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Corn Moisture Measurement Accuracy

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Disciplines
Agriculture | Bioresource and Agricultural Engineering

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Corn Moisture Measurement Accuracy

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ABSTRACT

THE four electronic moisture meters most commonly used by Iowa grain dealers were compared with the official United States Department of Agriculture (USDA) air-oven method on 881 samples of corn from the 1979 and 1980 harvests. Samples ranged in moisture from 11% to 38%, wet basis. With the manufacturer-developed calibrations used in 1979, all four brands gave biased readings with respect to the air-oven method. Calibration bias errors differed among brands and ranged from approximately 1.5% to -3.5% moisture content. A recalibration between the 1979 and 1980 harvests reduced both this bias and the discrepancy among meter brands. Random errors originated from three sources: the electrical properties of different samples (contributing about 85% of the total random error), the repeatability of a meter test on a specific sample (contributing about 10%), and the repeatability of the oven method on a specific sample (contributing about 5%). The coefficient of variation of a meter test with respect to the oven varied with moisture content and increased from a minimum of 2.5% to 15.5% moisture content to a maximum of 4.5% at both 11% and 38% moisture corn.

INTRODUCTION

Accurate measurement of moisture content is important to the corn trade for two reasons.

1. All grains are traded by weight; as moisture content increases, nutritional content, per unit of weight, decreases.

2. Allowable storage time is reduced by an increase in moisture content (Saul, 1967). The base moisture content for most corn trading is 15.5%. Corn at a higher moisture content is discounted about 2.5% of value per percentage point of moisture over 15.5%, including both weight shrink and drying expenses. Discount formulas vary from elevator to elevator, but at a price of $3.00 per bushel, the discount for 1 percentage point of excess moisture is approximately 7.5 cents per bushel.

Moisture content can be measured in the laboratory by a water extraction method such as oven heating, solvent distillation, or chemical removal. The United States Department of Agriculture adopted an air-oven method as the standard for corn moisture measurements (USDA, 1976). In the USDA method, whole-corn samples are heated for 72 h at 103°C. Other countries, and some professional societies within this country, recognize other reference standards in addition to the USDA method (Hunt and Pixton 1974). All laboratory methods do not agree with one another. Paynter and Hurburgh (1983) found that laboratory methods can differ by as much as 2-3 percentage points on the same sample. For trading purposes, however, a uniform basis must be established.

For trading, moisture is measured by an electronic meter calibrated to the reference standard. These meters respond to the electrical capacitance of a sample. The capacitance of the grain is compared with the capacitance of air, thus determining the dielectric constant of the grain (Nelson, 1978). In a meter test cell, samples of known weight are exposed to a high frequency voltage (1 to 20 mhz). Impedance of the capacitor containing the corn between its plates is translated into percentage moisture by either manual look-up charts, direct-reading potentiometers, or a microprocessor. The general relationship between capacitance and moisture content is consistent, but variations do exist among individual samples of the same oven moisture content (Nelson 1981).

The direct economic link between moisture content and market value causes both grain producers and grain buyers to want the best possible meter calibrations. Hurburgh et al. (1979) found evidence that the electronic meters used in Iowa were not accurately calibrated to the official oven method. More data were needed, however, to identify the specific calibration corrections needed. In cooperation with the Iowa Department of Agriculture research was undertaken to obtain this data.

OBJECTIVES

Research during the 1979 and 1980 corn harvest seasons addressed two objectives:

1. Collection of data to provide a reliable basis for updating moisture meter calibrations; and

2. Identification of the source(s) and magnitude(s) of random error in corn moisture measurements.

To accomplish these objectives, 312 samples from 29 origins were tested in 1979. In 1980, 569 samples from 11 origins were tested. The 1980 test data were corroborated by a University of Illinois study involving 357 samples (Paulsen et al., 1983).
TABLE 1. MOISTURE METERS AND THEIR CORN CALIBRATIONS

