United States Department of Agriculture
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Federal Grain Inspection Service

# Unified Grain Moisture Algorithm

Recipe Book

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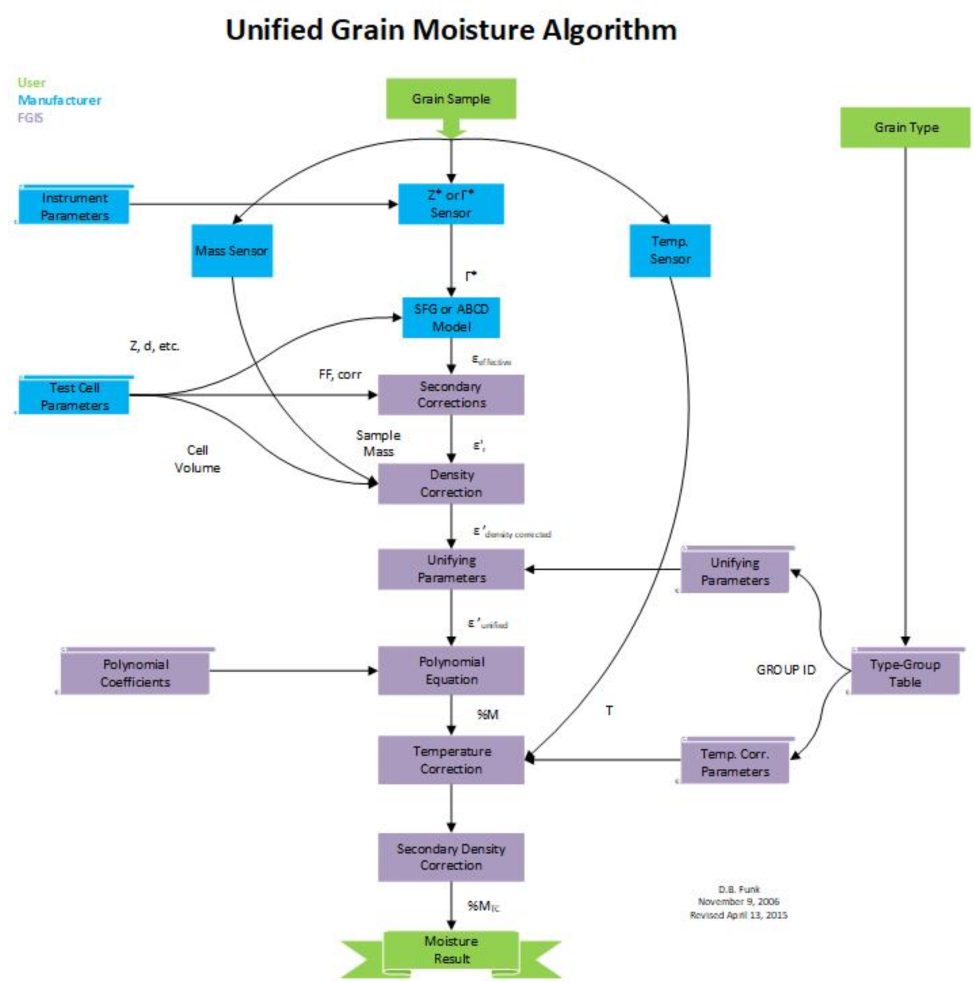
# UNIFIED GRAIN MOISTURE ALGORITHM

Recipe Book

**Contents**





## Unified Grain Moisture Algorithm

### *Introduction*

The purpose of this document is to present a concise description of FGIS's Unified Grain Moisture Algorithm (UGMA) and associated equations for use by entities who are involved in developing and seeking FGIS certification for UGMA-compatible grain moisture meters. More detailed explanations of the method (for those without considerable familiarity with the UGMA) are available as links on the Moisture Equipment page of the AMS website (www.ams.usda.gov).

### *UGMA Steps*

1. Measure the dielectric constant ($\varepsilon_{meas}$) of the grain at a defined frequency within the range of 148.5 to 150.5 MHz where the selected frequency is controlled within ± 0.05 MHz using a parallel-plate transmission line test cell of dimensions similar to those of the FGIS master cell and a loading method that provides for operator-independent measurements. This measurement requires the determination of complex impedance or complex reflection coefficient for the transmission line test cell and conversion to dielectric constant through an appropriate mathematical model for the specific test cell design. (Note: Grain-group-specific dielectric offset ($EO_s$) and dielectric slope ($ES_s$) factors may need to be applied (as $\varepsilon_{meas}' = \varepsilon_{meas} \cdot ES_s + EO_s$) to compensate for slight differences in loading methods among instrument models. The ***s*** subscripts refer to grain-group-specific parameters that may be different for different instrument models.)

2. Measure the ***Mass*** of the grain within the defined volume of the test cell (***TestCellVolume***).

3. Apply the Landau-Lifshitz, Looyenga-based density normalization to transform the measured dielectric constant to density-corrected dielectric constant ($\varepsilon_{den}$) with a common density basis ($\rho_{target}$ = 0.67405 g/ml) for all grain types.

$$\varepsilon_{den} = \left[\left(\varepsilon_{meas}^{1/3} - 1\right) \cdot \frac{\rho_{target} \cdot TestCellVolume \cdot VR_s}{Mass} + 1\right]^3 \tag{1}$$

(**Note**: Grain-group-specific volume ratio factors ($VR_s$) may need to be inserted as multipliers in the target mass calculation (target density times test cell volume) to compensate for slight differences in loading methods among instrument models.)

4. Apply grain-group-specific unifying parameters: Slope parameter ($SP_s$), Translation parameter ($TP_s$), and Offset parameter ($OP_s$) (Table 2) to the density-corrected dielectric constant as in Eq. 2.

$$\varepsilon_{adj} = (\varepsilon_{den} - OP_s) \cdot SP_s + 2.5 + \frac{TP_s}{6} \tag{2}$$

5. Calculate the initial moisture estimate (***Moisture 1***) from the adjusted dielectric constant using the 5th order polynomial calibration (Eq. 3), where ***KCC*** is the vector of polynomial coefficients.

$$\text{Moisture1} = \sum_{i=0}^{5} \left( \text{KCC}_i \cdot \varepsilon_{adj}^{i} \right) \quad (3)$$

6. Using Eq. 4, apply the translation parameter (***TP$_s$***, moisture axis shift) to get the predicted moisture (prior to temperature correction) (***Moisture2***).

$$\boldsymbol{Moisture2 = Moisture1 - TP_s} \quad (4)$$

7. Apply the temperature correction function (Eq. 5). (Notes: The temperature correction function (Eq. 7), a function of temperature and moisture, may use from one to three coefficients depending on the nature of the correction required. The form of Eq. (5), used here and below, is meant to state that the ***TempCorr*** is a function involving parameters ***Temperature*** and ***Moisture2***.)

$$\boldsymbol{Moisture3 = Moisture2 - TempCorr(Temperature, Moisture2)} \quad (5)$$

8. Apply the secondary density correction to obtain the final predicted moisture result. This correction, which was primarily intended to overcome the effect of kernel density in corn, has also proven useful for adjusting the calibration line shape by moisture range. Currently, this correction is applied to corn (density), long grain rough rice (line shape), medium grain rough rice (line shape), oats (density) and soybeans (line shape).

$$\boldsymbol{MoistureFinal = Moisture3 - SecDensCorr(Moisture3, Mass)} \quad (6)$$

*Measured Values: (Note: These are critical measured parameters for demonstrating conformance with the UGMA.)*

- ***$\varepsilon_{den}$*:** density-corrected dielectric constant at approximately 149 MHz
- Sample temperature
- Sample mass

*Unifying Parameters*

Three grain-group-dependent parameters are necessary to use the same polynomial calibration (basic calibration curve shape) for all grain groups. Unifying parameters are derived using an optimization algorithm that FGIS will provide upon request as an Excel file.

- ***OP$_s$***: Offset parameter
- ***SP$_s$***: Slope parameter
- ***TP$_s$***: Translation parameter

## *Calibration Coefficients*

The calibration is the relationship between the adjusted dielectric constant and reference moisture content (back corrected for sample temperature and secondary density correction, and adjusted by the translation parameter). ***KCC*** is the vector containing the coefficients of the fifth order polynomial calibration equation. One "dummy point" was inserted in the calibration data (Figure 1) to control the shape of the extreme high moisture end of the polynomial curve. At some point in the future, the order of the polynomial curve may be increased to 7 to allow better fit for extremely dry samples; manufacturers should allow for this possibility in their software. Currently the secondary density correction is being employed in a special way to accomplish small line shape changes on certain grains, because changing the polynomial curve would require modification of all calibrations that are based on the existing curve.

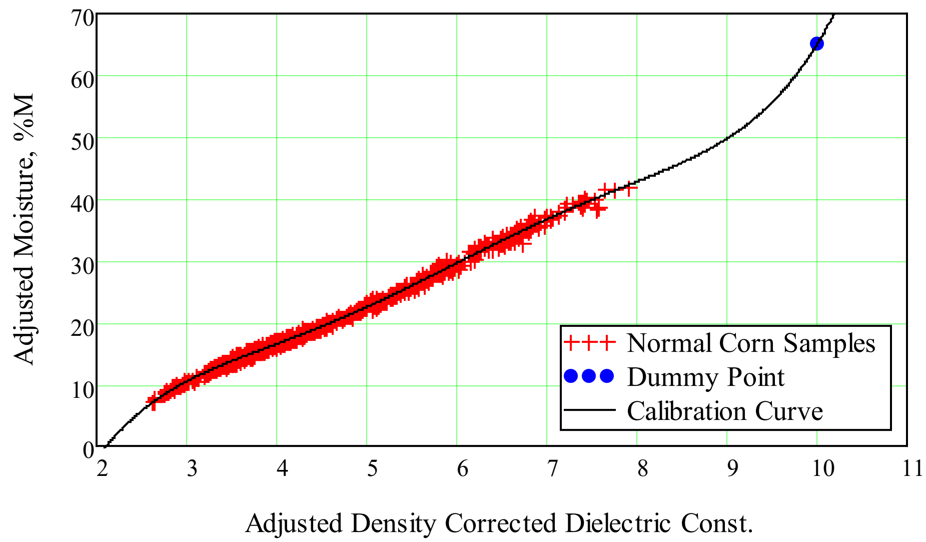



***Figure 1.*** Calibration curve

## *Temperature Correction*

Temperature correction is applied to the predicted moisture to minimize the effect of sample temperature—that is, to cause the final moisture estimate to closely match the estimate that would be given for that sample if measured at room temperature (22°C). FGIS has developed temperature corrections over a wide temperature range (from -18°C to 45°C). The UGMA exhibits a significant advantage (relative to most other moisture meters) in its ability to accurately predict moisture content for grain (at normal market moisture levels) at temperatures well below 0°C. The form of the correction can be moisture level dependent and may be linear or quadratic with temperature. Accurate temperature correction over wide temperature and moisture ranges usually requires the moisture-dependent/quadratic temperature correction, but less demanding applications may use the simpler corrections with fewer determined coefficients. (That is, the ***KCTQ*** and/or ***KTCS*** values may be zero.)

$$Moisture3 = \frac{Moisture2 - KTC_s \cdot (T - TTC) - KTCQ_s \cdot (T - TTC)^2}{1 + KTCS_s \cdot (T - TTC)} \quad (7)$$

The target temperature (***TTC***) was chosen as 22°C because that is the nominal laboratory temperature for all the calibration sample tests at FGIS. Making the target temperature equal to the nominal laboratory temperature minimizes the interaction between the temperature coefficients and the unifying parameters and polynomial calibration coefficients.

