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Field corn stover moisture relations determined by *in-situ* weight and grab sample techniques

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Abstract. Field corn variety Dekalb 743 was combine-harvested in two stages at corn kernel moisture contents of about 25 and 15% wet basis. Harvest coincided with initiation of on-field corn stover moisture measurements collected up to twice-daily as grab samples and as in-situ weights of 2.5 × 2.5 m steel baskets containing stover. Moisture determinations were made for about a month after the first harvest. Control treatments of tent-sheltered stover and mower-cut stover were included to aide normalization of data due to direct sun/precipitation and combine conditioning, respectively. An automatic weather station collected hourly weather data and soil moisture samples coincided with stover moisture measures. Overall, grab versus basket weight moisture determinations closely agreed. A gradual decline in stover moisture, from an initial moisture content of about 50 to 70 % (w.b.) for the 25 % (w.b.) grain harvest, also exhibited diurnal variation of about 8 % (w.b.). An

occasional precipitation event typically resulted in stover moisture reaching original levels from as low as 15 % (w.b.). No differentiation was made between intra- and inter-cellular moisture. Conditioning and shattering effect of the combine notably reduced stalk moisture at an increasing rate compared to non-shattered, mown stalks. Combined stalks often had moisture 20 % (w.b.) less than mown stalks. Only a small fraction of stalks passed completely through the combine threshing cylinder and shredder, so the wrangled-action that stalks experienced as the header snapped ears from the stalks produced a significant conditioning effect. In general, stover moisture was asymptotical over time and reached moisture content below 20% w.b. and 15% w.b. for the two stages of harvest. Rainfall added moisture but the stover quickly dried back to their original state within 4 days period.

Introduction

Water, or moisture, is a fundamental component of living organisms including biomass crops. Biomass moisture influences the management of feedstock streams (Sokhansanj et al., 2002) and the energy economy of conversion processes (Brammer and Bridgewater, 2002). Moisture content also affects biomass physical processes involving grinding (Mani et al., 2002) and manufacturing of composite products (Panigrahi et al., 2002).

Direction of U.S. biomass use development was well planned (DOE, 1999; DOE, 2002; DOE, 2003a; and DOE, 2003b) and includes crop residues such as corn stover. Corn stover is generally recognized as an underutilized source of biomass and is available at a ratio of about 1:1 stover:grain fresh weight, though Pordesimo et al. (2004) determined that a ratio of 0.8:1 stover:grain fresh weight was more realistic at a grain harvest moisture range of 18-31% wet basis (w.b.). Some conservative estimates projected corn stover availability at 61-91 million dry tones/year (Kadam and McMillian, 2003).

Strategies differ on collecting corn stover either dry (Perlack and Turhollow, 2003) or wet (Shinners et al., 2003). Selection of collection strategy may depend on end use and other factors. One rationale for collecting biomass allowed to dry on the field is to utilize the solar gain as an energy source (Liang et al., 1996). Field drying of other crops has been documented. Pan evaporation was used to predict forage crop drying in the field (Pitt, 1984). Barr and Brown (1995) developed a model to predict bulk swath forage moisture content, and they applied the Penman-Monteith equation and considered rewetting by dew and rain. Evapotranspiration was used to predict the field-wilting rate of ryegrass for silage (Borreani and Tabacco, 1998). A limited number of studies examined field drying of corn stover. Edens et al. (2002) detemined that corn stalks had the highest moisture content and made up one-half of the dry plant material, excluding the grain. Shinners et al. (2003) also noted that the stalk remained wet compared to leaf and husk fractions, and remained at a high moisture content throughout the test compared to that reported by Edens. Shinners attributed the lack of dry down to ambient differences between the Upper Midwest and Tennessee.

Corn stover contains moisture at varying levels depending on environmental conditions and elapsed-time after harvest. Prediction of moisture in corn stover would be helpful in the management of harvest, storage, and biomass conversion operations. General observations attribute differences in field drying of corn stover to environmental conditions. There is lack of information to develop mathematical prediction of corn stover moisture as a function of measured ambient conditions.

The overall objective herein was to evaluate the field moisture relationships of corn stover under southeast U.S. conditions after harvest as a function of time and environmental factors. The secondary objective was to determine the effect of stalk conditioning on moisture relations. Knowledge of environmental and conditioning effects on stover moisture may contribute to a general understanding of stover moisture relations applicable to other locations and practices.

Materials and Methods

Stover Harvest Strategy

Two stages of corn harvest provided a range of initial moisture conditions. The first stage harvest, or early harvest, was conducted at grain moisture content of about 25% wet basis (w.b.) on September 24, 2004. The second stage harvest, or late harvest, took place at grain moisture content at approximately 15% w.b on October 8, 2004. The moisture range coincided with typical grower practice. The stover on the field from both harvests was monitored until October 24, or 157 days after sowing (DAS).

Harvesting method was used to vary the degree of stalk conditioning and shattering. Some plots were harvested with an Allis Chalmers Gleaner K2 combine, with 330 corn-head and operational discharge shredder. The header wrangled many stalks as the corn ears were snapped off. The other harvest method was with a tractor-operated sickle mower. The mower simply sheared the stalks allowing the corn plants, ear and all, to fall to the ground. This method was selected to provide a means of cutting the corn stalks without a conditioning effect. It was more of a control treatment that was included to establish baseline data for intact stalks.

In-Situ Stover Moisture Measurement

Steel baskets were constructed to facilitate rapid *in-situ* weights of corn stover (Figure 1). A 2.5 by 2.5 m frame, constructed from 3-mm thick 50 mm equal leg angle iron, supported a grid of welded 5-mm wire. Wire grid spacing was 200 by 200 mm. A total of 18 baskets were distributed two per plot over nine plots. Random locations in plots were selected and corn stover from a 2.5 by 2.5 m sample area was distributed onto baskets to resemble field distribution.

A certified digital crane scale measured stover-loaded basket mass (Figure 2). Mass sampling times included mornings and afternoons of most weekdays and some weekends. Near the end of the sampling period for the late harvest period when moisture changes were small, only afternoon mass measures were taken. An Intercomp CS1500 scale (Intercomp Co., Minneapolis, MN) had 250 kg capacity, 0.1 kg resolution, and an overall accuracy of +/- 0.1% of applied load. A tractor-mounted, three-point boom pole suspended scale, cable rigging, and loaded baskets. Once baskets had been suspended for weighing they were lowered back into original locations. Strategic traffic patterns were established in the field to not disturb baskets and random grab sample locations.

