 September in Georgia. Pordesimo et al. (2004a, 2004b) reported that the dry matter yield of stover peaked at the time of grain physiological maturity and decreased by almost 40% when harvest was delayed until winter in Tennessee. Shinners and Binversie (2007) found that the dry matter yield of stover decreased by about 20% between August and October over a three-year study period in Wisconsin. The higher dry matter loss in stover in 2009 than that in 2010 might be due to several reasons. Firstly, in 2009, the length of the study period was 94 days (21 August to 23 November), while the study period in 2010 was only 43 days (29 July to 10 September). A longer study period would obviously lead to a higher dry matter loss in stover. Secondly, the greater rainfall in 2009 would also tend to increase the loss of leaf and husk after plant maturity. Thirdly, varietal difference in corn plants could also affect the corn stover yield. Compared with the stalk and leaf fraction, dry matter loss in the cob during the entire study period was relatively low (less than 10%) in both 2009 and 2010. The loss of cob more likely represented deterioration of the dry matter by cellular respiration, microbial action, or insect activity.

GRAIN AND STOVER MOISTURE

The moisture content of grain and stover is important because it affects the selection of harvest equipment and storage methods, which affect the cost of grain and stover collection. Figure 3a and 3b show the moisture content of corn and stover in seven harvests during the study periods in 2009 and 2010. In 2009, the moisture content of grain decreased rapidly before corn physiological maturity (30 September), from 72% to 40% (w.b.), with an average drying rate at 0.8 percentage points per day. After corn maturity, the drying rate of grain was lower, with an average of 0.3 percentage points per day. At the end of the study period (23 November), the grain moisture was around 21% (w.b.). In 2010, the moisture content of grain decreased steadily throughout the study period, from 57% to 15% (w.b.), and the grain moisture was 35% (w.b.) at maturity (19 August). The average drying rate of grain was almost one percentage point per day. The drying rate found in this study was different from those reported by other researchers. Pordesimo et al. (2004b) reported a drying rate of 0.8 percentage points per day in Tennessee in the U.S. Southern Corn Belt. Shinners and Binversie (2007) found that the drying rate was approximately 0.6 percentage points per day in Wisconsin in the U.S. Northern Corn Belt. Nielson et al. (2009) reported that grain would dry by approximately 0.25 to 0.5 percentage points per day in late October to early November in Indiana. The main reason for the different drying rates is due to the differences in weather conditions and daylight length at the different locations.

As a rule of thumb, stover moisture is twice that of the grain (Nielson, 1995; Buchele, 1975). In 2009, the moisture content of stover was around 76% (w.b.) at the beginning of the study (21 August) and decreased slightly between 21 August and 13 October. After that, the moisture content decreased rapidly from 72% to 47% (w.b.), with an average drying rate of 0.6 percentage points per day. In 2010, when the weather was warmer with less precipitation, the moisture content of stover remained stable at the beginning of the study. After that, the moisture content decreased steadily throughout the study, from 73% to 55% (w.b.), with an average drying rate of 0.5 percentage points per day. The leaf and husk in stover were the main sources of moisture loss because of their large surface area and thin cross-section, which promotes drying (Shinners and Binversie, 2007). In 2009, the moisture content of cob decreased from 70% to 37% (w.b.) in the 94-day study period. In 2010, the moisture content of cob decreased from decreased from 61% to 27% (w.b.) in the 43-day study period. One interesting observation in both 2009 and 2010 is that the moisture content of cob started to decrease rapidly when the moisture content of grain was below 30% (w.b.). This phenomenon might be due to the high moisture gradient between cob and grain when the moisture content of grain is low. The two-year average results showed that when the grain was at maturity, the moisture contents of grain, stalk and leaf, cob, and stover were 37.7%, 71.1%, 54.5%, and 69.7% (w.b.), respectively. The high moisture content in corn stover indicated that ensiling could be an effective storage option when the stover is harvested in a single pass.