The listed temperature correction coefficient values (see Table 3) were estimated from FGIS tests done in 2007-2013 using a special insulated test cell (GP test cell) and precision impedance analyzers (HP-4291A and Agilent E4991A) and FGIS tests performed in 2013 with commercial UGMA moisture meters. FGIS conducted additional tests in 2017-2019 with commercial UGMA moisture meters.

*Secondary (Bulk) Density Correction*

The secondary (bulk) density correction is applied to the predicted moisture to reduce the error caused by extremes in corn density related to kernel density. This correction appears to be unnecessary for most grain types other than corn. The correction (Eq. 8) was developed by Zoltan Gillay in 2010 and was published at the ISEMA 2011 Conference in Kansas City in June 2011. Additional details are shown below. Note that both the ***TargetDensity*** and the ***SlopeCorrection*** values are moisture-dependent and are found by linear interpolation from the TD Table (Table 5) and SC Table (Table 6), respectively. This method may also be applied as a line shape correction to the predicted moisture to improve moisture measurement accuracy at moisture extremes for some grain types. When used for line shape correction, the parameters in the secondary density correction equation are adjusted to modify the slope of the calibration curve in selected moisture ranges—without making a secondary density correction.

Note that the value of the *Mass/TestCellVolume* term in Equation 8 is approximately 0.5 and varies only a little around this value. The values of *TargetDensity* and *SlopeCorrection* at different predicted moisture levels are specified in lookup tables (TDTable and SCTable, respectively). By setting *TargetDensity* to a number much larger than 0.5 (such as 100) and the *SlopeCorrection* value to a small number, the slope of the calibration curve can be adjusted as desired without interference from sample mass.

$$\boldsymbol{SecDensCorr(Moisture3, Mass) = \left(\frac{Mass}{TestCellVolume} - TargetDensity\right) \cdot SlopeCorrection} \tag{8}$$

Where:

$$\boldsymbol{TargetDensity = LinearInterpolation(TDTable, Moisture3)} \tag{9}$$

$$\boldsymbol{SlopeCorrection = LinearInterpolation(SCTable, Moisture3)} \tag{10}$$

## *Parameters, Coefficients, and Grain Groups*

The parameters may be refined annually as FGIS conducts tests on additional samples.

The full numeric resolution shown in the tables is necessary to agree with FGIS results within 0.01% M.

The first eleven grain groups (soybeans, sorghum, sunflower, corn, oats, hard wheat, soft wheat, durum, barley, long grain rough rice, and medium grain rough rice) are the "major" grains and are evaluated annually. The other grain groups are revised as more samples of "minor" grain types are tested.

***Table 1**.* Grain types within grain groups

| Major Groups | Grain Type Names |
|---|---|
| 1. **Soybeans** | Soybeans |
| 2. **Sorghum** | Sorghum |
| 3. **Sunflower** | Sunflower Seed, Oil-type |
| | Sunflower Seed, Confectionary (minor grain) |
| 4. **Corn** | Corn |
| 5. **Oats** | Oats |
| 6. **Hard Wheat** | Wheat, Hard White |
| | Wheat, Hard Red Winter |
| | Wheat, Hard Red Spring |
| 7. **Soft Wheat** | Wheat, Soft Red Winter |
| | Wheat, Soft White |
| 8. **Durum** | Durum |
| | Khorasan (minor grain) |
| 9. **Barley** | Barley, Six-Rowed |
| | Barley, Two-Rowed |
| | Hulless Barley (minor grain) |
| 10. **Rice, Long Rough** | Rice, Long Grain Rough |
| 11. **Rice, Medium Rough** | Rice, Medium Grain Rough |
| **Minor Groups** | |
| 12. **Rice, Short Rough** | Rice, Short Grain Rough |
| 13. **Rice, Long & Medium Milled** | Rice, Long Grain Milled |
| | Rice, Medium Grain Milled |
| 14. **Rice, Brown** | Rice, Long Grain Brown |
| | Rice, Medium Grain Brown |
| | Rice, Short Grain Brown |

*Table 1.* Continued

| Minor Groups | Grain Type Names |
|---|---|
| 15. **Rice, Short Milled** | Rice, Short Grain Milled |
| | Rice, Second Head Milled |
| | Rice, Screenings Milled |
| | Rice, Brewers Milled |
| 16. **Rice, Parboiled** | Rice, Long Grain Brown Parboiled |
| | Rice, Second Head Milled Parboiled |
| | Rice, Long Grain Milled Parboiled |
| | Rice, Medium Grain Milled Parboiled |
| | Rice, Brewers Milled Parboiled |
| 17. **Beans 1** | Beans, Blackeye |
| | Beans, Pinto |
| | Beans, Cranberry |
| | Beans, Pink |
| | Peas, Split |
| 18. **Beans 2** | Beans, Baby Lima |
| | Beans, Garbanzo (Chickpeas) |
| | Beans, Small Red |
| | Beans, Yelloweye |
| 19. **Beans 3** | Beans, Black |
| | Beans, Great Northern |
| | Beans, Large Lima |
| 20. **Beans 4** | Beans, Small White |
| | Beans, Pea |
| 21. **Beans 5** | Beans, Kidney |
| | Lentils |
| 22. **Peas** | Peas, Mottled |
| | Peas, Smooth Dry |
| | Peas, Wrinkled Dried |
| 23. **Safflower** | Safflower |
| 24. **Canola** | Canola |
| | Rapeseed |
| 25. **Mustard** | Mustard Seed, Yellow |
| | Mustard Seed, Brown |
| 26. **Mustard, Oriental** | Mustard Seed, Oriental |
| 27. **Triticale & Rye** | Triticale |
| | Rye |
| 28. **Flaxseed** | Flaxseed |
| 29. **Popcorn** | Popcorn |
| 30. **Buckwheat** | Buckwheat |
| | Buckwheat Groats |
| 31. **Hulless Oats** | Hulless Oats |

***Table 2**.* Unifying parameters for each grain group with target temperature *TTC* = 22°C. FGIS-approved calibrations.

| Grain Group Name | OP | SP | TP |
|---|---|---|---|
| **Soybeans*** | 2.21777 | 0.83990 | 0.25808 |
| **Sorghum*** | 2.49888 | 1.15784 | 0.52871 |
| **Sunflower*** | 2.89560 | 0.60030 | 3.31453 |
| **Corn*** | 2.58119 | 1.01116 | 0.04656 |
| **Oats*** | 2.50520 | 1.20700 | 1.71883 |
| **Wheat, Hard*** | 2.45262 | 1.17814 | 0.74465 |
| **Wheat, Soft*** | 2.4003 | 1.10205 | 0.47202 |
| **Durum*** | 2.47479 | 1.14080 | 0.97078 |
| **Barley*** | 2.40171 | 1.15489 | 0.86412 |
| **Rice, Long Rough*** | 2.56801 | 1.12434 | -1.00000 |
| **Rice, Medium Rough*** | 2.60926 | 1.20464 | -0.30137 |
| **Rice, Short Rough** | 2.53800 | 1.24900 | 0.00000 |
| **Rice, Long & Medium Milled** | 2.51059 | 1.04112 | 6.17909 |
| **Rice, Brown** | 2.61542 | 1.21730 | 2.24150 |
| **Rice, Short Milled** | 2.56639 | 1.12468 | 0.00000 |
| **Rice, Parboiled** | 2.72023 | 1.28083 | 3.53399 |
| **Beans 1** | 2.04415 | 0.82087 | -2.14253 |
| **Beans 2** | 2.14871 | 0.90055 | -1.22113 |
| **Beans 3** | 2.15008 | 0.95575 | -1.12211 |
| **Beans 4** | 2.10321 | 0.95610 | -1.20983 |
| **Beans 5** | 2.02755 | 0.77947 | -2.34291 |
| **Peas** | 2.05219 | 0.99142 | -2.30674 |
| **Safflower** | 2.79858 | 0.72184 | 2.44242 |
| **Canola** | 2.72737 | 0.88238 | 3.83532 |
| **Mustard** | 2.45021 | 0.82628 | 1.34283 |
| **Mustard, Oriental** | 1.08520 | 0.43347 | -5.76496 |
| **Triticale & Rye** | 2.29327 | 1.04512 | -1.00000 |
| **Flaxseed** | 2.49214 | 0.55567 | 0.00000 |
| **Popcorn** | 2.71612 | 1.22804 | 1.92617 |
| **Buckwheat** | 2.32026 | 1.06465 | 0.00000 |
| **Hulless Oats** | 2.47479 | 1.14080 | 0.97078 |

*Also NTEP-certified

***Table 3.*** Temperature correction factors for Eq. 7. Moisture limit is the upper limit for sample temperatures below 0°C. FGIS-approved calibrations.