<table>
<thead>
<tr>
<th>Meter model</th>
<th>Percent of meters at country elevators</th>
<th>Year</th>
<th>Method</th>
<th>Applicable moisture range, %</th>
<th>Sample size, g</th>
<th>Calibration</th>
<th>Temperature (T) correction, added to moisture</th>
<th>Test weight (TW) correction, different from 56 lb/bu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Iowa*</td>
<td>Illinois†</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Steinitite</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>SS250</td>
<td>17</td>
<td>14</td>
<td>1979</td>
<td>#1 module 10.0-35.0</td>
<td>250</td>
<td>Automatic</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td></td>
<td>#4 module 10.0-25.0</td>
<td>250</td>
<td>Automatic</td>
<td>10.0-25.0</td>
<td>-0.05</td>
<td>0.10</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>hi MC chart 25.1-35.0</td>
<td>250</td>
<td>Automatic</td>
<td>25.1-35.0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Other 6</td>
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<td>Burrows</td>
<td></td>
<td></td>
<td>1979</td>
<td>Slope = 98.0, Intercept = 97.0</td>
<td>5.0-35.0</td>
<td>Automatic</td>
<td>None</td>
<td>None</td>
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<tr>
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<td>1980</td>
<td></td>
<td></td>
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<td>5.0-35.0</td>
<td>Automatic</td>
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<td>None</td>
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<tr>
<td>Motomco</td>
<td></td>
<td></td>
<td>1979</td>
<td>Chart C-1-C, 4.10-21.09</td>
<td>250</td>
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<td>None</td>
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<tr>
<td></td>
<td>1980</td>
<td></td>
<td></td>
<td>Chart C-2-D, 21.09-29.70</td>
<td>250</td>
<td>Automatic</td>
<td>None</td>
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<tr>
<td>Dickey</td>
<td></td>
<td></td>
<td>1979</td>
<td>Chart C-3-B, 29.24-49.24</td>
<td>150</td>
<td>Automatic</td>
<td>None</td>
<td>None</td>
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<tr>
<td>john GACII</td>
<td></td>
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<td>K1-K9 values (6/77)</td>
<td>-</td>
<td>Automatic</td>
<td>None</td>
<td>None</td>
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<td>K1-K9 values (7/80)</td>
<td>-</td>
<td>Automatic</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

*MIn 1980
†In 1981; after Paulsen et al. (1983)
‡Calibrations done by Federal Grain Inspection Service

MATERIALS AND METHODS

Equipment
The moisture meters were chosen based on Iowa Department of Agriculture data to be representative of the brands used at Iowa grain elevators. Meters from other manufacturers were included. Table 1 summarizes their pertinent characteristics and calibrations. Two meters of each model were donated by the respective manufacturers with the stipulation that the donated meters were randomly chosen from the inventory of new meters. The Iowa Department of Agriculture verified that our meters were in agreement to ±0.5 percentage points with meters of the respective models at the Department of Agriculture laboratory. In 1979, two other models of Steinitite meters, Automatic and RCT, were included. The similarity in performance among Steinitite models made it unnecessary to include Automatic and RCT in the 1980 tests. Only the data from Steinitite's current production model, SS-250, is presented.

The air-oven method recognized by the USDA (1976) and as endorsed by the American Society of Agricultural Engineers (ASAE, 1983) was the reference standard. In this method, 15-g samples (100 g if moisture content is greater than 25%) of whole corn were dried for 72 h at 103°C. Three replicate oven tests were made for every determination. We made two modifications to the official procedure.

1. Samples were weighed immediately upon removal from the oven, rather than after cooling in a desiccator. Taraba (1979) showed that error is not introduced by immediate weighing of hot objects. A desiccator would not have been practical for the 20,000 oven determinations involved in this project.

2. In samples over 25% moisture, 15-g subsamples were used. Sitzmann (1980) found no significant difference between oven moisture contents of 15-g and 100-g subsamples from the same high-moisture corn lot. Triplicate 100-g subsamples would have occupied an unacceptably large amount of oven shelf space and would have required more corn than was available from each sample.

Weighings for oven determinations were made to the nearest 0.001 g on a Mettler PN323 top-loading balance. Weighings for meter tests, test weight determinations, and foreign-material separations were made to the nearest 0.1 g on an NCI G2000 digital balance.

Test weight and broken-corn and foreign-material (BCFM) analyses were conducted according to USDA methods (USDA, 1976). BCFM is defined as all particles passing through a 4.8-mm (12/64-in.) screen plus any non grain material remaining atop the screen. Before moisture determinations were made, particles larger than 4.8 mm but smaller than 6.4 mm (16/64 in.) also were removed. These were large pieces of corn kernels and are referred to as large brokens (LBK).