Dry matter content on baskets was determined by sampling stover for moisture content determinations during basket loading. Previous measures of each basket mass established tare mass.

Grab-Sample Stover Moisture Measurement

Grab samples of stover were obtained in morning and afternoon collections and coincided with *in situ* moisture measurements. Two 200-mm long stalk sections from the middle of different stalks where combined in a sample bag and regarded as a sampling unit. Leaves were removed from stalk sections during placement in the bags. Two sampling units for stover samples in direct contact with soil (up) and two sampling units not in direct soil contact (down) were taken from each plot each sampling period. ASAE Standards method for forage moisture content determination (103°C oven temperature for 24 h) was used for the moisture contents determinations (ASAE Standards, 2000). No differentiation was made between intra- and inter-cellular moisture.

Control Treatment in Field

A control treatment of intact, mowed stalks on baskets under a tent shelter was included to establish baseline data for intact stalks not subjected to direct sun and precipitation. Tents covered about 2.5 by 2.5 m positioned about 1.5 m above the baskets. One tent was used each for mower early harvest and mower late harvest.

Corn Field

A one-hectare corn field (201.2 × 48.5 m) at the Knoxville Experiment Research Station, The University of Tennessee, Knoxville was used for the experiment. The field had a deep well drained alluvial soil (Sequatchie loam) on the first terrace of the Tennessee River. Field corn variety Dekalb 743 was planted on May 20, 2003 and given standard agronomic practices recommended for Tennessee. Row spacing was 0.76 m with plants spaced at 5-6 plants/m in the rows (79,000 plants/ha). At least seven border rows avoided potential field edge effects on plots.

Field plots were laid out to accommodate the early and late harvests with the combination of combine and mower harvesting methods (Figure 3). The combine harvested three replicate blocks during both early and late harvest stages. The mower harvested two blocks early and one block in the late harvest stage.

Environmental, Soil, and Evapotranspiration Parameters

Weather and soil measures taken during the experiment period were used to determine the effect of environmental, soil, and evapotranspiration parameters on the corn stover moisture relations. Weather data from an automatic weather station (Model: CM10, Campbell Scientific Inc., Logan, Utah) located about 200 m from the field were downloaded and the data were consolidated on a daily basis. Hourly data were logged as averages from at least 30-minute readings. Instrument sensors included pyranometer (Model: LI2005, ±3% typical error), tipping bucket rain guage (Model: TE525, ±1% accuracy), temperature and relative humidity probes (Model: HMP45C, ±0.4°C and ±2-3% relative humidity accuracy), and wind measurement sensors (Model: 03001-5 R.M. Young wind sentry set with anemometer ±0.5% accuracy and wind direction vane 5° to 10° accuracy). Environmental parameters monitored included solar radiation (MJ/s·m^2), rainfall (mm), maximum and minimum temperatures (°C), mean air temperature (°C), air relative humidity (%), wind speed (m/s), and wind direction (°N).

One soil sample per plot per sampling event was obtained for moisture content using the same determination method as stover discussed above. Also, one soil temperature measure (+/- 1° C) per plot per sampling event was obtained with a probe thermometer inserted 200 mm into the soil surface. All soil measures were taken from beneath stover on the ground.

Evapotranspiration was calculated using measured environmental parameters as input into the REF-ET Reference Evapotranspiration Calculator software, Ver. 2.0 developed by Allen (2000). Of the different evapotranspiration methods available in the software, FAO-56 Penman-Monteith method was used in this study.

Environmental Conditions

Mean daily environmental conditions indicated that evapotranspiration exceeded rainfall (Table1). Though this moisture deficit favored stover moisture reduction conditions, observed high relative humidity and low temperatures indicated low water holding capacity of the air, compared to arid conditions. Moderate wind speeds were observed. Mean wind direction indicated predominant wind from across the terrestrial landscape, and not the nearby river.

A fall-season trend was observed for environmental conditions through the experiment (Figure 4). Mean air temperature had a overall downward trend and a sharp decline near the end of the experiment. Corresponding decreases in maximum and minimum air temperatures and soil temperature were measured, especially in the final days of the experiment. Soil moisture declined slightly over time and indicated that evapotranspiration, and other losses, were greater than precipitation. Mean wind speed was somewhat consistent and low. Wide fluctuation in mean daily solar radiation was observed, and was likely due to varying levels of cloud cover. Mean relative humidity fluctuated from about 60 to 90 %. A sharp decline in relative humidity approximately corresponded with the decrease in temperatures near the experiment end. Calculated evapotranspiration was almost steady with a slight trend of reduction throughout the experiment.

Data analysis

Data were compiled and subjected to analysis of variance (ANOVA), mean separation, correlations, and regression analyses using statistical software (SAS Systems. 2002). Dependent variable was generally stover moisture content.

Independent variables included days-after-sowing (DAS), measures of environmental/weather conditions (Table 1), soil conditions, and evapotranspiration. Data were subjected to a mixed model ANOVA macro (Saxton, 2002) with a 5 percent level of significance. Tukey–Kramer mean separation analysis was conducted to compare all the possible pairwise combinations among the means. Pearson correlations between daily combinations of the dependent and continuous independent variables were examined. Multiple linear regressions were determined and sensitivity analyses were used to predict daily moisture content using the fewest, most important variables measured for that day. Coefficient of determination (r^2) and root mean square error were used to determine regression performances. Results were presented for the different data analyses typically sorted based on harvest stage, combine/mower harvest method, moisture determination method, morning/evening sampling time, stover above/below sample location, and/or treatment control (shelter).

Results

Main Effects on Mean Moisture of On-field Corn Stover

Logical trends were observed among mean moisture contents of main effects (Table 2). *In situ* field basket moisture data indicated the following points: Early harvest moisture was significantly greater than late harvest moisture by a factor over two. Daytime drying and nighttime rewetting of stover was indicated by evening measures that were 7-8 points lower that morning measures. Field variability in stover moisture was noticed among replication blocks. No significant differences were noted among sub samples (baskets). A corn stalk conditioning effect led to reduced moisture, though the effect only pertained to stover subjected to the early harvest. The tent shelter with non-conditioned mowed stalks had significantly less moisture than stover under the open sky, but only for the late harvest. Evidently the tent shelter did not significantly affect the internal plant moisture from the early harvest. Less variability in moisture content was observed for stover under tent shelters.