| Grain Group Name | KTC | KTCS | KTCQ | Lower Temp. Limit (°C/°F) | Upper Moist. Limit (%M) |
|---|---|---|---|---|---|
| **Soybeans*** | 0.00973 | 0.00694 | -0.00022 | -18/0 | 20 |
| **Sorghum*** | 0.10770 | 0.00000 | -0.000656 | -18/0 | 16 |
| **Sunflower*** | 0.00706 | 0.00508 | -0.000624 | -18/0 | 13 |
| **Corn*** | 0.15920 | -0.00282 | -0.0007688 | -18/0 | 19 |
| **Oats*** | 0.09910 | 0.00000 | -0.000348 | -18/0 | 13 |
| **Wheat, Hard*** | 0.09590 | 0.00153 | -0.000581 | -18/0 | 19 |
| **Wheat, Soft*** | 0.09590 | 0.00153 | -0.000581 | -18/0 | 19 |
| **Durum*** | 0.09590 | 0.00153 | -0.000581 | -18/0 | 19 |
| **Barley*** | 0.12050 | -0.00060 | -0.0006995 | -18/0 | 18 |
| **Rice, Long Rough*** | 0.22020 | -0.00865 | -0.001119 | -18/0 | 18 |
| **Rice, Medium Rough*** | 0.22020 | -0.00865 | -0.001119 | -18/0 | 18 |
| **Rice, Short Rough** | 0.22020 | -0.00865 | -0.001119 | -18/0 | 18 |
| **Rice, Long & Medium Milled** | 0.06357 | 0.003096 | -0.000372 | -18/0 | 16 |
| **Rice, Brown** | 0.10380 | 0.00000 | -0.000628 | -18/0 | 16 |
| **Rice, Short Milled** | 0.10380 | 0.00000 | -0.000628 | -18/0 | 16 |
| **Rice, Parboiled** | 0.12898 | 0.00000 | -0.000366 | -18/0 | 13 |
| **Beans 1** | 0.04440 | 0.00648 | -0.000146 | -18/0 | 15 |
| **Beans 2** | 0.05876 | 0.00494 | 0.000000 | -18/0 | 15 |
| **Beans 3** | 0.04440 | 0.00648 | -0.000146 | -18/0 | 15 |
| **Beans 4** | 0.04440 | 0.00648 | -0.000146 | -18/0 | 15 |
| **Beans 5** | 0.006029 | 0.010148 | 0.000000 | -18/0 | 15 |
| **Peas** | 0.07163 | 0.003416 | -0.00045 | -18/0 | 15 |
| **Safflower** | 0.05840 | 0.00000 | -0.000240 | -18/0 | 12 |
| **Canola** | 0.026848 | 0.004508 | -0.0001893 | -18/0 | 8 |
| **Mustard** | -0.040953 | 0.015318 | 0.000000 | -18/0 | 9 |

***Table 3.*** Continued

| **Grain Group Name** | **KTC** | **KTCS** | **KTCQ** | **Lower Temp. Limit (°C/°F)** | **Upper Moist. Limit (%M)** |
|---|---|---|---|---|---|
| **Mustard, Oriental** | -0.040953 | 0.015318 | 0.000000 | -18/0 | 9 |
| **Triticale & Rye** | 0.072583 | 0.004229 | -0.000691 | -18/0 | 16 |
| **Flaxseed** | -0.01520 | 0.01090 | 0.000000 | -18/0 | 10 |
| **Popcorn** | 0.15920 | -0.00282 | -0.0007688 | -18/0 | 19 |
| **Buckwheat** | 0.109279 | 0.00000 | -0.000528 | -18/0 | 13 |
| **Hulless Oats** | 0.09590 | 0.00153 | -0.000581 | -18/0 | 19 |

* Also NTEP-certified

***Table 4****.* FGIS-approved and NTEP-certified UGMA 5$^{th}$ order polynomial coefficients with 22°C target temperature.

| **Exponent** | ***KCC*** |
|---|---|
| 0 | -112.71 |
| 1 | 111.3076 |
| 2 | -40.37566 |
| 3 | 7.403341 |
| 4 | -0.649454 |
| 5 | 0.02193348 |

***Table 5a****.* ***TDTable for Corn.*** FGIS-approved and NTEP-certified secondary density correction target density lookup table (***TDTable***) to determine the ***Target Density*** value by linear interpolation. ***Moisture3*** is the temperature-corrected predicted moisture from Eq. 7.

| ***Moisture3*** | ***Target Density*** g/ml |
|---|---|
| 0 | 0.7168 |
| 15 | 0.7168 |
| 17 | 0.7116 |
| 19 | 0.7018 |
| 27 | 0.6451 |
| 30 | 0.6297 |
| 33 | 0.6253 |
| 100 | 0.6253 |

***Table 5b. TDTable for Soybeans.*** FGIS-approved and NTEP-certified secondary line shape correction lookup table (***TDTable***) to determine the ***TargetDensity*** value by linear interpolation. ***Moisture3*** is the temperature-corrected predicted moisture from Eq. 7.

| ***Moisture3*** | ***Target Density*** g/ml |
|---|---|
| 0 | 100 |
| 5 | 100 |
| 7 | 100 |
| 10 | 100 |
| 100 | 100 |

***Table 5c. TDTable for Long Grain Rough Rice.*** FGIS-approved and NTEP-certified secondary line shape correction lookup table (***TDTable***) to determine the ***TargetDensity*** value by linear interpolation. ***Moisture3*** is the temperature-corrected predicted moisture from Eq. 7.

| ***Moisture3*** | ***Target Density*** g/ml |
|---|---|
| 0 | 100 |
| 8 | 100 |
| 15 | 0 |
| 21 | 0 |
| 30 | 100 |
| 100 | 100 |

***Table 5d. TDTable for Medium Grain Rough Rice.*** FGIS-approved and NTEP-certified secondary line shape correction lookup table (***TDTable***) to determine the ***TargetDensity*** value by linear interpolation. ***Moisture3*** is the temperature-corrected predicted moisture from Eq. 7.

| ***Moisture3*** | ***Target Density*** g/ml |
|---|---|
| 0 | 100 |
| 10 | 100 |
| 15 | 0 |
| 21 | 0 |
| 30 | 100 |
| 100 | 100 |

***Table 5e. TDTable for Oats.*** FGIS-approved and NTEP-certified secondary line shape correction lookup table (***TDTable***) to determine the ***TargetDensity*** value by linear interpolation. ***Moisture3*** is the temperature-corrected predicted moisture from Eq. 7.

| ***Moisture3*** | ***Target Density*** g/ml |
|---|---|
| 0 | 0 |
| 11 | 0.525 |
| 100 | 0.525 |

***Table 6a. SCTable for Corn.*** FGIS-approved and NTEP-certified secondary density correction ***Slope Correction*** lookup table (***SC Table***) to determine the ***Slope Correction*** value by linear interpolation. ***Moisture3*** is the temperature-corrected predicted moisture from Eq. 7.

| ***Moisture3*** | ***Slope Correction*** %M per g/ml |
|---|---|
| 0 | 10.4 |
| 13 | 10.4 |
| 33 | -17 |
| 100 | -17 |

***Table 6b. SCTable for Soybeans.*** FGIS-approved and NTEP-certified secondary line shape correction ***Slope Correction*** lookup table (***SC Table***) to determine the ***Slope Correction*** value by linear interpolation. ***Moisture3*** is the temperature-corrected predicted moisture from Eq. 7.

| ***Moisture3*** | ***Slope Correction*** %M per g/ml |
|---|---|
| 0 | -0.02 |
| 5 | -0.02 |
| 7 | -0.005 |
| 10 | 0 |
| 100 | 0 |

***Table 6c. SCTable for Long Grain Rough Rice***. FGIS-approved and NTEP-certified secondary line shape correction ***Slope Correction*** lookup table (***SC Table***) to determine the ***Slope Correction*** value by linear interpolation. ***Moisture3*** is the temperature-corrected predicted moisture from Eq. 7.

| ***Moisture3*** | ***Slope Correction*** %M per g/ml |
|---|---|
| 0 | 0.013 |
| 8 | 0.013 |
| 15 | 0 |
| 21 | 0 |
| 30 | -0.035 |
| 100 | -0.035 |

***Table 6d. SCTable for Medium Grain Rough Rice***. FGIS-approved and NTEP-certified secondary line shape correction ***Slope Correction*** lookup table (***SC Table***) to determine the ***Slope Correction*** value by linear interpolation. ***Moisture3*** is the temperature-corrected predicted moisture from Eq. 7.

| ***Moisture3*** | ***Slope Correction*** %M per g/ml |
|---|---|
| 0 | 0.01 |
| 10 | 0.01 |
| 15 | 0 |
| 20 | 0 |
| 25 | -0.016 |
| 100 | -0.098 |

***Table 6e. SCTable for Oats***. FGIS-approved and NTEP-certified secondary line shape correction ***Slope Correction*** lookup table (***SC Table***) to determine the ***Slope Correction*** value by linear interpolation. ***Moisture3*** is the temperature-corrected predicted moisture from Eq. 7.

| ***Moisture3*** | ***Slope Correction*** %M per g/ml |
|---|---|
| 0 | 0 |
| 11 | -4.471 |
| 100 | -4.471 |

## *Performance Statistics*

FGIS collects calibration performance data on an annual basis for the 15 major crops. The minor grains have calibration performance data collected for three years on a rotating basis. However, the minor grains may be requested at additional times as needed to address any market concerns. Table 7 lists the minor grain groups in order of their data collection. The calibration performance data is analyzed and reviewed every year to determine what, if any, changes are needed to maintain the alignment between the FGIS Master UGMA system to the USDA reference Air Oven moisture. FGIS posts the performance statistics for the spring/summer crops by May 1 each year and for all crops by August 1 each year on the Moisture Equipment page of the AMS website (www.ams.usda.gov). Refer to Table 8 for the list of grains for May 1 and August 1 implementation dates.

***Table 7***. Minor grain groups that FGIS requests samples for during a three-year period before moving to the next group. Three years after the start of Group Three, data collection will start over for Group One.

| Group One | Group Two | Group Three |
|---|---|---|
| Beans 1 | Beans 2 | Beans 4 |
| Beans 3 | Hulless Barley | Buckwheat |
| Beans 5 | Hulless Oats | Buckwheat Groats |
| Brown Rice | Long Milled and Parboiled Rice | Mustard Seeds |
| Canola and Rapeseed | Medium Milled and Parboiled Rice | Processed Rice |
| Flaxseed | Peas | Rye |
| Short Grain Rough Rice | Popcorn | Safflower |
| Sunflower Seed (confectionary) | | Short Grain Milled Rice |
| | | Triticale |

***Table 8***. List of the spring/summer crops with performance statistics posted by May 1 and list of fall crops with performance statistics posted by August 1 every year.

| Spring/Summer Crops | Fall Crops | |
|---|---|---|
| Barley (all subclasses) | Beans | Peas |
| Hulless Barley | Buckwheat and Buckwheat Groats | Rapeseed |
| Hulless Oats | Canola | Rice (rough, milled, and parboiled) |
| Oats | Corn and Popcorn | Rye |
| Rye | Flaxseed | Safflower |
| Triticale | Grain Sorghum | Triticale |
| Wheat (all classes) | Lentils | Soybean |
| | Mustard Seeds | Sunflower (oil and confectionary) |

## *Details of Secondary Density Correction Method*

The secondary density correction dramatically reduces the error for corn caused by unusually low (or high) density samples. Figure 2 illustrates key aspects of the correction. The plot shows all the corn samples with the several low density samples (blue diamonds) segregated from the "normal samples" (red +). A similar approach may be applied to other grains where the moisture error correlates to the density, such as with oats; it is anticipated that most grains will not need a density correction.