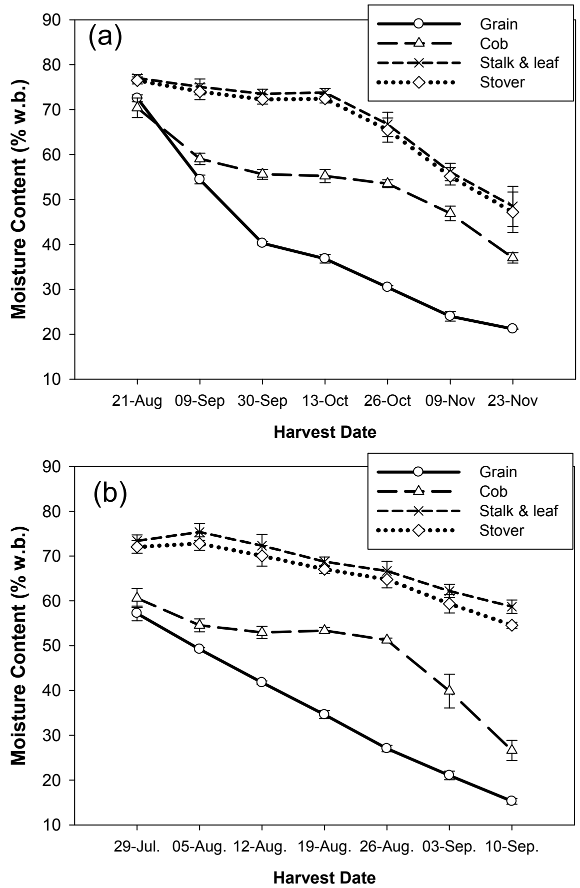

Figure 3. Moisture content (w.b.) of grain and corn stover fractions in seven harvests in (a) 2009 and (b) 2010.

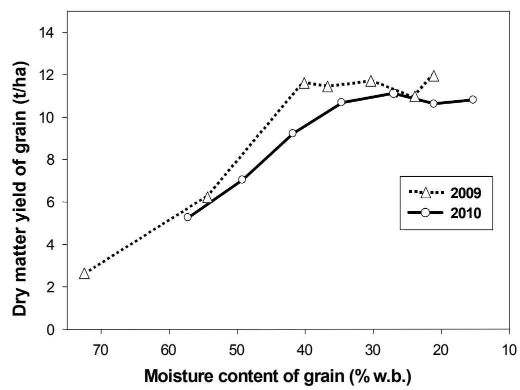

Figure 4. Relationship between dry matter yield and moisture content (w.b.) of grain in 2009 and 2010.

Table 1. Grain field loss during the 43-day study period in 2010.

	Date (2010)						
Source of Loss	29 July	5 Aug.	12 Aug.	19 Aug.	26 Aug.	3 Sept.	10 Sept.
Moldy kernels (%)	0	0	1.7	2.1	3.3	3.3	4.1
Stalk lodging (%)	0	0	0	1.2	2.4	3.6	3.6

The relationship between dry matter yield and moisture content of grain is shown in figure 4. In 2009, the dry matter yield of grain increased rapidly until it reached a plateau, when the moisture content of grain was 40% (w.b.). After the point at which the grain reached maturity, the dry matter yield became relatively stable. In 2010, the dry matter yield of grain reached a plateau when moisture content was 35% (w.b.). These data show that, in the U.S. Midwest Corn Belt, grain reaches its maturity stage when its moisture content is between 30% and 40%. It is comparable with the observation of Shinners and Binversie (2007), who found that grain moisture was around 35% (w.b.) at corn maturity in the U.S. Northern Corn Belt. However, Pordesimo et al. (2004a) reported that grain moisture was between 20% and 30% (w.b.) at its maturity stage in Tennessee. These differences could be due to the differences in weather conditions and daylight length between locations.

Field Losses

Grain losses prior to harvest are known to increase the longer the crop stands in the field after reaching maturity. These losses are mainly due to wind, animals, lodging, senescence, microbial activity, and biological degradation. Mold can form on corn ears during cool, wet growing seasons. The severity of the problem depends on variations in weather, crop genetics, and field management practices. High mold levels in corn can reduce the grain grade and storage life and affect livestock health and performance (Nielsen et al., 2009). Table 1 shows the moldy kernel and stalk lodging percentages in seven harvests during the 43-day study period in 2010. Grain mold became significant (1.7%) on 12 August, which in this study was seven days before grain maturity. At that time, the grain moisture was 42% (w.b.). After that, the moldy kernel percentage increased steadily as harvest was delayed. At the end of the study, at grain moisture of 15% (w.b.), the moldy kernel percentage reached 4.1%, which could potentially reduce the grain quality from No. 1 grade to lower grades and reduce the grain marketability (USDA, 2011).

