THE ACCURACY OF COTTON BALE MOISTURE SENSORS USED IN A SOUTH TEXAS COMMERCIAL GIN WITH LINT MOISTURE RESTORATION

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Abstract

Proper measurement of bale moisture content (mc) is crucial to proper management of a cotton gin. It is important to avoid producing wet cotton both for the benefit of the mills and because wet cotton is unacceptable for Commodity Credit Corporation Marketing Assistance Loan Program. Wet cotton is defined to be a bale of cotton which is at or above 7.5% wet basis (8.1% dry basis) at any point in the bale at the gin. Several meters are available from different manufacturers for the measurement of cotton mc and the accuracy of some of these meters have been evaluated in earlier studies. Based on the previous studies, data were collected with the Delmhorst handheld and Tex-Max® meters at two commercial gins in TX, which had lint moisture restoration capability and samples of lint taken from the same bales which were tested by the standard cotton mc measurement, the oven method, at the USDA, ARS Cotton Ginning Research Unit in Stoneville, MS. The data included measurements by each meter plus the reference mc for 534 bales. The Delmhorst bale moisture probe, corrected for bale temperature as documented in the manual, was the most accurate of the meters studied without additional calibration. After an offset correction to the readings the Sam Jackson Tex-Max® was the most accurate.

Introduction

In U.S. commerce, cotton bales weighing approximately 226 kg (500 lb.) are formed at the gin and covered with bagging to protect them during transportation and storage. These cotton bales are transported, stored, and sold based on the weight without regard to the lint moisture content (mc) but changing mc directly affects the bale weight and thus the value. Gin managers have always been concerned about the lint mc. Ginning at lower mc results in more efficient cleaning while ginning at higher mc results in better fiber length quality (Hughs et al., 1994). Moisture restoration of lint in gins has been practiced for many years (Griffin and Harrell, 1957). It was apparent that in a few cases too much moisture was added and lint quality degradation occurred during bale storage. In response to this problem the industry recommended that the lint leave the gin with mc below 7.5% wet basis (wb) (8.1% dry basis). Wet cotton has always been unacceptable for the Commodity Credit Corporation Marketing Assistance Loan Program (CCC Loan) but was not clearly defined. In 2006, the Farm Service Agency (FSA) of the USDA issued a definition of wet cotton, which is unacceptable for the CCC Loan, as a bale at the gin formed with mc of 7.5% wet basis or more at any point in the bale (Federal Register, 2006).

There are several different commercially available meters for bale mc determination on the market today. Several companies offer portable handheld meters for measuring the mc of fiber in a cotton bale. However, they have been regarded as having limited accuracy, are labor intensive in use, and no independent data was available indicating the accuracy of the meters in this application except for one review by Byler et al. (2009). That review found that the model C-2000 meter offered by Delmhorst (Delmhorst Instrument Co., Towaco, NJ), based on sample resistance, was low in cost compared to the competitors and was as accurate or more accurate than the others, although not very accurate with a Root Mean Square Error (RMSE) of 0.8 percent mc, wet basis. The Delmhorst meter readings also need to be corrected for bale temperature, which makes the meter less practical for use immediately after bale formation when the bales are at elevated temperatures (Byler; 2012, 2013).

A meter based on microwave transmission was available from Vomax®, model 851-B, and is currently offered as the Tex-Max® (Sam Jackson, Inc, Lubbock, TX). In a limited review of one of these meters by Delhom and Byler (2011) the Vomax meter tracked the reference oven based mc measurements well but consistently read approximately one percentage point too high.

If the gin is using moisture restoration the location of the lint mc meter relative to the moisture addition would affect the accuracy of bale mc reading. Past studies (Byler et al., 2002) have shown that any kind of recent moisture addition causes certain meters to read high, presumably because the adsorbed moisture on the lint affects the sensor more than if the same moisture had been absorbed into the fibers.

The standard method for cotton moisture measurement is to weigh the lint, dry it in an oven, and then reweigh it (Shepherd, 1972; ASTM 2006). The loss in weight is used to calculate the mc, defined as the weight lost divided by the original weight. This mc is also called mc wet basis and is different from the percentage of weight lost divided by the dry weight in the sample called moisture regain or mc dry basis. Some published literature on the effects of bale mc use the wet basis moisture and some use the dry basis moisture. The 7.5% limit in the FSA rule is explicitly stated to be wet basis but the corresponding dry basis mc would be 8.1%.