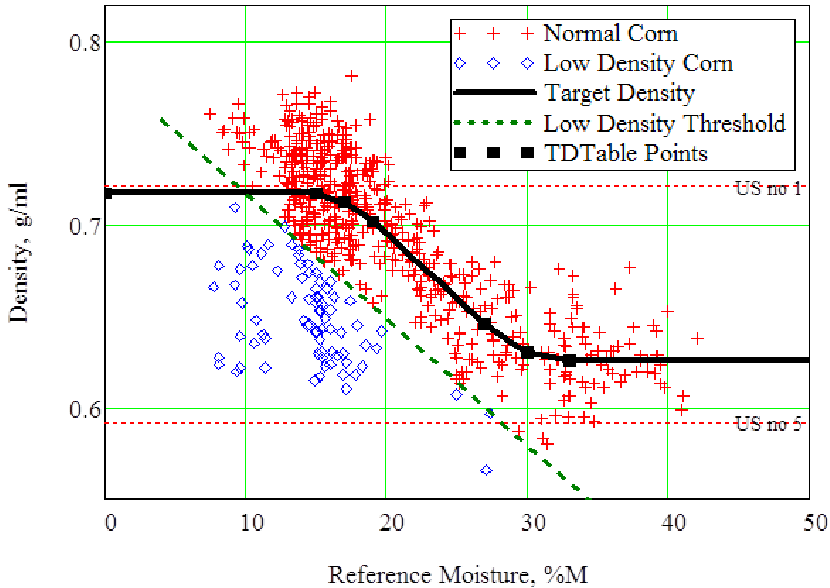



***Figure 2.*** Target density curve (***TDTable***, Table 5)

The separation or threshold function is by Eq. 11 and the dotted line in Figure 2.

$$LowDensityThreshold(\%M) = \left[\left(\frac{45-53}{30-15}\right)\cdot(\%M-15)+53\right]\cdot ConversionParameter \tag{11}$$

***ConversionParameter*** (0.01287 g/ml per lb/bu) transforms the values from lb/bu to g/ml.

Including the low density samples in the calibration caused significant errors both for the normal and low density samples. For optimizing the calibration for the normal samples, the low density samples were not included in the calibration. The samples for which the density corrections are zero lie on the solid line in Figure 2—the moisture-dependent target density (***TD***) curve. The predicted moisture error (correction to be applied) is proportional to the vertical distance between the sample density (***Mass/TestCellVolume***) and the target density (***TD***) curve. Therefore, the correction function (repeated here) is defined as:

$$SecDensCorr(Moisture3, Mass) = \left(\frac{Mass}{TestCellVolume} - TargetDensity\right)\cdot SlopeCorrection \tag{8}$$

The results of the ***SecDensCorr*** function are in units of %M. The calculated density correction is applied by subtracting it from the temperature-corrected predicted moisture as in Eq. 6. The slope correction factor ***SC*** (%M per g/ml density difference from target density at that moisture level) is moisture-dependent. See Figure 3. The slope correction ***SC*** crosses zero at about 21% moisture.

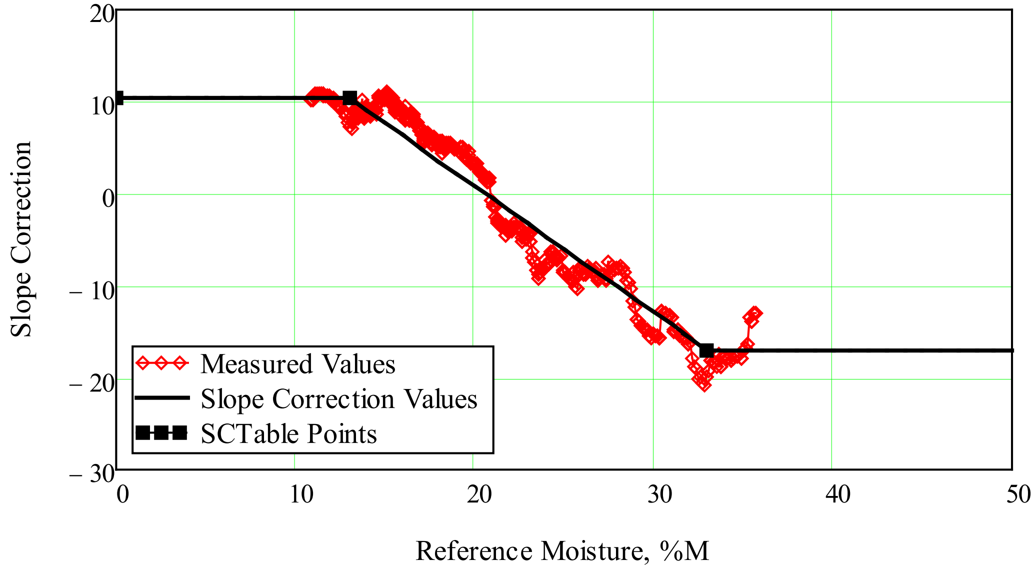



***Figure 3.*** Slope correction values. Visualization of the ***SC Table*** (Table 6).

Table 9 and Figure 4 show that by using the secondary density correction, the errors in predicted moisture for low density corn samples were significantly reduced. Furthermore, the standard deviation of the predicted moisture errors for "normal" samples was improved.

***Table 9***. Secondary density correction statistics; before (left) and after (right) correction.

| **Samples.** | **Mean Diff.** | **STD** | **Slope** |
|---|---|---|---|
| All | -0.03 | 0.51 | 0.00 |
| Low Dens. | -0.60 | 0.46 | 0.05 |
| Normal | 0.05 | 0.46 | -0.01 |

| **Samples** | **Mean Diff.** | **STD** | **Slope** |
|---|---|---|---|
| Overall | -0.01 | 0.41 | 0.00 |
| Low Dens. | -0.09 | 0.33 | 0.00 |
| Normal | 0.00 | 0.42 | 0.00 |

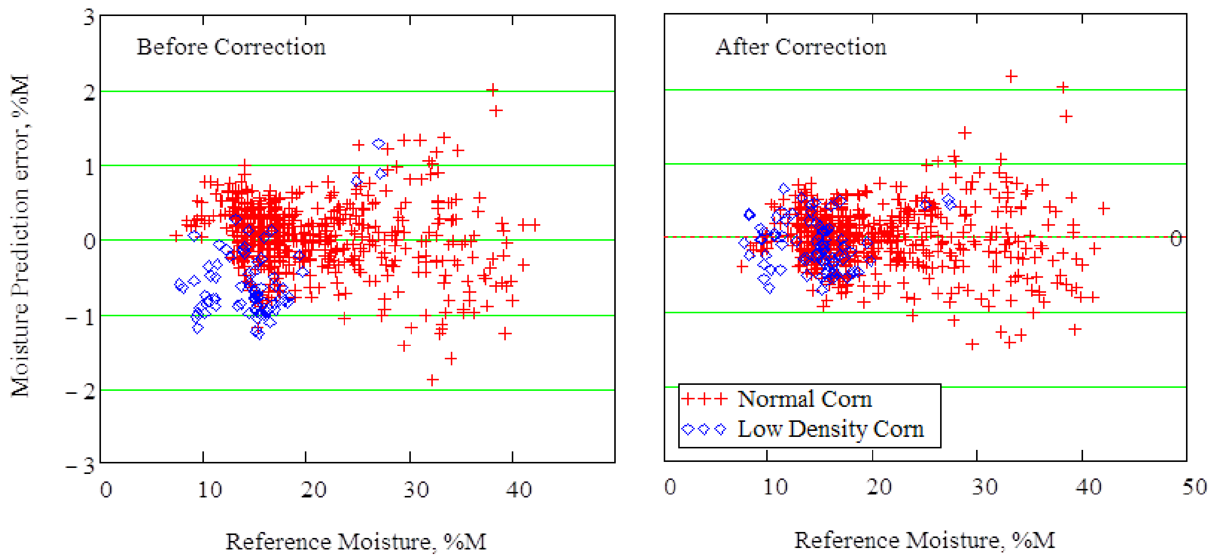



***Figure 4.*** Corn sample predicted moisture errors before and after secondary density correction for 2008-2010 corn.

### *Details of Secondary Line Shape Correction Method*

The secondary line shape correction dramatically reduces the error for soybeans, long grain rough rice, and medium grain rough rice caused by unusually dry samples and/or wet samples for the grain group. This correction addresses subtle differences in a grain group's line shape that may not be completely accounted for with the unifying parameters and without changing the UGMA from a fifth order polynomial to a seventh order polynomial. It should be noted that changing to a seventh order polynomial would require the unifying parameters for all grain groups be changed. Figure 5 illustrates key aspects of the correction. The long grain rough rice plot shows the samples below 15% moisture have a different slope compared to the samples above 15%. It also shows that the samples above approximately 20% moisture have a different slope compared to the samples below 20%.