The grab sample method indicated somewhat parallel trends, though differences were noted (Table 2). Early harvest moistures were only slightly greater than late harvest values – and differed from the strong trend indicated by the *in situ* basket method. Morning measures of moisture were about 7 points greater than afternoon measures. The grab method indicated no differences between field replication blocks and sub samples. Stover in contact with the ground had mean moisture content about 6 points greater than stover not in contact. No comparable distinction was available with *in situ* basket measures. Grab samples indicated combine harvesting had significantly less moisture than mower harvesting, though the magnitude of difference was not as great as indicated by the field basket method.

One could speculate that either the *in situ* baskets alter moisture relations, or provide a greater integrated measure of stover field moisture. Early harvest and morning measures by *in situ* baskets were much greater than grab samples, which suggested that stover was not suspended off of the ground and subject to increased drying.

Stover moisture trends during the experiement

Small amounts of rainfall resulted in increased moisture on the day of the precipitation event (Figures 5 – 9). Analyses herein examine the effects on rain on this basis of a daily effect. However, the corn stover continued to soak up the ambient moisture for several days afterwards. This was evidenced by a peak stover moisture content that occurred from two to six days after the rain (Figures 5 – 9). Combine harvested stover demonstrated a strong susceptibility to higher moisture levels than mown stover, and was attributed to the conditioning effect of the combine. The conditioning effect not only increased dry rate, it also increased wetting rate. The delay, or offset, in the rain effect varied depending on harvest timing, harvest method, and to some extent moisture measurement method. It should be noted that absolute peak moisture contents may have been missed due to discrete sampling times. Ongoing analyses will add an appropriate offset to better reflect the delayed effects of rain in correlations and regressions.

The rate of moisture reduction by the combine was greater than for mown stover and was greater than mown stover under the tent shelter (Figure 5), as determined by *in situ* field baskets for early harvest. Allowing shattered corn stover to be exposed to the open sky was a very effective means of removing moisture, though the strong susceptibility to rain discussed above was noted.

Rain effects apparently dominated the stover late harvest moisture relation for the *in situ* field baskets (Figure 6). Moisture of stover under the tent shelter was also affected by rain for two to three days after the precipitation event.

The grab sample method indicated that stover in contact with the ground had increased levels of moisture, except for days after a light rain event that increased the moisture content of stover above ground at a rate greater than moisture of stover in contact with he ground (Figure 7). A similar trend was observed for the mowed stover (Figure 8).

Near the end of the late harvested stover, the grab sample method indicated that all stover, no matter whether harvested by combine or mower or in contact with soil or not, approached the same moisture level at about 12 days after the light rain (Figure 9).

Correlations between stover moisture and environmental factors

Relations between stover moisture and environmental factors for the *in situ* field baskets are listed in Table 3. Data indicated strong inverse correlations between stover moisture content and days after sowing (DAS) for both early and late harvest stages (Table 3). Increased exposure between conditioned stover and relatively dry soil may explain the early harvest strong correlation between soil moisture and stover moisture, especially for combine-harvested stover and mown stover under the tent shelter. Soil temperature had an increased correlation with stover moisture in the late harvest, though the correlation coefficient was positive. Solar radiation was not significantly correlated with stover moisture, which may indicate that conduction and convection heat transfer were more important than radiation, at least during the fall season. Rain was moderately correlated with stover moisture in the early harvest, and not in the late harvest. The delayed effect of rain on in-field corn stover moisture was not included in correlations. Air temperature and relative humidity were more important, in terms of correlation with stover moisture, for the combined stover than the mown stover. Both coefficients were positive. Wind direction was somewhat correlation-important. Wind speed correlation coefficients were both positive and negative, indicating that drying potential may have been decreased and increased, respectively. Maximum temperature was generally not important. Minimum temperature correlation with stover moisture indicated that this factor was more important for combine than mower harvest, and late harvest. Evapotranspiration had a weak correlation with stover moisture, except for one case during early combine harvest. It was surprising that the evapotranspiration correlation coefficient was positive.

Correlations between grab sample determined stover moisture and factors are shown in Table 4. The negative coefficient for DAS was consistent with the *in situ* basket method. A strong correlation between soil moisture and stover moisture was noted for grab samples. Solar radiation had low correlation coefficients with stover moisture, and was consistent with the same correlation using *in situ* baskets. Rain was more significant for grab sample correlation with stover moisture than *in situ* baskets. Again, the delayed effect of rain on in-field corn stover moisture was not included in correlations. (Other factors may have delayed effects, too, such as relative humidity.) Air temperature and relative humidity correlations with stover moisture for both harvest methods had higher correlations for late harvests than early harvests. Wind direction was more important, in terms of correlation, for early combine harvest that other conditions and agrees with the *in situ* basket method. Wind speed had significant negative correlations with stover moisture for the late harvest. Maximum air temperature was more important for combine harvest, especially the late harvest. Minimum air temperature had very significant correlations with stover moisture, and coefficients for the late harvest were about two time larger than those for the early harvest. Evapotranspiration was important for the late combine harvest, and the coefficient sign was negative as expected.

Regression equations to predict stover moisture content

Table 5 lists multiple linear regression equations to predict moisture content as a function of environmental factors. No one general equation best predicted stover moisture. Multiple equations were provided based on sampling method, harvest stage, and harvest method. For each combination, two equations were listed with and without the DAS factor. The difference in equation performance with/without the DAS factor ranged from no effect based on r^2 to a difference in r^2 of 0.33. Rain was not included in the equations because of poor assistance in model fit, based on using the daily rain and stover moisture values. Future refinement of equations will examine the delayed effects of rain, and other factors, on stover moisture.

Conclusions

1. Measured moisture relations of corn stover depend on several factors including environmental conditions, harvest method, and moisture measurement method.

2. A combine provided a significant conditioning effect on stover that enhanced moisture removal, and moisture uptake after rain events. The conditioning effect of harvesting equipment should be taken into account in collection and processing of corn stover.

3. The full effect of rain events on increasing stover moisture occurred several days after the event. Moisture modeling equations should reflect this, and other factor, delayed response.

4. Stover moisture was significantly greater in the morning compared to afternoon, and was greater for stover contacting the soil compared with stover not in soil contact. Rain events can reverse these trends. Timing of dry stover collection is critical to minimize moisture content.

5. Correlation of stover moisture with an evapotranspiration factor was not as strong as correlations with other combinations of environmental factors. Moisture removal from corn stover on the ground during a fall season may not be best modeled by an evapotranspiration factor that is generally associated with active growth season and environment.

