THE ACCURACY AND CALIBRATION OF THREE COTTON BALE MOISTURE SENSORS USED IN A 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, unacceptable for Commodity Credit Corporation Marketing Assistance Loan Program, which 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. Several meters are available from different manufacturers for the measurement of cotton mc and the accuracy of some of these meters has been evaluated in earlier studies. Based on the previous studies, data were collected with three of these meters at a commercial gin 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 731 bales. The Delmhorst bale moisture probe, corrected for bale temperature as documented in the manual, was the most accurate of the three meters studied with no further corrections. When moisture was restored to bales the mc averaged 1.1 percentage points higher in the bale than in the lint flue. After a simple correction to the readings the Sam Jackson Tex-Max® was the most accurate. The Uster Intelligin® moisture meter was found to be accurate, but measured the mc of lint before final moisture restoration and was not helpful in improving the bale mc measurement. After further analysis it was found that a linear offset based on the temperature of the bale further improved the accuracy of the Tex-Max meter.

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. This cotton is transported, stored, and sold based on the bale 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 that with mc of 7.5% wb 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 hand-held 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 residual (rmsr) of 0.8% mc, wet basis. The Delmhorst meter readings also need to be corrected for bale temperature.

A meter based on microwave transmission has been 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.

The Intelligin (Uster Technologies, Inc., Knoxville, TN) moisture meter takes samples from the lint flue, typically before moisture restoration, measures the mc and then releases them back into the lint flow. 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. Also, 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 GA, (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 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%.

The purpose of this study was to examine the results of measuring cotton bale mc using several commercially available moisture meters operating in a commercial gin 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

The first step was to identify a cooperating gin which had the appropriate meters available for study. Several gin managers were contacted and Burlison Gin Co. Inc., Covington TN, was chosen to be the best location for the study. This gin consistently ginned at over 30 bales per hour, had a moist air type moisture restoration system capable of higher levels of moisture addition 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. The CGRU temporarily installed an Uster Intelligin station to monitor the mc of the lint in the lint flue, prior to final moisture restoration, as part of the project to allow tracking of lint mc prior to moisture restoration.

Four visits were made to the gin, on Sept. 24, Oct. 9, Oct. 30, and Nov. 5 2012, to collect data and obtain lint samples for mc determination by the oven method. Data from Intelligin were logged by bale number on the CGRU computer system. The Tex-Max data were recorded manually. The indicated bale mc and bale temperature for the Delmhorst meter were recorded manually with the bale number and entered into files for later analysis.

Lint samples from the 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. On each gin visit 270 lint samples were obtained and returned to the CGRU for moisture determination, wet basis, by the oven method (Shepherd, 1972). Most of the samples were of lint from the bale with a few samples taken at the lint flue. 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 three 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 all meters. This analysis was used to detect suspect data and based on this analysis two 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 of these corrections was compared to the oven mc for each bale resulting in four sets of residuals. The root mean square of each of these residual sets (rmsr) was calculated using the appropriate degrees of freedom to calculate a rmsr for each meter with each correction: none, offset, slope, offset and slope.

Results and Discussion

There were 1009 bales with bale mc data and data for 59 samples taken from the lint flue obtained by the oven method, which is the standard method of determining cotton moisture content. The mean value for the Uster mc in the flue minus the oven mc from a sample taken in the flue from the same bale was -0.20, so the Uster mc data was shown to be relatively accurate. The data from the flue mc compared with the bale mc data showed that some of the time the bales did not have a higher mc than the lint in the flue, and indeed part of the time the ginner was asked to eliminate moisture restoration. When the mc was greater in the bale than in the flue the average gain was 1.1 percentage points, with data for 699 bales. Ninety percent of the bales experienced a moisture content gain of between 0.1 and 2.0 percentage points. A quarter of the bales showed a gain of over 1.4 percentage points from the lint flue to the bale showing that for many of the bales measurable amounts of moisture were added. The mean mc in the lint flue was measured to be 4.1, or 4.3 correcting for the offset. The range of the lint mc in the flue was from 4.1 to 5.4, including the offset correction, which is lower than recommended

Because it was relatively labor intensive to insert the Delmhorst probe 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. A small thermocouple mounted in a needle (Model N, Electronic Development Labs, Danville, VA) was inserted into the hole created with the Delmhorst probe for measurement of the bale temperature.

After the data set was reduced for data missing from any of the three meters being tested there was complete data for 731 bales. The bale probe mc measurement was corrected for the bale temperature, the mean bale temperature was 113°F, the mean uncorrected probe mc was 7.1% and the mean corrected probe mc was 4.9%.