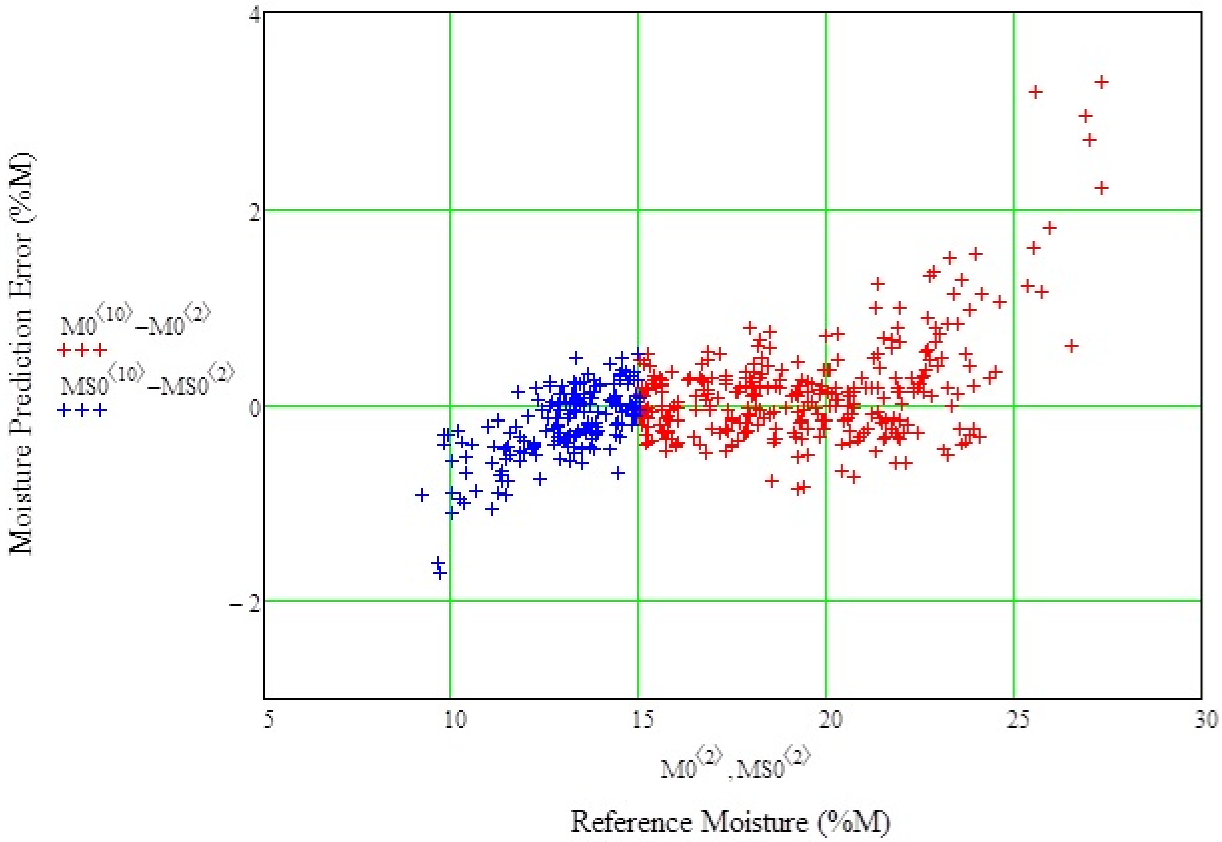



**Figure 5.** Long grain rough rice sample predicted moisture errors before secondary line shape correction for 2009 – 2013 crop.

Figure 6 illustrates the improvement in the moisture prediction error by applying the line shape corrections listed in Tables 5c and 6c. THR1 is the upper moisture limit for the slope correction applied to samples with a moisture below 15% (blue +) and THR2 is the lower moisture limit for the slope correction applied to samples with a moisture above 21% (green +).

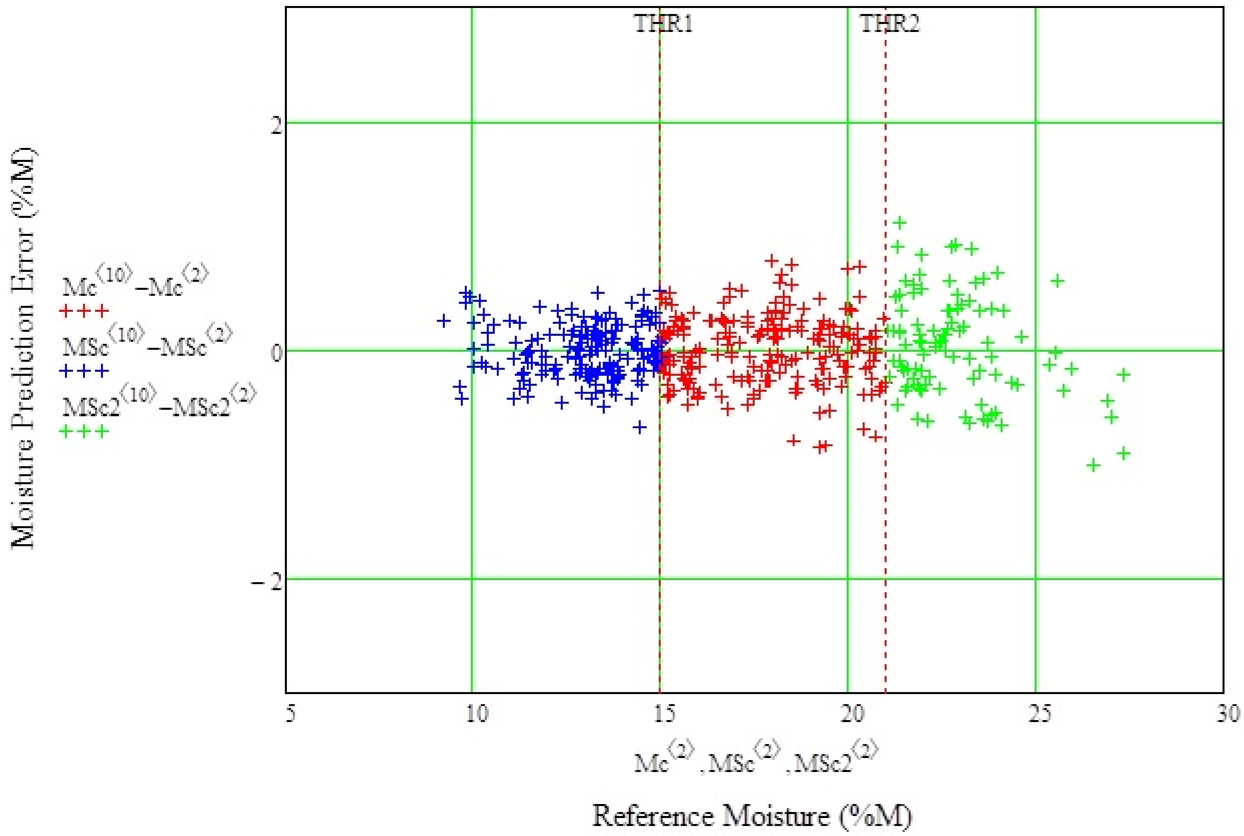



**Figure 6.** Long grain rough rice sample predicted moisture errors after applying the secondary line shape correction for 2009 – 2013 crop.

## *Sensitivity Analyses*

One of the major goals in developing the Unified Grain Moisture Algorithm was to define a measurement technology with sufficient detail that multiple manufacturers could design and produce instruments that could use the same calibrations and produce moisture measurements that are mutually consistent as well as accurate. Developers should not underestimate the extreme care required to design and manufacture instruments that can achieve UGMA-Compatible certification by FGIS. The purpose of this Sensitivity Analyses section is to share FGIS research results regarding the effects of several design parameters on moisture measurement results—and to thereby assist engineers in selecting innovative design strategies that can consistently achieve the necessary performance.

1. **Measurement frequency sensitivity.** Our analysis evaluated two cases of frequency sensitivity: 1) the deliberate choice of a known frequency other than 149.00 MHz, and 2) imprecision or instability in the measurement frequency of specific moisture meters. The exact choice of measurement frequency is not terribly critical; a manufacturer may have reasons to choose a specific frequency to avoid interfering with or being influenced by known problematic signal sources or sensors in the environment. The change in dielectric

constant values versus frequency is relatively small, so the same unifying parameters and calibration curve may be used over a limited frequency range. An evaluation with data for over 6000 samples of multiple grain types showed an average -0.02% moisture error per MHz for measurement frequency changes around 149 MHz. This sensitivity value assumed that the test cell model parameters (but not unifying parameters or calibration coefficients) were optimized for each test frequency. The second case assumes that the measurement frequency varied from the intended value, and that the test cell model parameters were not re-optimized for the specific measurement frequency. In this case, the frequency sensitivity was about ten times larger (+0.2% moisture per MHz of uncompensated measurement frequency error). For further information see: *Analysis of Frequency Sensitivity of the Unified Grain Moisture Algorithm*, ASAE Meeting Paper #053047, Zoltan Gillay and David Funk, 2005.

2. **Temperature measurement sensitivity.** Moisture measurement errors associated with temperature are due to temperature measurement errors and temperature correction function inadequacies. Typical temperature coefficients are about 0.1% moisture per degree Celsius difference from the reference temperature (22 °C). If the sample temperature sensor has significant thermal mass or other characteristics that cause measurement error to degrade at temperature extremes, significant moisture errors may result. Temperature measurement accuracy at room temperature must be especially good to avoid contributing significantly to moisture measurement errors during routine in-field performance verification (check testing). The temperature correction function must be sufficiently robust to provide good corrections over the full intended temperature (and moisture) range. Systematic temperature measurement errors for an instrument model (which could be corrected through the selected temperature correction function) cannot be tolerated in official moisture meters, which must use the same set of official moisture calibrations.

3. **Ranges of interest for dielectric constant, density-corrected dielectric constant, and related factors.** The following plots illustrate the ranges of parameters and sensitivities that are relevant for Official grain moisture measurements.

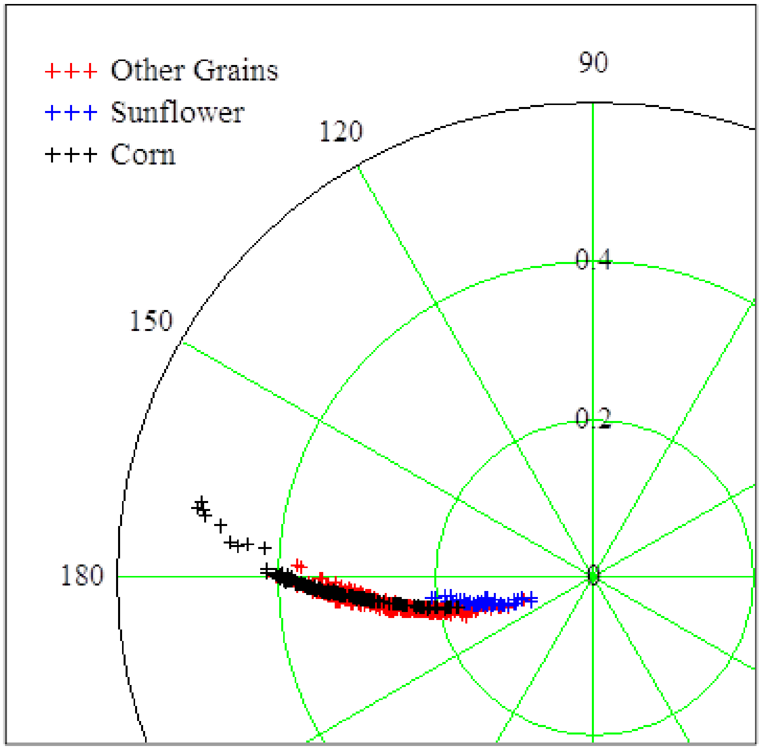



***Figure 7.*** Complex reflection coefficients measured with UGMA Master System for grain samples in 2008, 2009, and 2010 Calibration Studies.