Other grain quality tests (fast green dye and Stein breakage test) were performed in 1980. The only grain quality test directly involved with the moisture study was test weight because the Steinitite SS250 meter requires a test weight correction to its indicated moisture value.

The moisture meters used calibrations approved for use in Iowa at the time of the study. In 1979, these were the manufacturers' original calibrations. The 1980 data were obtained from new calibrations authorized in July 1980 by the Iowa and Illinois departments of agriculture. The 1980 calibrations were based on the 1979 data from this project.
Collection and testing of samples

Corn samples were obtained from several origins as shown in Table 2. Samples (3000 g each) were combine-shelled and were collected either at the combine or at country elevators where grain was being delivered for sale.

After collection, samples were taken to the laboratory, refrigerated at 2°C then warmed to room temperature in their polyethylene bags before testing. The laboratory procedure was:

1. Test weight, in pounds per bushel, was determined.
2. BCFM and LBK percentages were determined. Screenings were discarded.
3. Samples were divided into 0.946-L (1-qt) portions stored in glass canning jars. For convenience, this division was done by hand, not by a sample divider, because meter and oven moisture contents were compared within a portion, not across portions. If it was not possible to test portions immediately, they were returned to the refrigerator. Six portions were made in 1980 to serve 8 m. Any excess corn was discarded.
4. Each portion was tested three times in each of two meters. Three oven subsamples were removed from each portion. This procedure minimized the effect of sampling and moisture-loss errors on the comparison of a meter and the oven. The portions were arbitrarily numbered; the same two meters, in alternate order between samples, were used on a specific portion number.

A crucial element of the laboratory procedure was that, for every two meter tests (6 drops), there was an oven test. A preliminary study showed that more than six drops with a portion would cause a detectable loss in moisture (from drying in the room air).

Data analysis

The data for each year included oven moisture content, meter moisture content oven and meter variances, test weight, and other quality characteristics for each sample. Oven variance and meter variance measured the variation among replicate tests on the same portion. These variances were calculated by the statistical formula for variance (Steel and Torrie, 1960).

Calibration bias was quantified by least-squares regression of meter error (meter minus oven) against oven moisture content for each meter and year. An assumption of least-squares regression is that variance from the regression line is constant over the range of the data (Steel and Torrie, 1960). Nelson (1978) demonstrated that this assumption was not valid for electronic moisture meters. Plots of our meter-minus-oven values against oven moisture content also showed more random variation as oven moisture content increased. Although a violation of the constant-variance assumption will not affect coefficients estimated by least-squares regression, it will invalidate the single-value variance estimate normally used to describe the randomness of dependent variables.

Because variance was clearly a function of moisture content, samples were classified into increments of 2 percentage points of oven moisture, beginning at 8%. In each increment, the average bias (meter-minus-oven) was calculated; along with the average oven variance among replications, $V_{o}$, average meter variance among replications, $V_{m}$; and the variance of meter error with respect to the oven, $V_{mo}$. The two within-method variances, $V_{o}$ and $V_{m}$, contributed to the overall variance, $V_{mo}$, in any increment. The relationship among $V_{mo}$, $V_{m}$, and $V_{o}$ is:

$$V_{mo} = V_{ss} \cdot \frac{n_{d}}{n_{o}} + V_{o} \quad \cdots \quad \cdots \quad \cdots \quad [1]$$

where:

- $V_{ss}$ = sample-to-sample component of variance
- $n_{d}$ = number of meter drops per portion
- $n_{o}$ = number of oven replicates per portion

Equation 1 states that the total variance, $V_{mo}$, in a category is the sum of components due to sample properties, $V_{ss}$, meter precision, $V_{m}$, and oven precision, $V_{o}$. Equation [1] does not depend on any assumptions as to the distribution of errors across all samples, only that $V_{mo}$, $V_{ss}$, $V_{o}$, and $V_{m}$ are nearly constant over each classifying increment.

There were eight estimates of each variance component in every category (4 meters times 2 years). With the data from all meter models and both years pooled, the four variance components were regressed against oven moisture content. The regression equation for $V_{mo}$, established the total variance at a given moisture content; therefore, the percentages of variance contributed by $V_{ss}$, $V_{m}$, and $V_{o}$, could be determined. Finally, the data from this research were compared with the data obtained by Paulsen et al. (1983).