6. Regressive predictions of stover moisture content by environmental factors provide a solid means of predicting moisture relations, and were generally improved upon with an additional factor based on elapsed time. Usefulness of moisture prediction equations should emphasize simplicity balanced with accuracy. This appears to rely on some knowledge of whether stover moisture is monitored by *in situ* measures or by grab samples, and knowledge of the degree of stover shattering by the combine.

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Table 1. Mean daily environmental conditions and calculated evapotranspiration (ET_o) values during experiment in Knoxville Tenn.

Variable	Mean	SD[a]	Minimum	Maximum
		Early harvest		
Days after sowing (DAS)	139.3478	8.82	127	157
Soil moisture (% w.b.)	13.6900	1.14	11.75	16.40
Soil temperature (°C)	18.8230	2.44	10.41	22.81
Solar radiation ($MJ/m^2 \cdot s$)	15.1170	4.51	3.72	20.48
Rainfall (mm/day)	0.1657	0.44	0.00	1.52
Mean air temperature (°C)	14.8196	3.38	9.25	19.94
Maximum air temperature (°C)	22.0557	4.02	14.48	28.33
Minimum air temperature (°C)	8.6519	4.09	2.12	15.33
Air relative humidity (%)	79.0909	8.03	57.01	92.10
Wind direction (°N)	135.1391	33.06	84.50	213.80
Wind speed (m/s)	0.8999	0.45	0.39	2.02
ET_o FAO56-PM[b] (mm/day)	2.0961	0.52	0.75	3.02
		Late harvest		
Days after sowing (DAS)	148.4444	5.73	141	157
Soil moisture (% w.b.)	13.0400	0.83	11.75	14.36
Soil temperature (°C)	18.9735	3.28	10.41	20.82
Solar radiation ($MJ/m^2 \cdot s$)	13.9583	4.46	3.72	18.74
Rainfall (mm/day)	0.1976	0.50	0.00	1.52
Mean air temperature (°C)	15.1433	3.47	9.89	19.36
Maximum air temperature (°C)	22.2611	3.71	14.48	25.98
Minimum air temperature (°C)	9.1861	4.26	3.82	15.33
Air relative humidity (%)	78.9100	10.71	57.01	90.60
Wind direction (°N)	129.6444	25.01	84.50	169.00
Wind speed (m/s)	0.6737	0.28	0.39	1.16
ET_o FAO56-PM (mm/day)	1.8933	0.46	0.75	2.30

[a] SD = Standard deviation

[a] Evapotranspiration by FAO-Penman-Monteith method

Table 2. Mean separations (Tukey) of on-field moisture content data.

Category	Combined data[a]			Early harvest[b]			Late harvest[c]		
	Mean	SD[d]	Group	Mean	SD[d]	Group	Mean	SD[d]	Group
	Field basket method								
Early harvest	34.0728	12.5524	A	---	---	---	---	---	---
Late harvest	15.3201	9.4866	B	---	---	---	---	---	---
Morning measurement	38.3194	10.9051	A	38.3194	10.9051	A	---	---	---
Evening measurement	26.7107	13.9782	B	31.3705	12.8066	B	15.3201	9.4866	---
Replication - block 1	25.1327	14.6130	B	32.1024	13.1291	B	13.9813	8.8407	B
Replication - block 2	32.6221	13.0338	A	34.6735	11.8795	A	16.2106	10.0467	A
Replication - block 3	32.1843	13.9469	A	34.5856	13.0112	AB	17.7767	10.4073	A
Sub sample 1	32.1669	13.8451	A	35.7637	11.8042	A	14.9020	9.1367	A
Sub sample 2	26.9790	14.1283	A	30.6911	13.3545	A	15.8428	10.0127	A
Combine harvesting	27.9381	14.3677	B	30.9334	13.6073	B	15.9570	10.6674	A
Mower harvesting	36.0086	12.4012	A	41.0907	7.0503	A	15.6800	7.1123	A
Shelter tent – control[e]	33.2549	12.4609	A	38.8739	5.4774	A	10.7789	3.5154	B
	Grab sample method								
Early harvest	25.7813	18.1111	A	---	---	---	---	---	---
Late harvest	21.1891	14.9550	A	---	---	---	---	---	---
Morning measurement	29.0322	16.8521	A	29.0322	16.8521	A	---	---	---
Evening measurement	22.8483	17.6778	B	23.5088	18.6271	B	21.1891	14.9550	---
Replication - block 1	23.2237	17.4777	A	23.9534	18.4540	A	20.8628	13.7097	A
Replication - block 2	25.7518	17.1837	A	26.4201	17.2922	A	22.4106	16.3968	A
Replication - block 3	25.7533	18.1836	A	26.8180	18.5390	A	20.4298	15.3812	A
Sub sample 1	25.7629	18.0500	A	26.5813	18.4703	A	21.5298	15.1408	A
Sub sample 2	25.3579	17.5875	A	26.2073	18.0434	A	20.9648	14.3564	A
Stover above[f]	21.8599	17.0594	B	22.0694	17.0267	B	20.9655	17.2751	A
Stover below[g]	27.9594	17.7028	A	29.4931	18.4235	A	21.4127	12.3099	A
Combine harvesting	24.1276	17.8601	B	24.9241	18.4817	B	21.5105	15.4168	A
Mower harvesting	26.6870	17.0290	A	27.4243	17.2979	A	19.3142	12.0128	A

[a] Early and late harvest data combined

[c] Late harvest at grain moisture around 15% (w.b.); only evening measurement was taken

[e] Mower harvested stover

[g] Stover touching the ground

[b] Early harvest at grain moisture around 25% (w.b.)

[d] SD = Standard deviation

[f] Stover not touching the ground

Table 3. Pearson correlation coefficients between moisture content and selected factors monitored for stover on field baskets. The delayed effect of rain was not included in these versions.