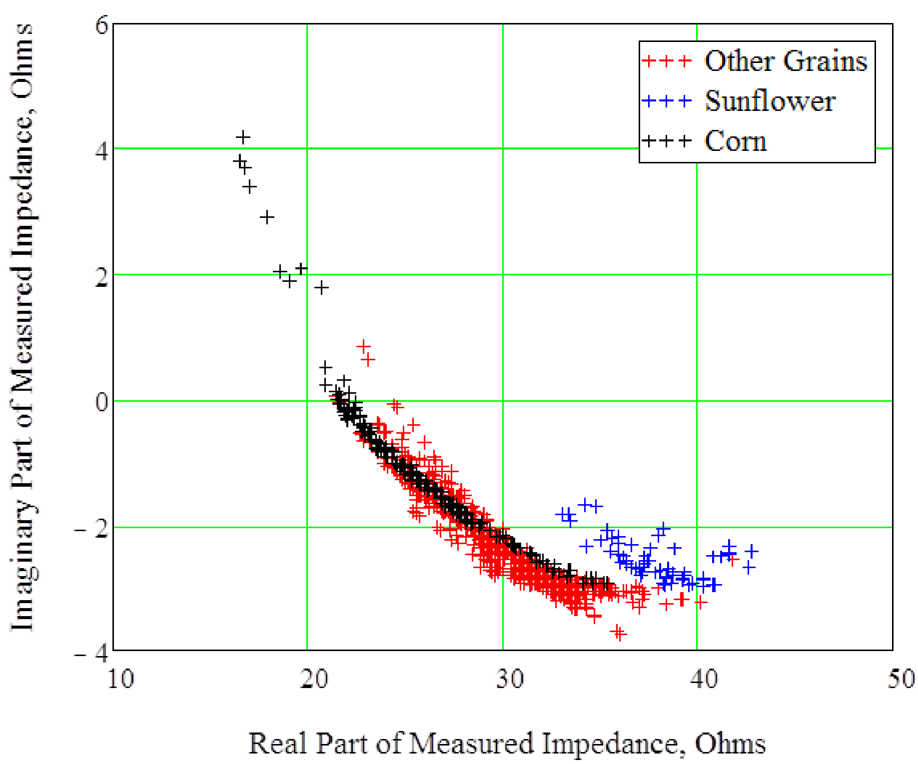



***Figure 8***. Complex impedance values measured with UGMA Master System for grain samples in 2008, 2009, and 2010 Calibration Studies.

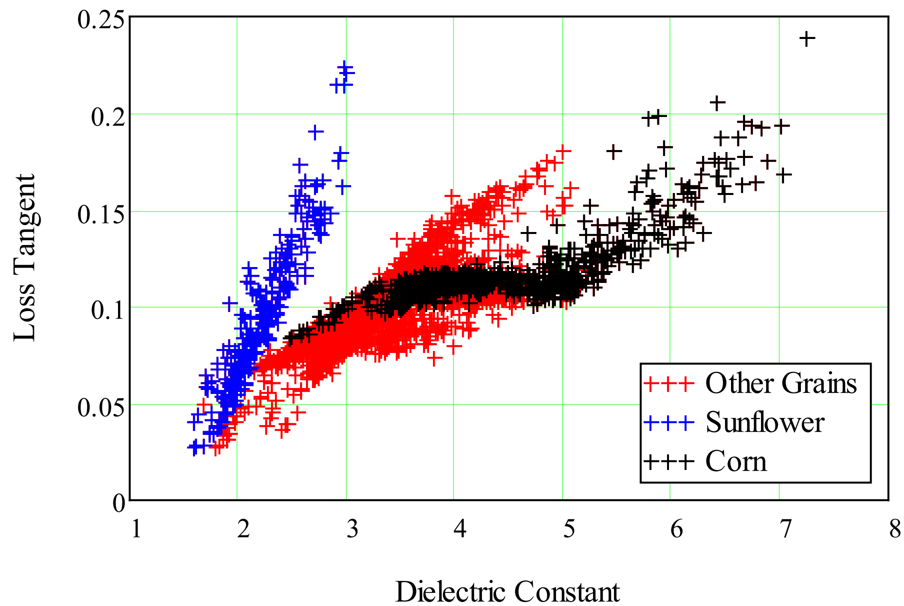



***Figure 9.*** Loss tangent versus dielectric constant values for grains tested in 2008, 2009, and 2010 Calibration Studies.

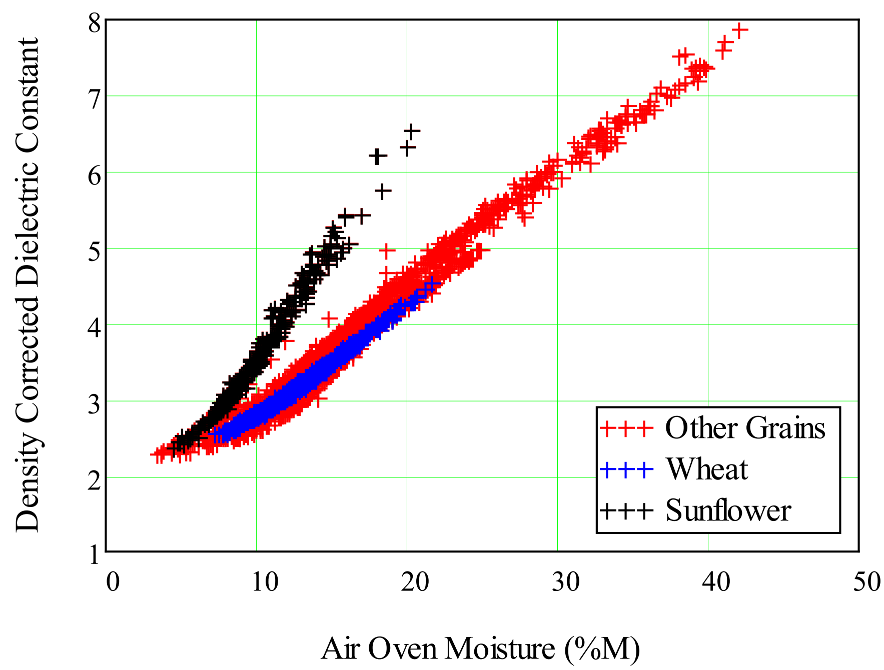



***Figure 10.*** Density-corrected dielectric constant ($\varepsilon_{den}$) versus moisture values for grains tested in 2008, 2009, and 2010 Calibration Studies.

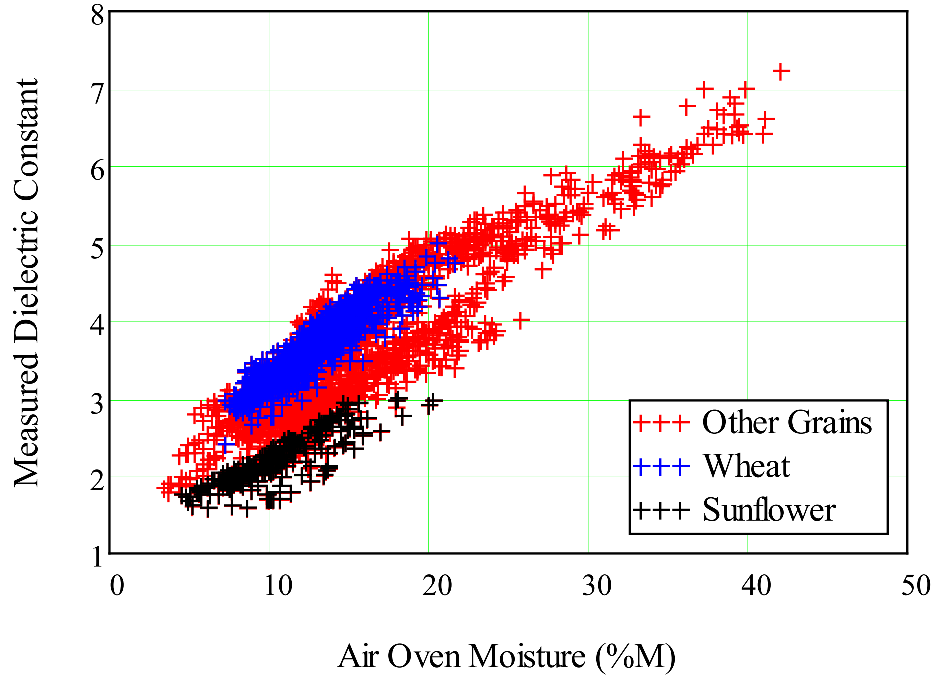



***Figure 11***. Measured ($\varepsilon_{meas}$) dielectric constant values (prior to density correction) for grains tested in 2008, 2009, and 2010 Calibration Studies.

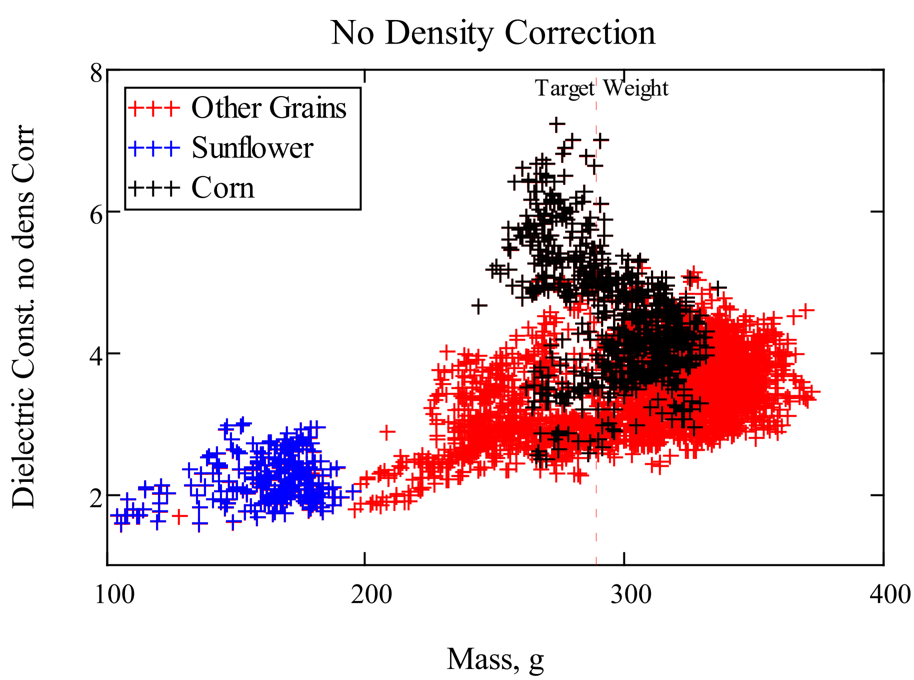



***Figure 12***. Measured ($\varepsilon_{meas}$) dielectric constant values (without density correction) versus sample mass for grains tested in 2008, 2009, and 2010 Calibration Studies.