All oven mc were calculated wet basis. The average bale mc measured by the oven method was 4.9% and 90% of the oven mc values were between 4.1% and 6.0%. This cotton was relatively dry, but was not beyond the range often observed in commercial gins. Any meter calibration, such as was conducted as part of this study, is only valid for the range of reference measurements. So this study applies to cotton bales in the range 4.1% to 6.0%. During one of the visits to the gin the gin manager increased the moisture restoration until the bale would not come out of the bale press, but the mc was still well below 7.5%. Meters often operate satisfactorily beyond the range for which they are calibrated, but there is no evidence in this study regarding the important question of how these meters operate around the crucial 7.5% mc because no cotton was encountered during the study in that range.

Each of the meter readings was compared to the oven mc for the same bale and rmsr 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 without any correction was the data from the Delmhorst probe, corrected for measured bale temperature as documented in the Delmhorst instructions.

Table 1. Root means square residuals of uncorrected and readings with simple corrections.

	Sam Jackson Tex-Max	Delmhorst probe, corrected for temperature	Uster Intelligin (lint in the flue)
Uncorrected	1.8	0.64	1.2
Offset only	0.40	0.62	0.57
Slope only	0.39	0.64	0.57
Offset and slope	0.39	0.40	0.57

After the single offset correction for each meter the Tex-Max proved to be the most accurate meter. 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. After correction for offset and slope the Delmhorst probe was improved and was as accurate as the Tex-Max after offset correction.

Figure 1 is a plot of the Delmhorst hand held 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 much greater than desired. Based on the pattern seen in this figure correction with offset and slope would improve the prediction, as shown statistically. However the scatter would still be problematic.