	Combine field basket[a]		Mower field basket[b]		Shelter tent control basket[c]	
Variable	MC[d]		MC[d]		MC[d]	
	r	*p*	*r*	*p*	*r*	*p*
			Early harvest			
DAS	-0.519	<.0001	-0.582	<.0001	-0.819	<.0001
Soil MC (% w.b.)	0.603	<.0001	0.492	<.0001	0.851	<.0001
Soil temperature	0.196	0.0039	0.202	0.0881	0.235	0.1676
Solar radiation	0.074	0.2768	0.030	0.8012	0.122	0.4793
Rain	0.345	<.0001	0.347	0.0028	0.378	0.0228
Air temperature	0.242	0.0003	0.206	0.0825	0.295	0.0806
Relative humidity	0.261	0.0001	0.275	0.0196	0.318	0.0588
Wind direction	0.298	<.0001	0.228	0.0543	0.230	0.1763
Wind speed	0.221	0.0011	0.238	0.0442	0.262	0.1228
Maximum temp	0.150	0.0276	0.140	0.2411	0.255	0.1337
Minimum temp	0.287	<.0001	0.242	0.0409	0.288	0.0890
ET_o FAO56-PM	0.182	0.0072	0.144	0.2268	0.314	0.0619
			Late harvest			
DAS	-0.591	<.0001	-0.486	0.0408	-0.891	0.0013
Soil MC (% w.b.)	0.199	0.1498	0.339	0.1681	0.233	0.5460
Soil temperature	0.546	<.0001	0.445	0.0640	0.668	0.0494
Solar radiation	-0.156	0.2602	-0.140	0.5805	-0.316	0.4070
Rain	-0.062	0.6556	-0.136	0.5914	0.268	0.4854
Air temperature	0.456	0.0005	0.371	0.1300	0.616	0.0776
Relative humidity	0.431	0.0012	0.379	0.1211	0.651	0.0576
Wind direction	0.190	0.1681	0.200	0.4269	-0.205	0.5959
Wind speed	-0.238	0.0832	-0.205	0.4143	-0.431	0.2471
Maximum temp	0.206	0.1355	0.141	0.5766	0.362	0.3390
Minimum temp	0.640	<.0001	0.559	0.0159	0.732	0.0251
ET_o FAO56-PM	0.026	0.8510	0.010	0.9677	-0.071	0.8556

[a] Combine harvested stover

[b] Mower harvested stover

[c] Mower harvested stover under shelter tent

[d] MC = Moisture content (% w.b.)

Table 4. Pearson correlation coefficients between moisture content and selected factors monitored for stover grab samples. The delayed effect of rain was not included in these versions.

Variable	Combine grab sample[a] MC[c]		Mower grab sample[b] MC[c]	
	r	*p*	*r*	*p*
	Early harvest			
DAS	-0.246	<.0001	-0.306	<.0001
Soil MC (% w.b.)	0.533	<.0001	0.487	<.0001
Soil temperature	0.143	0.0021	0.127	0.0493
Solar radiation	0.002	0.9711	0.084	0.1950
Rain	0.464	<.0001	0.405	<.0001
Air temperature	0.227	<.0001	0.225	0.0005
Relative humidity	0.277	<.0001	0.271	<.0001
Wind direction	0.163	0.0004	0.135	0.0367
Wind speed	0.048	0.3080	0.073	0.2617
Maximum temp	0.127	0.0062	0.130	0.0441
Minimum temp	0.265	<.0001	0.249	<.0001
ET_o FAO56-PM	0.006	0.9049	0.092	0.1538
	Late harvest			
DAS	-0.332	<.0001	-0.272	0.1993
Soil MC (% w.b.)	0.503	<.0001	0.573	0.0034
Soil temperature	0.475	<.0001	0.389	0.0606
Solar radiation	-0.217	0.0100	-0.206	0.3349
Rain	0.462	<.0001	0.184	0.3906
Air temperature	0.459	<.0001	0.406	0.0493
Relative humidity	0.671	<.0001	0.647	0.0006
Wind direction	-0.099	0.2432	-0.212	0.3196
Wind speed	-0.501	<.0001	-0.549	0.0054
Maximum temp	0.396	<.0001	0.352	0.0913
Minimum temp	0.578	<.0001	0.558	0.0046
ET_o FAO56-PM	-0.245	0.0036	-0.280	0.1852

[a] Combine harvested stover

[b] Mower harvested stover

[c] MC = Moisture content (% w.b.)

Table 5. Multiple linear regressions predicting on-field corn stover moisture content primarily as a function of environmental conditions. The delayed effect of rain was not included in these versions.

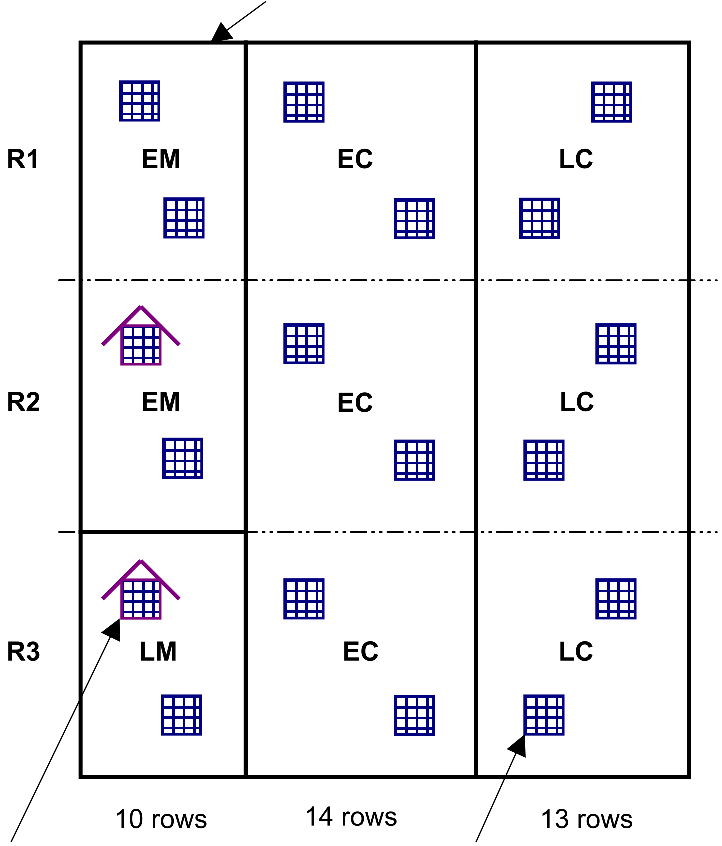
Moisture relations	R^2	RMSE
Field basket method – Early harvest:		
Combine harvested stover		
$MC = 44.02 - 0.58\ DAS + 3.68\ SM + 3.24\ SR + 10.22\ WS + 2.34\ MIT - 29.80\ EP$	0.57	9.09
$MC = -59.56 + 4.93\ SM + 2.39\ SR + 10.20\ WS + 2.12\ MIT - 19.61\ EP$	0.51	9.65
Mower harvested stover		
$MC = 77.80 - 0.35\ DAS + 1.21\ SM + 0.06\ RH + 3.32\ WS - 2.05\ AT + 1.97\ MIT$	0.49	5.24
$MC = 10.67 + 1.80\ SM + 0.15\ RH + 5.18\ WS - 1.88\ AT + 1.90\ MIT$	0.39	5.70
Stover under shelter tent – control		
$MC = 41.83 - 0.29\ DAS + 2.15\ SM + 0.06\ RH + 0.13\ AT$	0.84	2.36
$MC = -15.40 + 3.29\ SM + 0.07\ RH + 0.17\ AT$	0.75	2.84
Field basket method – Late harvest:		
Combine harvested stover		
$MC = -972.76 + 3.42\ DAS + 4.44\ RH + 143.06\ WS + 3.75\ MIT$	0.86	4.14
$MC = -130.45 + 1.33\ RH + 43.65\ WS + 1.28\ MIT$	0.60	6.94
Mower harvested stover		
$MC = -693.69 + 2.53\ DAS + 3.09\ RH + 99.56\ WS + 2.55\ MIT$	0.80	3.63
$MC = -71.07 + 0.79\ RH + 26.07\ WS + 0.72\ MIT$	0.47	5.71
Stover under shelter tent – control		
$MC = -43.42 - 0.003\ DAS + 0.52\ RH + 14.88\ WS + 0.41\ MIT$	0.88	1.70
$MC = -44.12 + 0.52\ RH + 14.96\ WS + 0.41\ MIT$	0.88	1.52
Grab samples method – Early harvest:		
Combine harvested stover		
$MC = -97.84 + 0.47\ DAS + 7.67\ SM - 0.41\ RH + 3.09\ MIT - 1.89\ MXT$	0.37	14.73
$MC = -14.91 + 6.43\ SM - 0.43\ RH + 2.99\ MIT - 1.83\ MXT$	0.35	14.91
Mower harvested stover		
$MC = -174.76 + 0.48\ DAS + 6.47\ SM + 5.15\ SR + 11.33\ AT - 2.87\ MIT - 3.98\ MXT - 40.37\ EP$	0.43	13.20
$MC = -97.93 + 5.15\ SM + 5.31\ SR + 12.44\ AT - 4.09\ MIT - 3.56\ MXT - 45.22\ EP$	0.42	13.34
Grab samples method – Late harvest:		
Combine harvested stover		
$MC = -938.58 + 3.97\ DAS - 1.13\ SR + 4.09\ RH + 33.64\ EP$	0.82	6.57
$MC = -91.12 - 1.70\ SR + 1.46\ RH + 10.94\ EP$	0.52	10.84
Mower harvested stover		
$MC = -449.04 + 1.91\ DAS + 10.02\ SM + 0.51\ RH + 2.37\ MIT$	0.83	5.47
$MC = -92.89 + 9.28\ SM - 0.23\ RH + 1.65\ MIT$	0.57	8.46