RESULTS AND DISCUSSION

Average characteristics of the samples are presented in Table 3. Variances were converted to the more conceptually useful descriptor standard deviation. While oven variance did not change with moisture content, meter variance did.

Calibration bias of meters

Regressions of meter error (meter moisture, $M_{m}$, minus oven moisture, $M_{o}$) against oven moisture are shown by year in Figs. 1 and 2. The obvious difference in performance between 1979 and 1980 was the result of the recalibration in July 1980. The regression equations and corresponding $R^2$-values are contained in Table 4. Variances are not given for the regression equations because a single-value variance would not represent the changes in variability over moisture content.

These were two important benefits from the 1980 recalibration (a) The discrepancy among brands was substantially reduced, and (b) calibration bias was less...
TABLE 3. AVERAGE QUALITY CHARACTERISTICS OF THE SAMPLES

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven moisture content, M&lt;sub&gt;0&lt;/sub&gt; percent</td>
<td>20.23</td>
<td>17.95</td>
<td>37.46</td>
<td>31.65</td>
<td>9.27</td>
<td>11.37</td>
</tr>
<tr>
<td>Standard deviation among oven replicates, V&lt;sub&gt;0&lt;/sub&gt;, percentage points</td>
<td>0.207</td>
<td>0.148</td>
<td>2.640</td>
<td>1.570</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Standard deviation among meter replicates, V&lt;sub&gt;m&lt;/sub&gt;, percentage points</td>
<td>0.191</td>
<td>0.173</td>
<td>4.420</td>
<td>1.922</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Test weight, kg/m&lt;sup&gt;3&lt;/sup&gt; (lb/bu)</td>
<td>709.0</td>
<td>728.4</td>
<td>756.8</td>
<td>809.4</td>
<td>628.1</td>
<td>606.2</td>
</tr>
<tr>
<td>Broken corn-foreign material, percent</td>
<td>1.2</td>
<td>0.8</td>
<td>7.7</td>
<td>6.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Large broken kernels, percent†</td>
<td>-</td>
<td>3.1</td>
<td>-</td>
<td>5.3</td>
<td>-</td>
<td>0.0</td>
</tr>
</tbody>
</table>

*Only one replication per sample in 1979.
†Not measured in 1979.

responsible for differences between meters and the oven, as evidenced by the reduced R<sup>2</sup>-statistics. Regression coefficients for all meters and both years were significant above the 95% confidence level.

Meter performance in 1980 at moistures above 22% was not acceptable to the departments of agriculture in Iowa and Illinois. Consequently a second recalibration was adopted by Iowa and Illinois on September 1, 1981 (Hill et al., 1981). The Federal Grain Inspection Service of USDA participated in data gathering for the second recalibration and adopted the second-generation Iowa-Illinois calibrations for official inspections covered by the United States Grades and Standards Act. The 1981 calibrations were based on the ISU 1980 data and data from the companion study at the University of Illinois. Table 5 compares the Iowa State University 1980 results, by increments of 2% moisture, with those from the Illinois study as reported in Paulsen et al. (1983).

Since Paulsen et al. (1983) also tested three oven replicates and three meter drops per sample, our data could be compared statistically with theirs. Of the 33 data comparisons in Table 5, only 14 were significantly different (P<0.05). Of those 14, Iowa State University had lower values than the University of Illinois in eight cases and higher values in six cases. Below 24% moisture, only one comparison differed by more than the 0.5 percentage points used as the legal tolerance in both Iowa and Illinois. The seemingly large discrepancy in average error for the Motomco meter can be explained by the erratic performance in the upper two increments. Without the 28-30 and 30-32 increments, the average errors for Motomco are ~0.04 percent points and ~0.27 percentage points for Iowa State and Illinois, respectively.