During the 2011 ginning season, the author reviewed the use of these meters at a gin located in Georgia, (Byler, 2012). The gin added little moisture to the lint and the Intelligin meter was the most accurate with no user calibration with a root mean square difference between the meter and the oven based mc of the bale of 0.57 percentage points. After additional calibration of an offset of 1.9 percentage points the Tex-Max was the most accurate with a root mean square difference of 0.43. The meters would be most useful as the mc of the lint approaches the upper limit of 7.5% but the average lint mc was 4.3% and 90% of the observations were between 3.6% and 6.7% and no lint was encountered with a mc as high as 7.5%. During the 2012 ginning season these meters were studied at a gin located in Tennessee (Byler, 2013). The meter testing at this gin included more and varied moisture restoration at the lint flue. The Delmhorst probe was more accurate in measuring bale mc than the Intelligin meter because the Intelligin meter measured the mc before moisture restoration. After calibration the Tex-Max was the most accurate at this gin with an offset of 1.8 percentage points.

The purpose of this study was to examine the results of measuring cotton bale mc using several commercially available moisture meters operating in two commercial gins in Texas and was designed to include effects of moisture restoration on the meter accuracy. The intention was to also include data for lint mc as high as or perhaps slightly above 7.5% and to test the hypothesis based on previous studies for possible correction methods to the Tex-Max meter.

Materials and Methods

UnitedAg in El Campo, TX, agreed to work with the Ginning Unit in Stoneville, MS in the study of these meters. They have two gins which were used, one near Hillje, TX, and the other in Danevang, TX. These gins consistently ginned at over 35 bales per hour, had a moist air type moisture restoration system capable of higher levels of moisture addition, an Uster Intelligin for moisture and other data collection, and used the Tex-Max in moisture control. The USDA, ARS Cotton Ginning Research Unit, Stoneville, MS (CGRU) had available a Delmhorst bale probe meter.

Three visits were made to the area, on Aug. 27 and Sept. 10, 2013 data and samples were obtained at the Hillje Gin, but the Danevang Gin was not operating. On Oct. 22-23, 2013 both gins were operating and data and lint samples for mc determination by the oven method were collected. The Tex-Max data were recorded manually by bale number. The indicated bale mc and bale temperature for the Delmhorst C-2000 meter were recorded manually with the bale number and entered into files for later analysis. A small thermocouple mounted in a needle (Model N, Electronic Development Labs, Danville, VA) was inserted into the hole created with the Delmhorst probe and a Lutron model YK-2005RH (Mitchell Instrument Co., Inc., San Marcos, CA) meter was used to indicate the bale internal temperature.

Because it was relatively labor intensive to insert the Delmhorst C-2000 probe 30-E/C into bales a hammer-drill was employed. This approach proved to be quite successful because the insertion force was reduced to a reasonable amount and the time required to insert the probe was likewise significantly reduced.

The lint samples from each bale were subsamples of the lint sent to the classing office. The lint was placed in metal cans immediately after having been removed from the bale and the cans sealed. A total of 702 lint samples were obtained and returned to the CGRU for moisture determination, wet basis, by the oven method (Shepherd, 1972). Some of the lint samples were taken at the lint flue and some of them were taken when data from the Tex-Max or

Delmhorst probe were missing. The data were combined into one data set and read into SAS, (SAS Institute, 2003) and analyzed by procedures MEANS, UNIVARIATE and GLM.

The data were examined and bales for which data were not available for the oven plus the two meters were discarded, so that all readings would be compared using data from the same bales. Next, the uncorrected residuals were calculated (meter reading – oven reading) and analyzed statistically by bale for each meter. This analysis was used to detect suspect data and based on this analysis one typographic error was corrected and four observations were rejected. This final data set was then used for further analysis. The average oven and meter readings were calculated for each meter and the difference was used as the offset correction. GLM was used to calculate the best fit straight line correction for each meter with and without intercept. Each measurement was corrected using offset, slope only and slope with offset and the oven mc was subtracted from each corrected measurement for each bale resulting in four sets of residuals. The root mean square of each of these residual sets was calculated using the appropriate degrees of freedom to calculate a Root Mean Square Error (RMSE) for each meter with each correction: none, offset, slope, and offset with slope.

Results and Discussion

There were 534 bales with bale mc data and data for 57 samples taken from the lint flue obtained by the oven method, which is the standard method of determining cotton moisture content. There were data for 302 bales from Hillje Gin, collected over four days, and 232 bales from Danevang Gin, collected over two days.