Note: RMSE = Root mean square error, *MC* = Moisture content (% w.b.), *DAS* = Days after sowing,
SM = Soil moisture content (% w.b.), *SR* = Solar radiation (MJ/m^2s), *MIT* = Minimum air temperature (°C),
EP = Evapotranspiration by FAO-Penman-Monteith method (mm/day), *RH* = Air relative humidity (%),
WS = Wind speed (m/s), *AT* = Mean air temperature (°C), *MXT* = Maximum air temperature (°C)

Figure 1. Stack of field baskets in front of the experiment corn field.

Figure 2. A typical afternoon mass determination of basket loaded with corn stover using a suspended crane scale

Experimental field (152 × 39 m); 37 rows



Field basket under shelter tent (2.5 × 2.5 m)

Field basket directly exposed (2.5 × 2.5 m)

EM – Early-mower harvested plot
LM – Late-mower harvested plot
EC – Early-combine harvested plot
LC – Late-combine harvested plot
R1, R2, R3 – Up, middle, and bottom replication plot blocks

Figure 3. Experimental field layout for corn stover field moisture relationship study

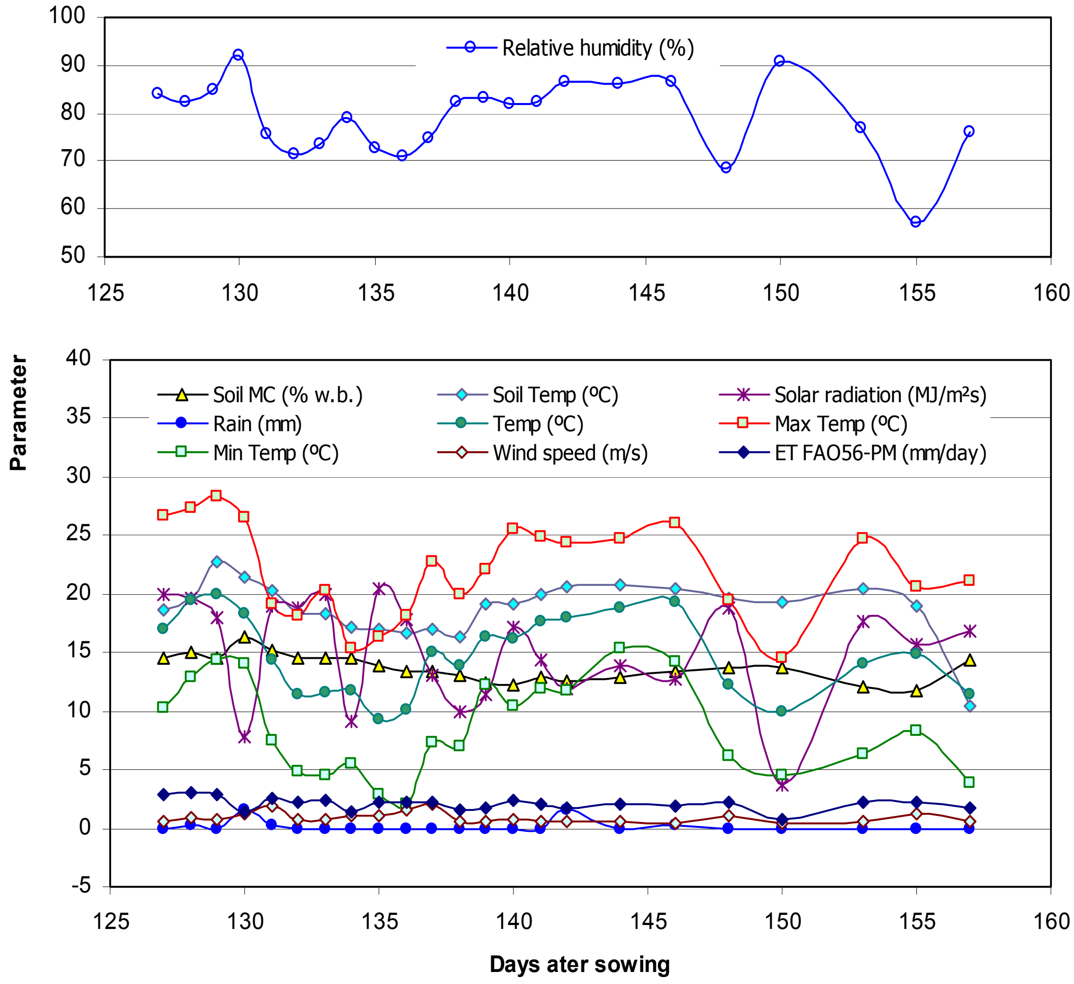


Figure 4. Environmental parameters during the experimental period in research station, Knoxville (24 September to 24 October, 2003)