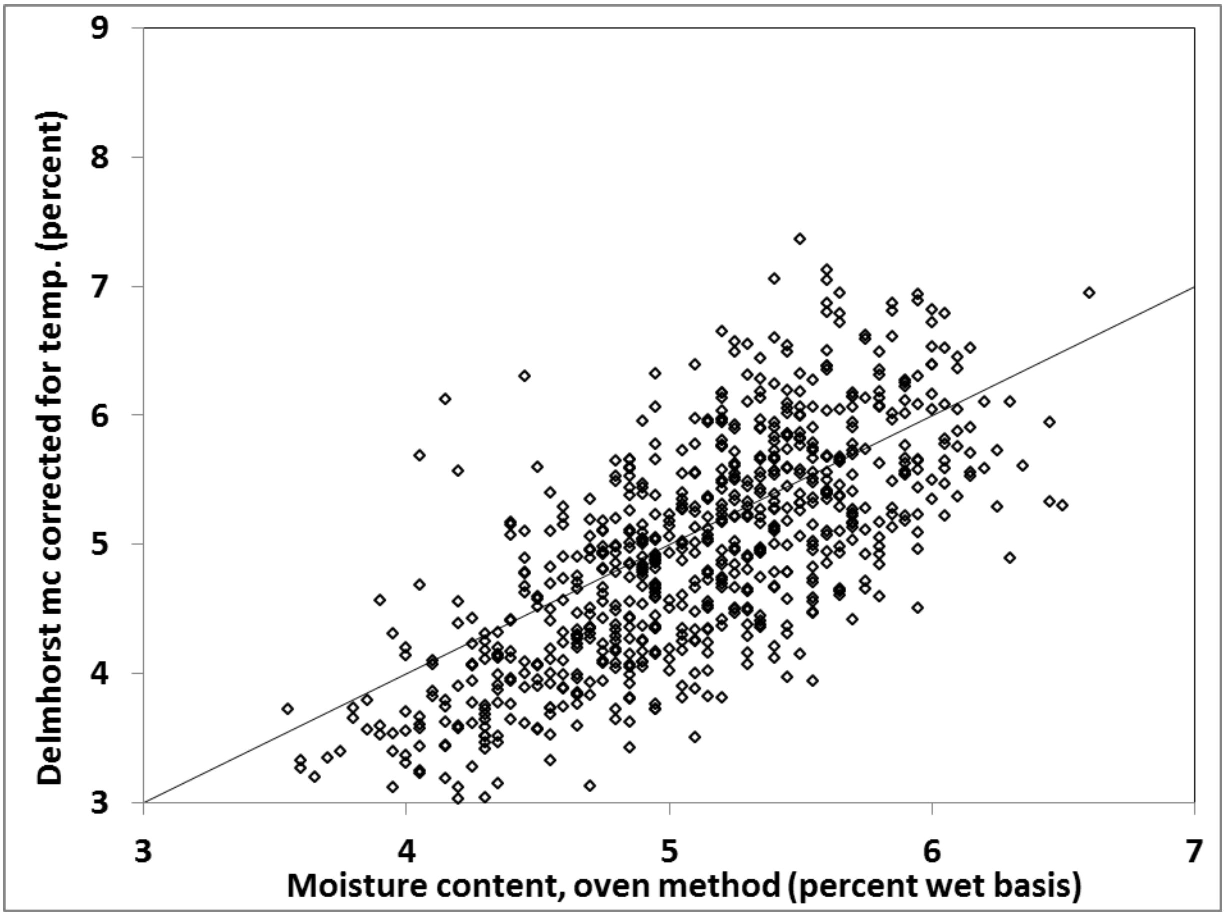

Figure 1. Delmhorst probe measurements, corrected for bale temperature, before offset and slope correction with a line showing a perfect fit.

Figure 2 is a plot of the Samuel Jackson, Inc Tex-Max readings uncorrected and corrected with an offset compared to the oven mc data for the same bales. The uncorrected data was 1.77% higher than the corrected data. This was the best fit of the three meters after correction.

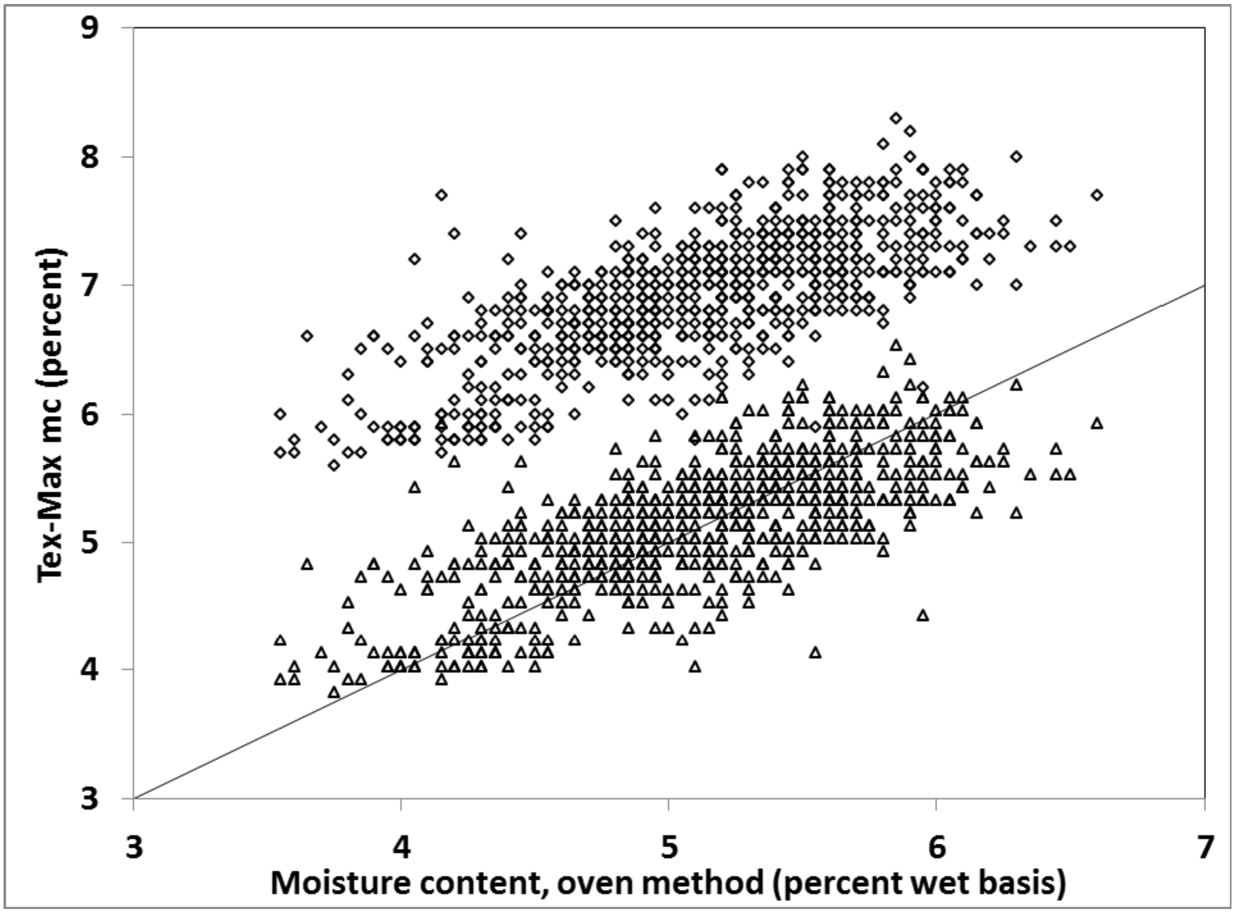

Figure 2. Samuel Jackson, Inc. Tex-Max readings, uncorrected, diamonds, and corrected for offset, triangles, with a line showing perfect fit.