All oven mc were calculated wet basis. The average bale mc measured by the oven method was 5.7% at both gins. The mc range covering 98% of the oven mc values was 4.4% to 7.1% at Danevang Gin and was 4.4% to 8.0% at Hillje Gin where efforts had been made to extend the mc to higher levels than had been seen in the past. This cotton was generally less dry than had been observed in similar studies and is within the range observed in commercial gins. In the 2012 and 2013 reports the range of oven mc was from 3.2% to 6.8%. The data set obtained this year included 16 observations with mc greater than 7.0% including several above 7.5%. Because 7.5% was a crucial mc level efforts were made to include a few bales above that value, necessary for proper calibration verification.

The bale probe mc measurements were corrected for each bale separately following the manufacturer's instructions for the bale temperature, the mean bale temperature was 104°F at Danevang Gin and the mean bale temperature was 103°F at Hillje Gin, the mean uncorrected probe mc was 7.3% at Danevang Gin and was 7.2% at Hillje Gin, and the mean corrected probe mc was 5.4% at Danevang Gin and was 5.7% at Hillje Gin. Each of the meter readings was compared to the oven mc for the same bale and RMSE values were calculated for uncorrected readings, readings corrected with an offset only, slope only, and with an offset and slope, Table 1. Based on these data the most accurate prediction of the bale mc before correction was the data from the Delmhorst probe, as corrected for measured bale temperature as documented in the Delmhorst instructions, with a RMSE of 0.81.

Table 1. Root Mean Square Errors of uncorrected and readings with simple corrections, smaller RMSE is better.

	Sam Jackson Tex-Max, Danevang Gin	Sam Jackson Tex-Max, Hillje Gin	Sam Jackson Tex-Max combined gins	Delmhorst probe, corrected for temperature
Uncorrected	1.55	1.33	1.30	0.81
Offset only	0.46	0.61	0.55	0.80
Slope only	0.48	0.59	0.55	0.81
Offset and slope	0.46	0.59	0.55	0.53

After the offset correction for the readings the Tex-Max proved to be the most accurate meter. The Tex-Max meters at the two gins appeared to respond nearly identically with the same offset. Combining the data from the two gins, with two separate Tex-Max meters, resulted in an overall RMSE of 0.55. The slope or offset and slope correction of the Tex-Max resulted in virtually the same statistical fit as the offset only, and the difference would be unimportant to a gin. The offset observed at these two gins showed that the meters indicated 1.17 percentage points too high, on average. This compares to the results with the meters located at the gins in Georgia and Tennessee which had an offset of about 1.8 percentage points. After correction for offset and slope the Delmhorst probe measurement was improved and was as accurate as the Tex-Max after offset correction.

Figure 1 is a plot of the Delmhorst handheld probe meter data corrected for measured bale temperature compared to the oven mc data for the same bales. The overall fit appears adequate, but the scatter was greater than desired. Although there were few data points with oven mc above 7.0%, Figure 1 shows that this meter operated satisfactorily at the higher mc values of special interest.