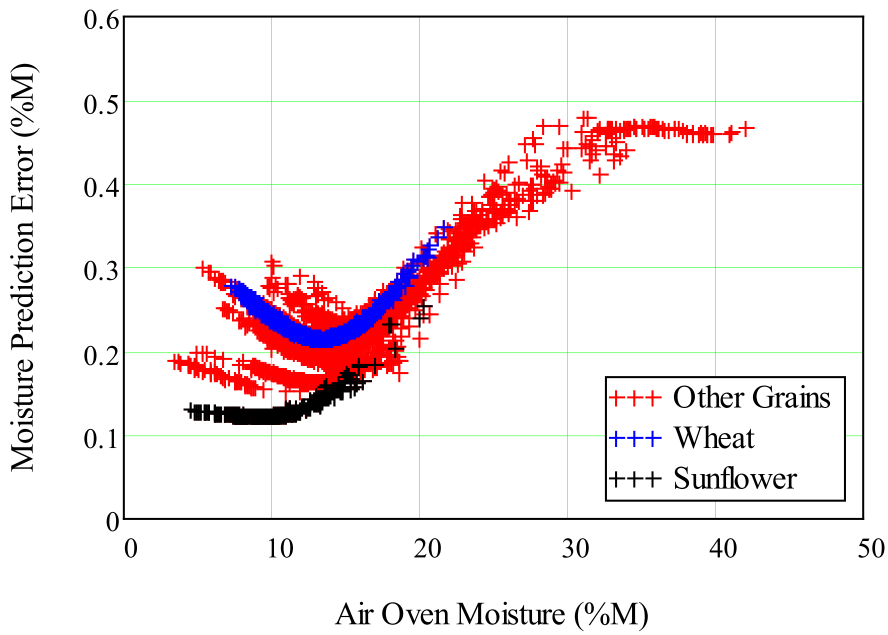



***Figure 13.*** Moisture prediction errors resulting from 1% (of value) errors in density-corrected dielectric constant for grains tested in 2008, 2009, and 2010 Calibration Studies. Simulation equation: $\varepsilon_{den} = \varepsilon_{den} \cdot 1.01$

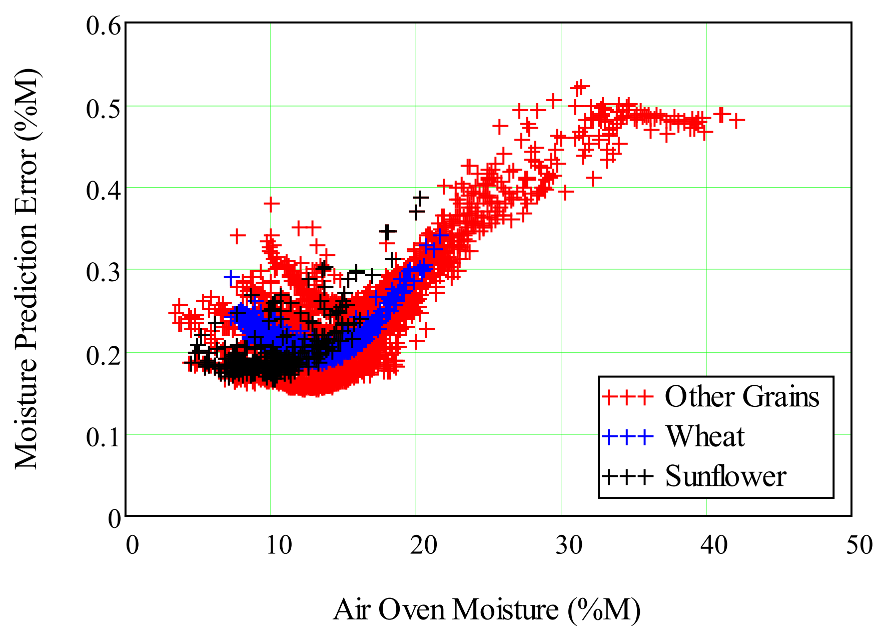



***Figure 14***. Moisture prediction errors resulting from 1% (of value) errors in measured dielectric constant (prior to density correction) for grains tested in 2008, 2009, and 2010 Calibration Studies. Simulation equation: $\varepsilon_{meas} = \varepsilon_{meas} \cdot 1.01$

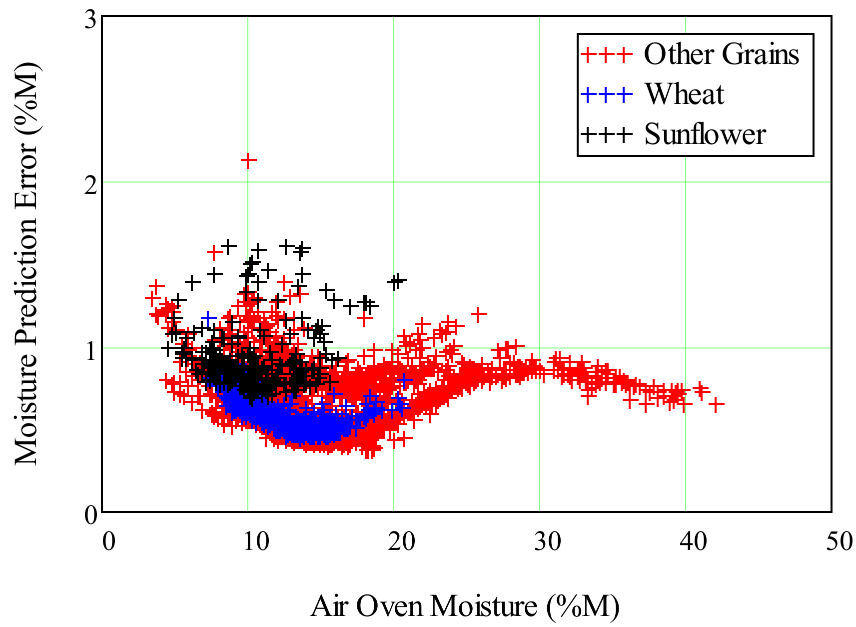



***Figure 15***. Moisture prediction errors resulting from a change 0f +0.1 in measured dielectric constant (prior to density correction) for grains tested in 2008, 2009, and 2010 Calibration Studies. Simulation equation: $\boldsymbol{\varepsilon_{meas} = \varepsilon_{meas} + 0.10}$

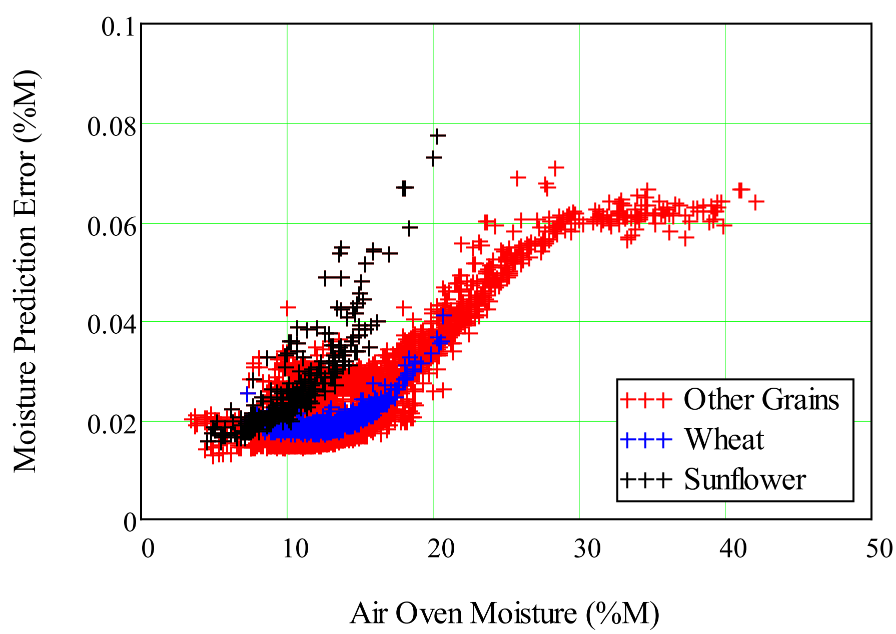



***Figure 16***. Moisture prediction error resulting from a simulated -0.3 gram mass measurement error for grains tested in 2008, 2009, and 2010 Calibration Studies. (A negative mass measurement error results in a positive moisture prediction error and vice versa.)

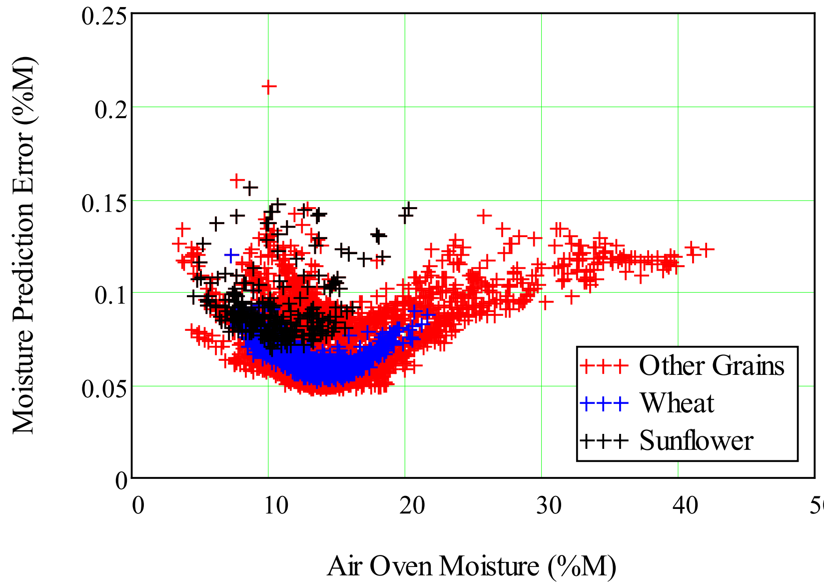



***Figure 17.*** Moisture prediction error caused by a simulated +0.001 error (not relative) in the magnitude of the measured reflection coefficient (at the test cell connector) for grains tested in 2008, 2009, and 2010 Calibration Studies with the FGIS Master UGMA system. (Note: This sensitivity is dependent on instrument design.) Simulation equation: $\Gamma = (|\Gamma| + 0.001) \cdot e^{i \cdot arg(\Gamma)}$