There were three reasons for including the Uster Intelligin meter in the study. First, in the previous year's study the Uster meter was the most accurate of the meters studied with no correction, but only low levels of moisture restoration took place so the mc in the lint flue was nearly the same as the mc in the bale. At this gin where more moisture was added after the lint flue the meter was not the most accurate.

Second, the Tex-Max meter has been observed to have a considerable offset and the Uster meter has proven to be reliable and accurate. Perhaps the Uster meter could be used to calibrate the offset in the Tex-Max when no moisture is being added after the lint flue and atmospheric conditions were suitable. This idea was tried and based on the measurement of 7 bales the offset was observed to be -2.0. This offset would have significantly improved the accuracy of the Tex-Max readings but would have been slightly too large for the whole data set. Perhaps more observations over several time periods would have yielded a better estimate of the offset, but the concept seems sound and the offset obtained was acceptable. When all 731 bales were used to calculate the Tex-Max correction based on the Delmhorst readings, corrected for temperature, the offset was -1.9 percentage points. The variation of readings with the Delmhorst was much greater than with the Uster meter, so a large number of readings would be required to get a good estimate of the offset.

Third, it was thought that if an accurate reading of the lint mc was made before moisture restoration and an additional reading made after the moisture restoration the two readings could be combined for a more accurate bale mc prediction. For the Tex-Max corrected for slope and intercept the root mean square residual was 0.39. When the Uster reading of the lint mc in the flue was added the root mean square residual was 0.39, showing that using the mc of the lint before moisture restoration in the model did not improve the Tex-Max measurement (P=0.8). Adding the mc measurement with the Delmhorst probe, after temperature correction, also did not improve the Tex-Max measurement. When the temperature readings taken as part of the Delmhorst probe measurement were added it contributed significantly ($P<0.0001$) and the root mean square residual was reduced to 0.35, indicating an improved prediction of bale mc. Figure 3 shows that the Tex-Max readings corrected for slope, intercept, and bale temperature were closer to the line showing a perfect prediction, verifying that the prediction was improved when the bale temperature was included. The Tex-Max is believed to measure bale mc by the absorption of microwave energy and the dielectric properties of water are known to be temperature and frequency dependent (Giacoletto, 1977). The mean temperature for the bales studied was 113°F but ten percent of the bales were at or above 129°F and ten percent at or below 99°F, so there was a measurable range of temperature at which the mc was measured.