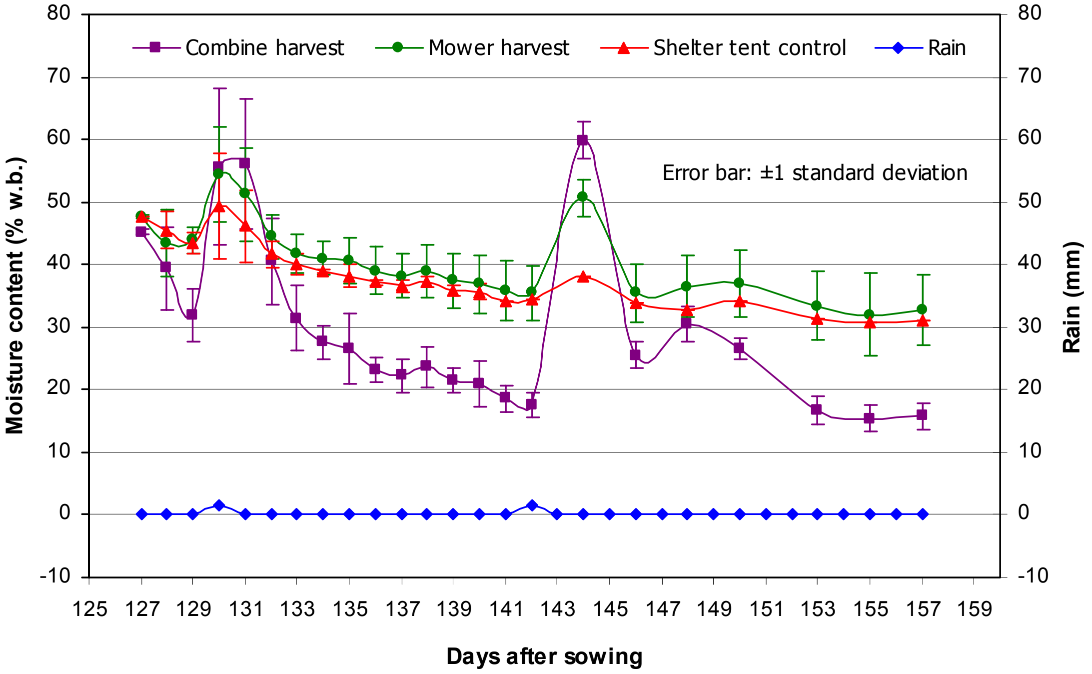


Figure 5. Early harvested on-field corn stover moisture average curves by field basket method

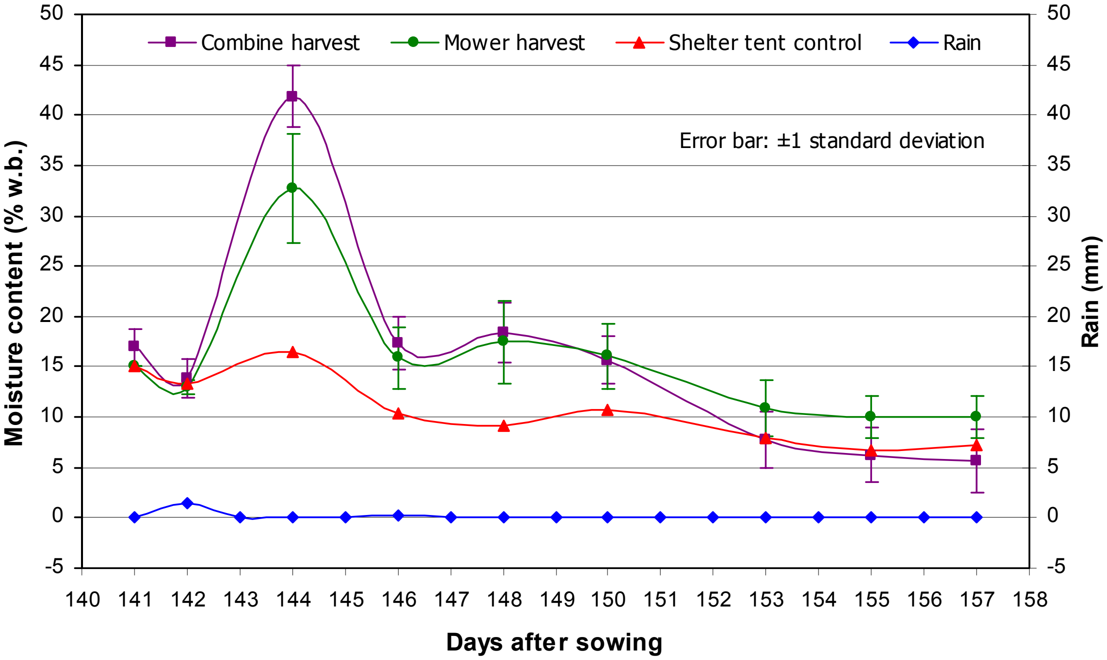


Figure 6. Late harvested on-field corn stover moisture average curves by field basket method