In most years, growers can get the crop out of the field early enough that lodging is not a major problem; however, lodging could be a major harvest loss when weather is severe, such as high wind and rainfall. This study shows that the lodging started in 19 August, when the grain just reached its physiological maturity (table 1). At that time, 1.2% of the corn plants were lodged. As harvest was delayed, lodging became greater. At the end of the study, at grain moisture of 15% (w.b.), the stalk lodging percentage reached 3.6%, which represents a relatively high loss for corn harvest.

Comparison

Table 2 shows the two-year average moisture content and dry matter yield of corn and stover at grain maturity and at late harvest (at the end of the study period). The two-year average grain moisture was 37.4% (w.b.) at grain maturity, and it decreased to 18.2% (w.b.) at the end of the study period. The two-year average dry matter yields of grain at maturity and late harvest were relatively close, with only 1% difference. The small difference is reasonable because kernel dry matter usually reaches its maximum at physiological maturity, and severe stress after grain maturity has little effect on grain yield (Nielsen, 2008). From grain maturity to late harvest, the two-year average stover moisture decreased from 67.7% to 50.6% (w.b.). The average dry matter yield of stover was 13.2 t ha^{-1} at the time grain reached maturity, and decreased by 16.8% at the end of the study period. The moldy kernel percentage increased from 2.1% to 4.1% between the grain maturity and late harvest stages, which would potentially decrease the grain quality and marketability (USDA, 2011). During the same period, the plant lodging percentage increased from 1.2% to 3.6%. Based on this comparison, early harvest of grain and stover at grain maturity has several advantages: higher dry matter yield of stover, lower moldy kernel percentage, and fewer plant lodgings.

Conclusions

The two-year average kernel moisture was 37.4% (w.b.) at physiological maturity. At the same time, the average stover moisture was 67.7% (w.b.). The dry matter yield of grain increased rapidly until reaching grain maturity and remained relatively stable after grain maturity, with an average yield of 11.1 t ha^{-1} over the two-year study. For corn stover, the two-year average dry matter yield was 14.8 t ha^{-1} at the beginning of the study (filling stage), and it decreased to 13.2 t ha^{-1} at physiological maturity and further decreased throughout kernel dry down. During corn dry down, the moldy kernel percentage increased from 2.1% to 4.1%, and the plant lodging percentage increased from 1.2% to 3.6%.

Table 2. Dry matter yield of corn plant fractions and field losses of corn during and after grain maturity.[a]

	Grain		Stover		Moldy	Stalk
Stage	Moisture (% w.b.)	Yield (t ha^{-1})	Moisture (% w.b.)	Yield (t ha^{-1})	Kernels (%)	Lodging (%)
Grain maturity[b]	37.4	11.1	67.7	13.2	2.1	1.2
Late harvest[c]	18.2	11.2	50.6	11.0	4.1	3.6
Change (%)	-51.3	1.0	-25.3	16.8	95.2	192.6

[a] Moisture contents and dry matter yields are based on two-year averages. Mold and lodging percentages are from 2010.
[b] The time at which the grain just reached physiological maturity.
[c] At the end of the study period in each year.

Acknowledgements

This project was supported by the USDA National Institute of Food and Agriculture (Hatch Project No. V-202 720-4795 f-202-720-9366). We thank Mrs. Xu Li and Mr. Shaochun Ma for helping in corn harvesting and sample preparation.

References

AACC. 1984a. Method 44-15A. In *Approved Methods of the AACC*. 8th ed. St. Paul, Minn.: American Association of Cereal Chemists.

AACC. 1984b. Method 44-19. In *Approved Methods of the AACC*. 8th ed. St. Paul, Minn.: American Association of Cereal Chemists.

Buchele, W. F. 1975. Harvesting and utilization of corn stalks from Iowa farms. In *Energy in Agriculture Collection*. 7th ed. East Lansing, Mich.: Michigan State University, Department of Agricultural Engineering.

Center, C. F., G. D. Jones, and M. T. Carter. 1970. Dry matter accumulation and depletion in leaves, stems, and ears of maturing maize. *Agron. J.* 62(4): 535-537.

Cone, J. W., and F. M. Engels. 1993. The influence of aging on cell wall composition and degradability of three maize genotypes. *Animal Feed Sci. Tech.* 40(4): 331-342.