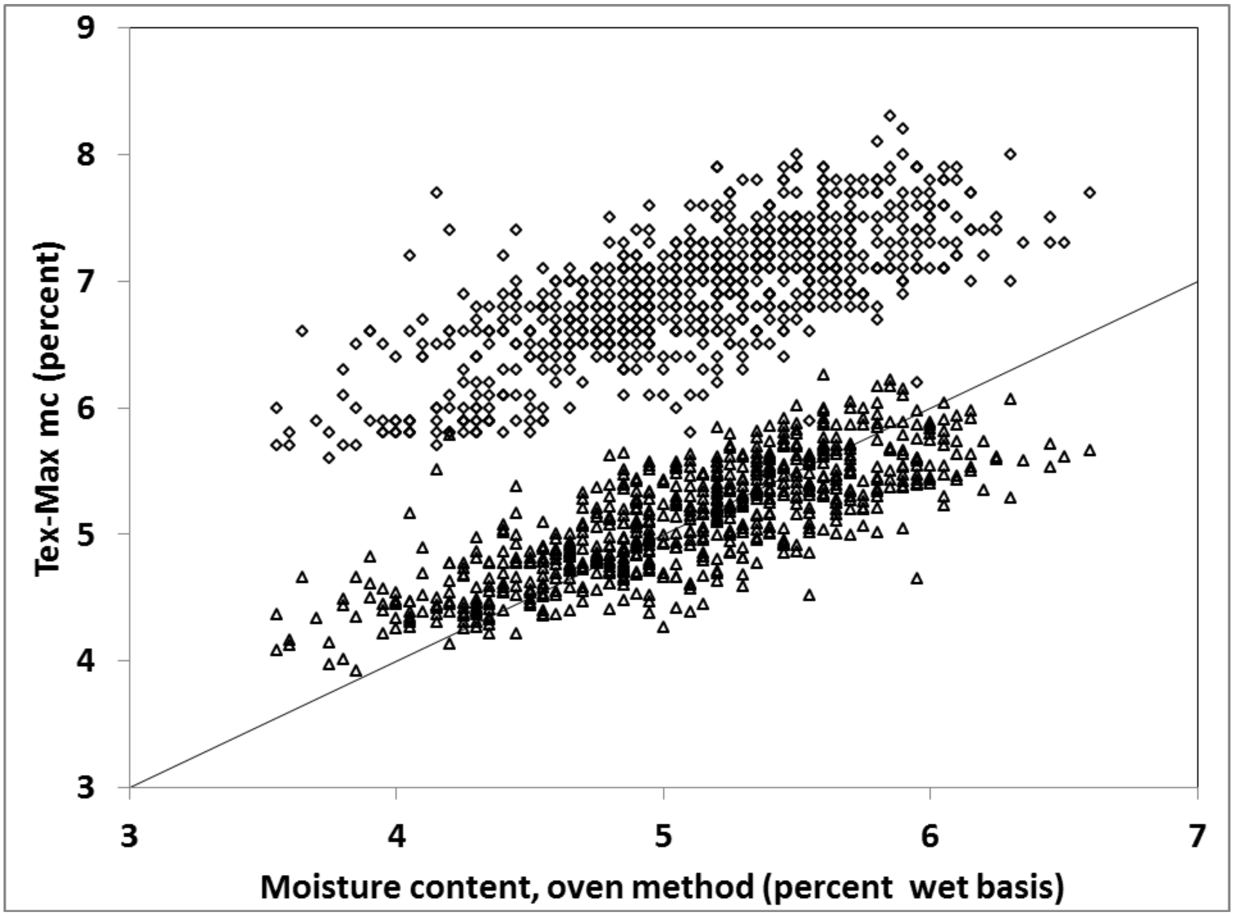

Figure 3. Samuel Jackson, Inc. Tex-Max readings, uncorrected, diamonds, and corrected for offset, slope, and temperature, triangles, with a line showing a perfect fit.

Most of the actual values of a measured value are expected to be within plus or minus two times the root mean squared residual, when the prediction fits the data well. For the Tex-Max data corrected for offset twice the root mean square residual was 0.8 so if the corrected reading were 5.0 the actual value should be between 4.2 and 5.8, see Figure 2. If the Tex-Max reading was corrected for slope, offset, and temperature and the predicted value was 5.0 the actual mc should be between 4.3 and 5.7, see Figure 3. Even though the improvement when temperature was included was statistically significant, and the plotted data shows a better distribution of the predicted mc, and temperature is relatively easy and inexpensive to measure it is questionable whether the improvement from measurement of temperature is of sufficient value to consider it commercially.

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 root mean squared residual observed during calibration below the desired maximum. In this control situation 7.5% (wet basis) is the maximum and twice the best root mean square residual would be 0.8% so the maximum reasonable set point would be 6.7%. The readings in this study were for bales, the small samples of lint within the bale would vary from the overall bale mc reading. Therefore the maximum set point should be somewhat lower than this. Because meters can drift with time and little is known about the drift of these meters the root mean square residual of 0.4 would not be applicable on a larger scale and at other gins. A prudent gin manager should choose a set point lower than 6.7% to allow for these additional issues. If the Delmhorst probe were used without correction a maximum set point might be 6.0%. 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 then compare the meters with the oven mc data. Several visits were made to a commercial gin and three commercial meters which were studied resulting in complete data for 731 bales. The gin 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 was limited with 90% of the oven mc data in the range 4.1% to 6.0% wet basis and 90% of the bales had a mc gain of from 0.1 to 2.0 percentage points. The goal of obtaining data with bale moisture content around or slightly above 7.5% was not achieved. With the uncorrected meters the Delmhorst probe, corrected for bale temperature as described in the manual, was the most accurate. After appropriate linear corrections the Samuel Jackson Tex-Max meter was the most accurate with an offset correction of -1.8. The Delmhorst probe data corrected for the temperature of the cotton and an additional offset and slope correction was equally as accurate as the Tex-Max. The Tex-Max data were not improved by including the Uster measurement of lint mc in the lint flue, but the Uster meter appears helpful in determining the Tex-Max offset. The bale temperature measured as part of the Delmhorst probe measurement further improved the bale mc prediction by the Tex-Max, although the improvement was slight and a simple offset is the most practical correction available.

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