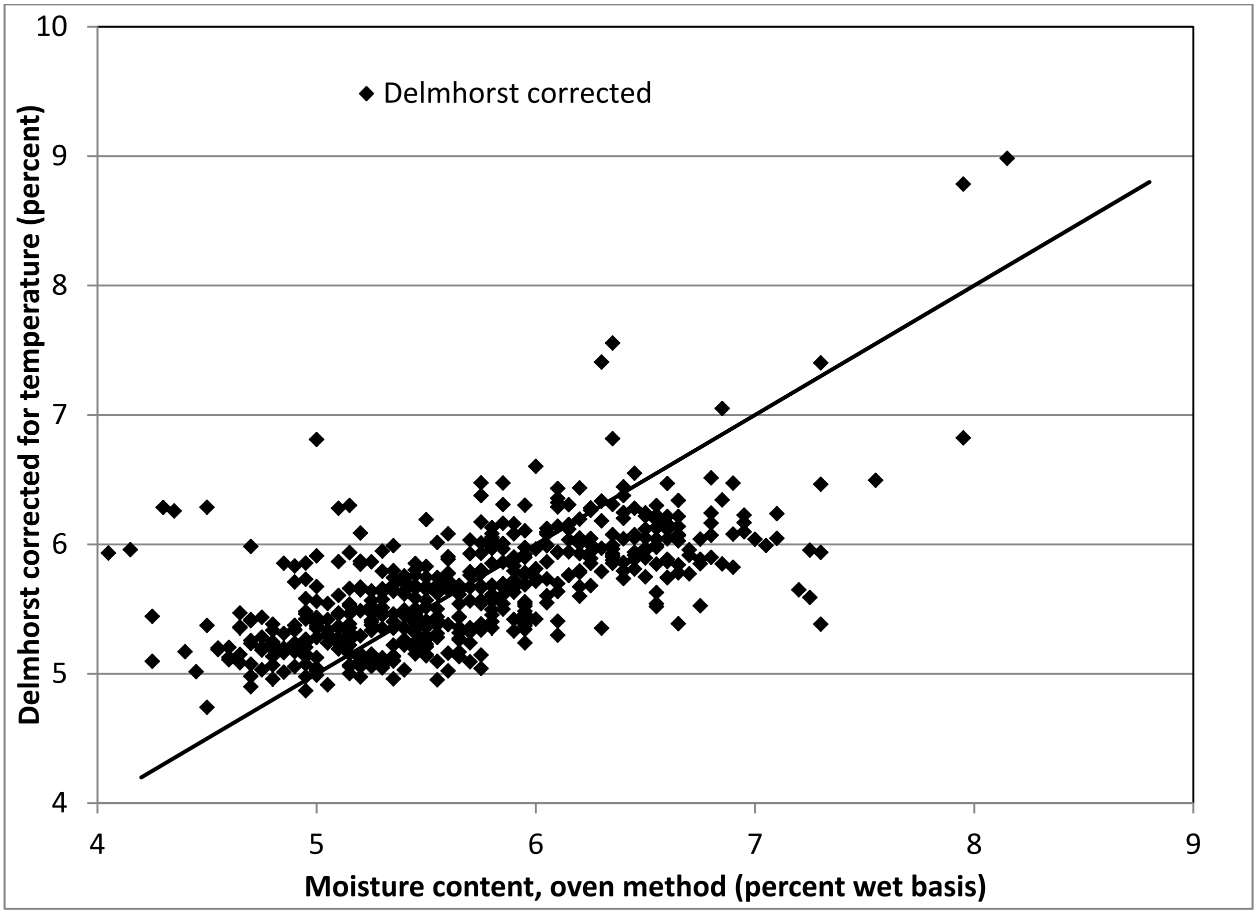

Figure 1. Delmhorst probe measurements from both gins, corrected for bale temperature, with offset and slope correction with a solid line showing a perfect fit.

Figure 2 is a plot of the Tex-Max readings uncorrected and corrected with an offset compared to the oven mc data for the same bales. The uncorrected data was 1.17% higher than the corrected data. The relatively few observations with oven mc above 7.0% were handled well as shown in Figure 2 with observably smaller errors then with the Delmhorst in this range.