Cummins, D. G. 1970. Quality and yield of corn plants and component parts when harvested for silage at different maturity stages. *Agron. J.* 62(6): 781-784.

Dabney, S. M., J. A. Delgado, and D. W. Reeves. 2001. Using winter cover crops to improve soil and water quality. *Commun. Soil Sci. Plant Anal.* 32(7): 1221-1250.

Darby, H. M., and J. G. Lauer. 2002. Harvest date and hybrid influence on corn forage yield, quality, and preservation. *Agron. J.* 94(3): 559-566.

Eckhoff, S. R. 2010. Freezing instead of drying high-moisture corn. *Resource* 17(6) (Nov.-Dec.): 5-9.

Kaminsky, T. 1989. Investigation of the feasibility of collection, densification, storage, transportation, and marketing of agricultural biomass. Publication No. I-4305-1-E-89. Saskatoon, Saskatchewan, Canada: Saskatchewan Research Council.

McMaster, G. S., and W. Wilhelm. 1997. Growing degree-days: One equation, two interpretations. *Agric. Forest Meteorol.* 87(4): 291-300.

Nielsen, R. L. 1995. Questions relative to harvesting and storing corn stover. West Lafayette, Ind.: Purdue University, Department of Agronomy. Available at: www.agry.purdue.edu/ext/corn/pubs/agry9509.htm. Accessed June 2011.

Nielsen, R. L. 2008. Grain fill stages in corn. West Lafayette, Ind.: Purdue University, Department of Agronomy. Available at: www.agry.purdue.edu/ext/corn/news/timeless/GrainFill.html. Accessed June 2011.

Nielsen, R. L., C. Woloshuk, and K. Wise. 2009. Manage moldy corn. West Lafayette, Ind.: Purdue University, Department of Agronomy. Available at: www.ag.purdue.edu/extension/cornmold/Pages/causes.aspx. Accessed June 2011.

Pordesimo, L. O., W. C. Edens, and S. Sokhansanj. 2004a. Distribution of aboveground biomass in corn stover. *Biomass Bioenergy* 26(4): 337-343.

Pordesimo, L. O., S. Sokhansanj, and W. C. Eden. 2004b. Moisture and yield of corn stover fractions before and after grain maturity. *Trans. ASAE* 47(5): 1597-1603.

Russell, J. R. 1986. Influence of harvest date on the nutritive value and ensiling characteristics of maize stover. *Animal Feed Sci. Tech.* 14(1-2): 11-27.

Shinners, K. J., and B. N. Binversie. 2007. Fractional yield and moisture of corn stover biomass produced in the northern U.S. Corn Belt. *Biomass Bioenergy* 31(8): 576-584.

Shinners, K. J., B. N. Binversie, R. E. Muck, and P. Weimer. 2007. Comparison of wet and dry corn stover harvest and storage. *Biomass Bioenergy* 31(4): 211-221.

Shinners, K. J., A. D. Wepner, R. E. Muck, and P. J. Weimer. 2011. Aerobic and anaerobic storage of single-pass, chopped corn stover. *BioEnergy Research* 4(1): 61-75.

Smith, M. S., W. W. Frye, and J. J. Varco. 1987. Legume winter cover crops. *Advances in Soil Sci.* 7: 96-139.

Sewell, J. R., L. L. Berger, T. G. Nash, M. J. Cecava, P. H. Doane, J. L. Dunn, M. K. Dyer, and N. A. Pyatt. 2009. Nutrient digestion and performance by lambs and steers fed thermochemically treated crop residues. *J. Animal Sci.* 87(3): 1024-1033.

USDA. 2010. Chapter 1. Statistics of grain and feed. In *Agricultural Statistics 2010*. Available at: www.nass.usda.gov/Publications/Ag_Statistics/2010/Chapter01.pdf. Accessed June 2011.

USDA. 2011. Subpart D. United States standards for corn. In *Official United States Standards for Grain*. Available at: http://archive.gipsa.usda.gov/reference-library/standards/810corn.pdf. Accessed June 2011.

Weaver, D. E., C. E. Coppock, G. B. Lake, and R. W. Everett. 1978. Effect of maturation on composition and *in vitro* dry matter digestibility of corn plant parts. *J. Dairy Sci.* 61(12): 1782-1788.