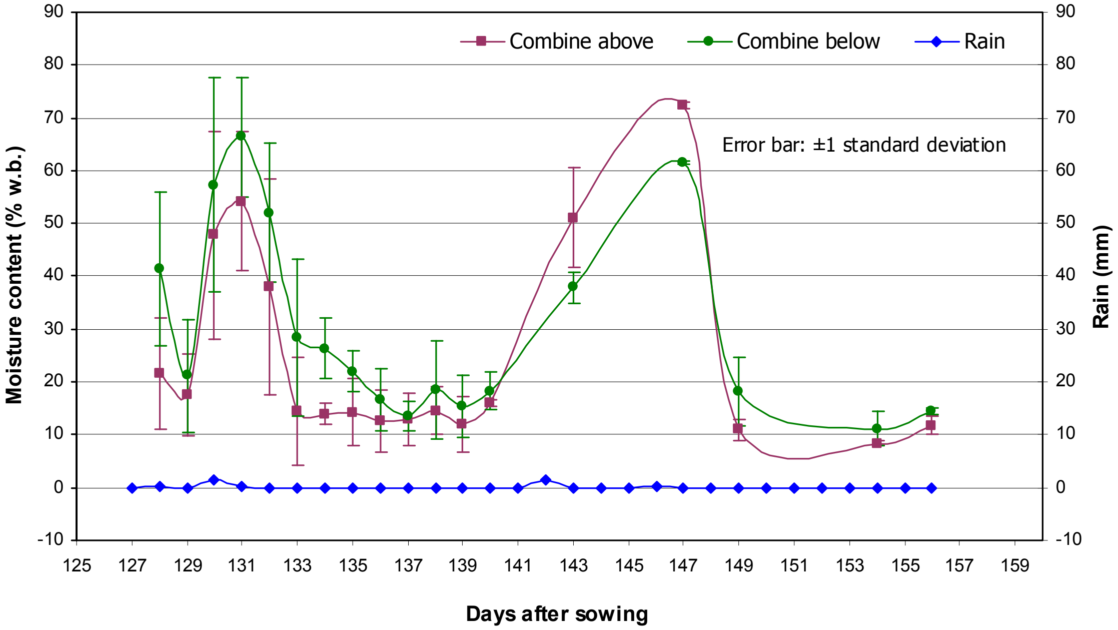


Figure 7. Early combine harvested on-field corn stover moisture curves by grab samples method

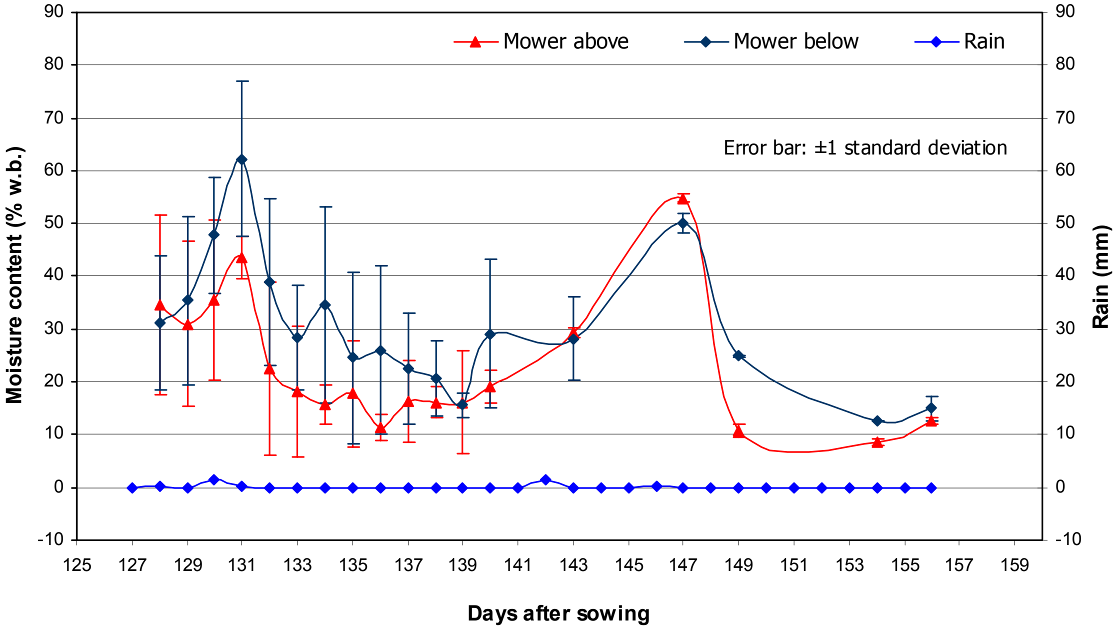


Figure 8. Early mower harvested on-field corn stover moisture curves by grab samples method

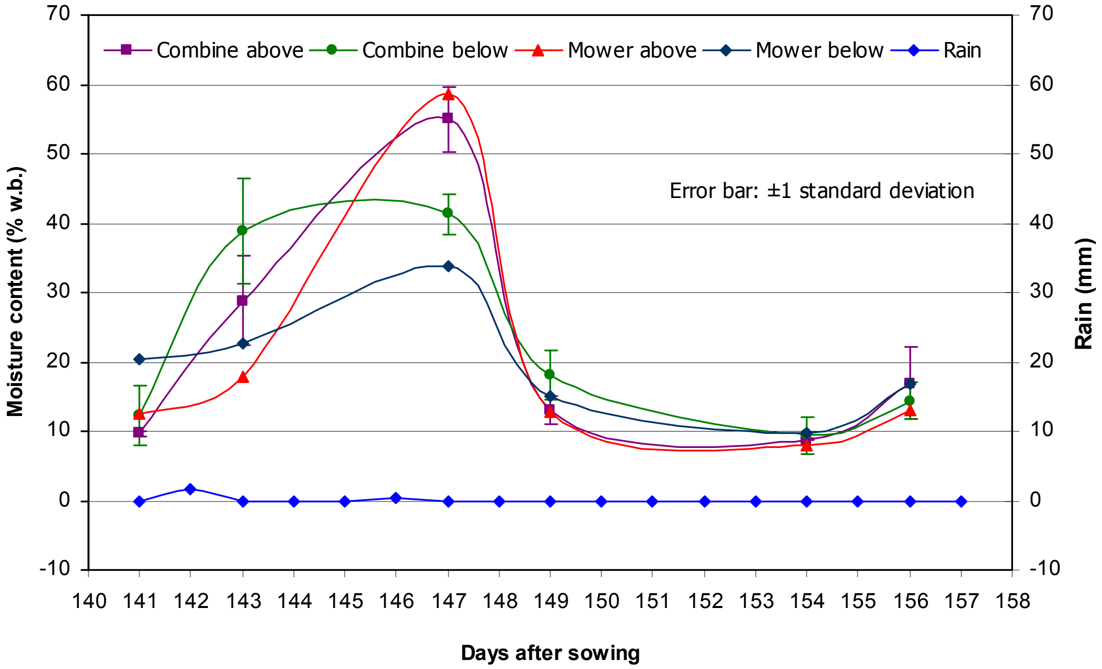


Figure 9. Late harvested on-field corn stover moisture average curves by grab samples method