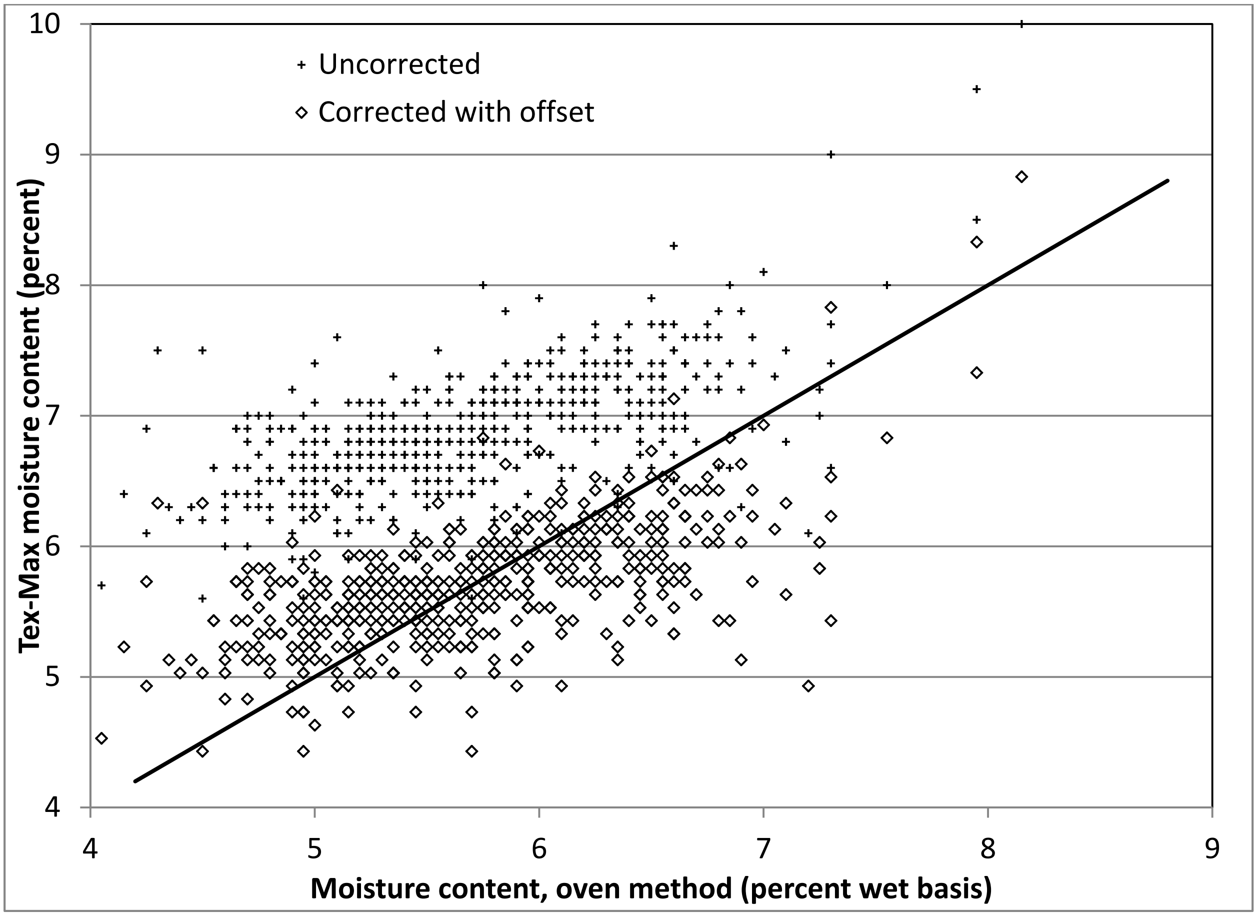

Figure 2. Samuel Jackson, Inc. Tex-Max readings from both gins, uncorrected, plus, and corrected for offset, diamonds, with a solid line showing perfect fit.

Most of the actual values of a measured value are expected to be within plus or minus two times the RMSE, when the prediction fits the data well. For the Tex-Max data corrected for offset twice the RMSE was 1.1% so if the corrected reading were 5.5% most of the actual value should be between 4.4% and 6.6%, see Figure 2.

The set point in control of bale mc should be chosen to assure that a maximum level not be attained. Some assurance that the maximum would rarely, but occasionally, be observed would be to use a set point at least two times the RMSE observed during calibration below the desired maximum. In this control situation 7.5% (wet basis) is the maximum and twice the RMSE would be 1.1% so the maximum reasonable set point would be 6.4%. Alternatively, viewing this data from the ginner's standpoint, if the Tex-Max were used for mc control and 7.5% was used at the set point the average actual bale mc would be about 6.3%, which is nearly the same as the desired maximum set point and would result in very few bales with a mc above 7.5% under normal operating conditions. The offset for the meters in the 2012 and 2013 reports was about 1.8% and the offset for these two meters was significantly lower at 1.2%. Perhaps the owners of these meters should ask the manufacturer for additional information regarding the offset of the meters in their gins.

The readings in this study were for bales, the small samples of lint within the bale would vary from the overall bale mc reading. Because meters can drift with time and little is known about the drift of these meters, the RMSE of 0.55 might not be applicable on a larger scale and at other gins. If the Delmhorst probe were used without correction a maximum set point might be 5.9%. More accurate meters and meters with a proven stability over time could be developed. With the increasing emphasis on properly measuring cotton bale mc perhaps progress will be made in improving this situation in the cotton ginning industry.

Conclusion

The goal of this project was to collect data with several commercially available cotton bale moisture measurement meters along with oven mc data and compare the meter data with the oven mc data. Several visits were made to commercial gins and two commercial meters were studied resulting in complete data for 534 bales. The gins had capability for moisture restoration and normally operated with some moisture restoration but for some of the data the moisture restoration was turned off. The reference mc range had 98% of the oven mc data in the range 4.4% to 7.6% wet basis. The goal of obtaining data with bale moisture content around or slightly above 7.5% was achieved with 16 observations above 7.0% and a few at or above 7.5%. The meters operated normally at and above the crucial 7.5% level, although verified with very few observations. For uncorrected readings the Delmhorst probe, corrected for bale temperature as described in the manual, was the most accurate. After appropriate linear corrections the Tex-Max meter was the more accurate meter with an offset correction of -1.2. The Delmhorst probe data corrected for bale temperature and with an additional offset and slope correction was equally as accurate as the Tex-Max.

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