Random Variability

The variability in the comparison of meters with the oven increased both with an increase and a decrease in moisture from the optimum 15-20%. After the samples were divided into increments of 2% oven moisture,
regression of variance components against oven moisture content yielded two equations:

$$V_{mo} = 0.006588(M_o)^2 - 0.2329(M_o) + 2.2085$$

............................[2]

$$V_m = 0.006766(M_o)^2 - 0.0211(M_o) + 0.182$$

............................[3]

and one constant

$$V_o = 0.0296$$

Application of equation [1] produced an equation for the sample-to-sample component of variance, $V_{ss}$:

$$V_{ss} = 0.006362(M_o)^2 - 0.2259(M_o) + 2.2085$$

............................[4]

Overall variance equation [2] is specific to three replicates per sample. Therefore a general equation for $V_{mo}$ would be:

$$V_{mo} = (0.006362M_o^2 - 0.2259M_o + 2.2805)$$

$$+ (0.0006766M_o^2 - 0.0211M_o + 0.182)n_d^{-1}$$

$$+ 0.0296n_o^{-1}$$

The minima in quadratic equations [2], [3] and [4] occurred between 15% and 20% moisture. Standard deviations of the variance components, the square roots of variances, are plotted on Fig. 3. Lines of constant coefficient of variation, CV, (ratio of standard deviation to mean), also are shown. For the analysis in Fig. 3, a typical elevator procedure of one meter test per sample was assumed, rather than the laboratory method of three tests per sample.

Variability estimates from Nelson (1978) are shown on Fig. 3, as are those from Paulsen et al. (1983). There is good agreement as to the magnitude of random error in corn moisture testing. Paulsen et al. (1983) did not fit an equation to the variance, reasoning that chart changes and possible weaknesses in manufacturers calibration techniques may be creating legitimate variability in the variance, variability which should not be masked by a smooth curve. This reasoning does not recognize that the 1980 calibrations were based on the 1979 Iowa State University, 1980 data only.
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85-90% of all random errors. Clearly a better variance (100%), the shares contributed by $V_m$ and $m$ within that increment. Therefore, an equation modelling oven moisture content.

Fig. 3—Standard deviations of variance components as a function of oven moisture content.

University data; data obtained not at discreet points but, instead, across the full range of moisture content. Not all meters have chart changes or correction factors; meters with continuous single calibrations had as much variation in variance as those with multiple calibrations. Variation in sample-to-sample electrical properties is the best explanation. The estimate of variance within a moisture increment depends on the makeup of samples within that increment. Therefore, an equation modelling the variance of moisture meters is appropriate.

With the meter-to-oven variance used as a total variance (100%), the shares contributed by $V_m$, $V_m$, and $V_o$ were determined, again assuming one meter test per sample. The bar chart of Fig. 4 presents this information. Sample-to-sample variance contributed 85-90% of all random errors. Clearly a better understanding of grain electrical properties offers the greatest opportunity to reduce random errors. More precise meters or reference methods and replicate meter or oven tests will not add appreciably to overall accuracy. Given current technology, the variance estimates from this work should be useful to manufacturers and regulatory agencies alike, as they periodically verify the accuracy of meters in trade.

CONCLUSIONS

Four moisture meter models were performance-tested against the official air oven method. The following conclusions are drawn:

1. In 1979, moisture meter corn calibrations were biased with respect to the air-oven method. Bias patterns were described by meter model-specific regression equations of meter error as a function of oven moisture content. For the meter models in most common usage at Iowa elevators, moisture meter values were generally higher than the oven at moisture contents below 30% and lower than the oven at moisture contents above 30%.

2. The 1980 recalibration reduced, but did not totally eliminate, meter bias. It did narrow the discrepancy among models to 0.5 percentage points or less at corn moisture contents between 12% and 26%.

3. All meters exhibited random variability with respect to the oven. Variability could be traced to the oven, the meter, and the sample. Oven variance was constant over moisture content. Meter variance was estimated by equation [3] and sample variance by equation [4]. Minimum overall variance occurred between 15% and 20% moisture.

4. Sample-to-sample variability, $V_s$, in electrical characteristics contributed 85 to 90% of the total variability. Therefore, studies of grain composition relative to dielectric properties offer the best potential to further improve moisture measurement accuracy.

5. Oven variability, $V_o$, among replicate determinations on the same sample contributed less than 4.0% of the total variability and was not influenced by moisture content.

6. Meter variability, $V_m$, contributed on an increasing share of variability as moisture increased, but never contributed more than 12.5% of the total.

7. The meter biases and estimates of variability were in agreement with those observed by researchers at the University of Illinois.

Fig. 4—Relative magnitude of meter-to-oven variance components.

References


properties of shelled field corn. ARS-S-184. Agricultural Research Service, U.S. Department of Agriculture, Southern Region, Box 53326, New Orleans, LA.