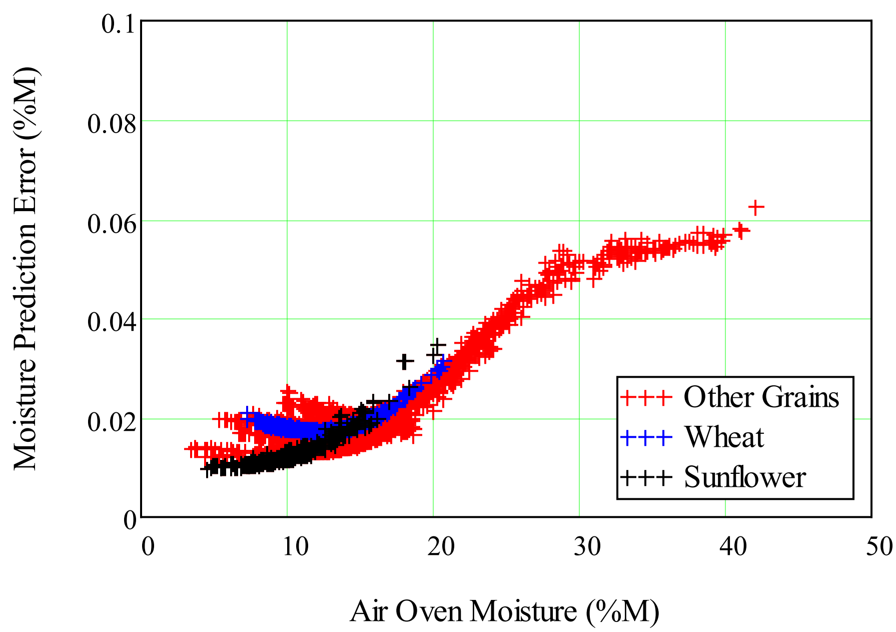



***Figure 18.*** Moisture prediction error caused by a simulated +0.1% relative change in the magnitude of the measured reflection coefficient (at the test cell connector) for grains tested in 2008, 2009, and 2010 Calibration Studies with the FGIS Master UGMA system. (Note: This sensitivity is dependent on instrument design.) Simulation Equation:
$\Gamma = |\Gamma| \cdot 1.001 \cdot e^{i \cdot arg(\Gamma)}$

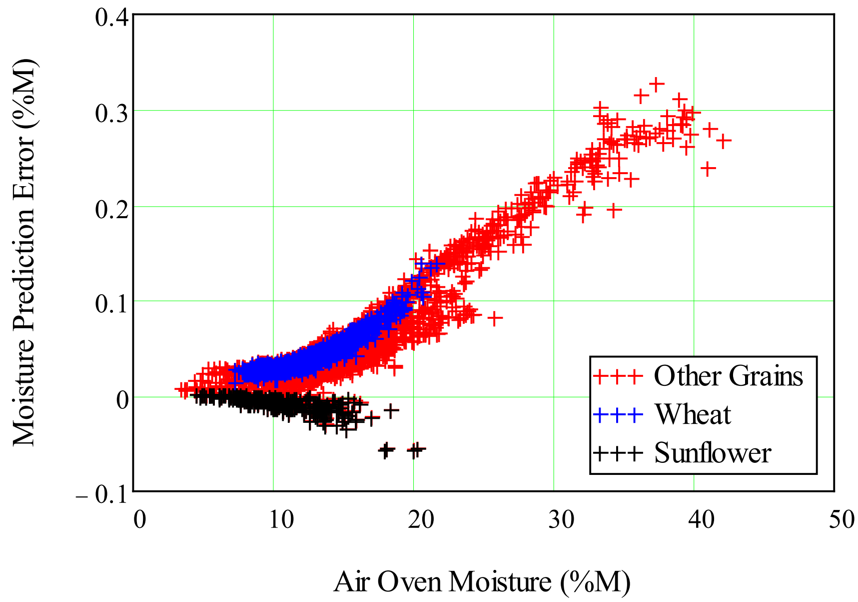



***Figure 19***. Moisture prediction error caused by a simulated -1 degree error in the phase of the measured reflection coefficient (at the test cell connector) for grains tested in 2008, 2009, and 2010 Calibration Studies with the FGIS Master UGMA system. (Note: This sensitivity is dependent on instrument design.) Simulation Equation:
$\Gamma = |\Gamma| \cdot e^{i\cdot(\arg(\Gamma)-1°)}$

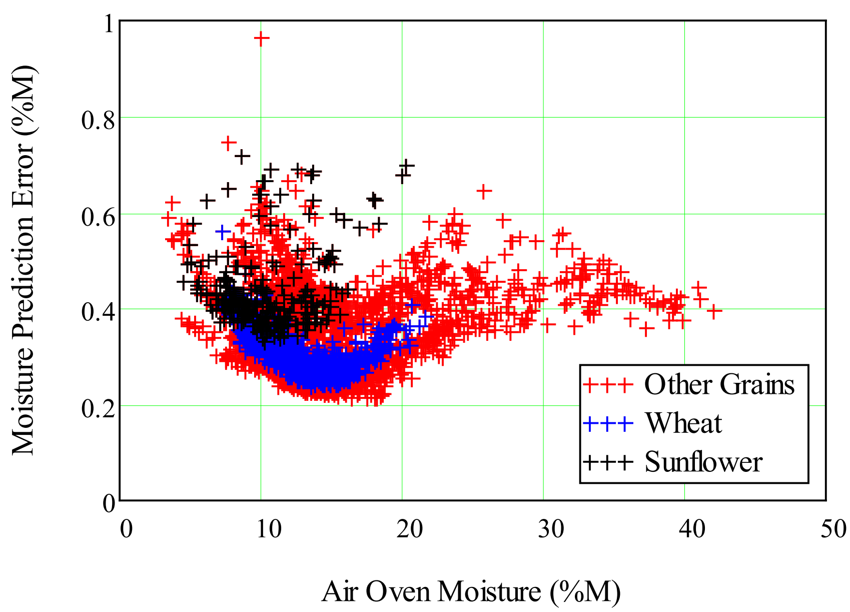



***Figure 20***. Moisture prediction error caused by a simulated -1% (relative) error in the magnitude of the measured test cell complex impedance (at the test cell connector) for grains tested in 2008, 2009, and 2010 Calibration Studies with the FGIS Master UGMA system. (Note: This sensitivity is dependent on instrument design.) Simulation equation:
$Z = |Z| \cdot 0.99 \cdot e^{i\cdot arg(Z)}$

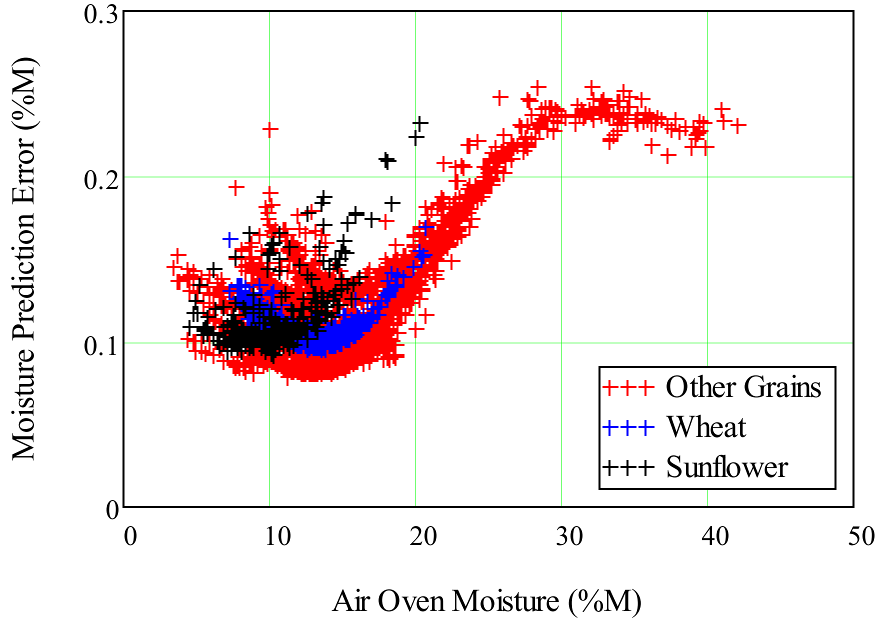



***Figure 21***. Moisture prediction error caused by a simulated -0.1 ohm error in the magnitude of the measured test cell complex impedance (at the test cell connector) for grains tested in 2008, 2009, and 2010 Calibration Studies with the FGIS Master UGMA system. (Note: This sensitivity is dependent on instrument design.) Simulation equation: $Z = (|Z| - 0.1) \cdot e^{i \cdot arg(Z)}$

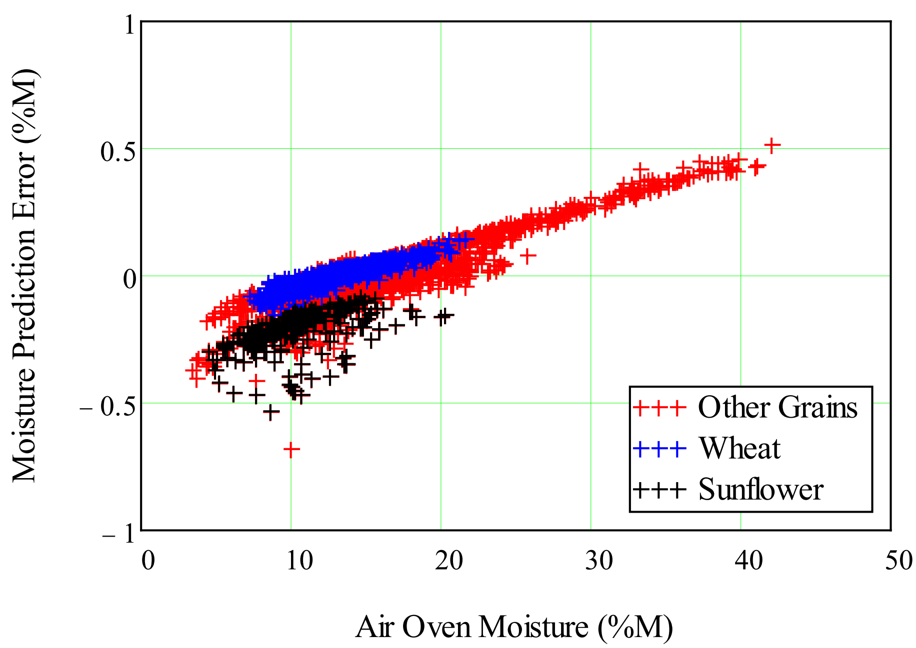



***Figure 22***. Moisture prediction error caused by a simulated -1 degree error in the measured phase of the test cell impedance (at the test cell connector) for grains tested in 2008, 2009, and 2010 Calibration Studies with the FGIS Master UGMA system. (Note: This sensitivity is dependent on instrument design.) Simulation equation:
$Z = |Z| \cdot e^{i \cdot (arg(Z) - 1°)}$

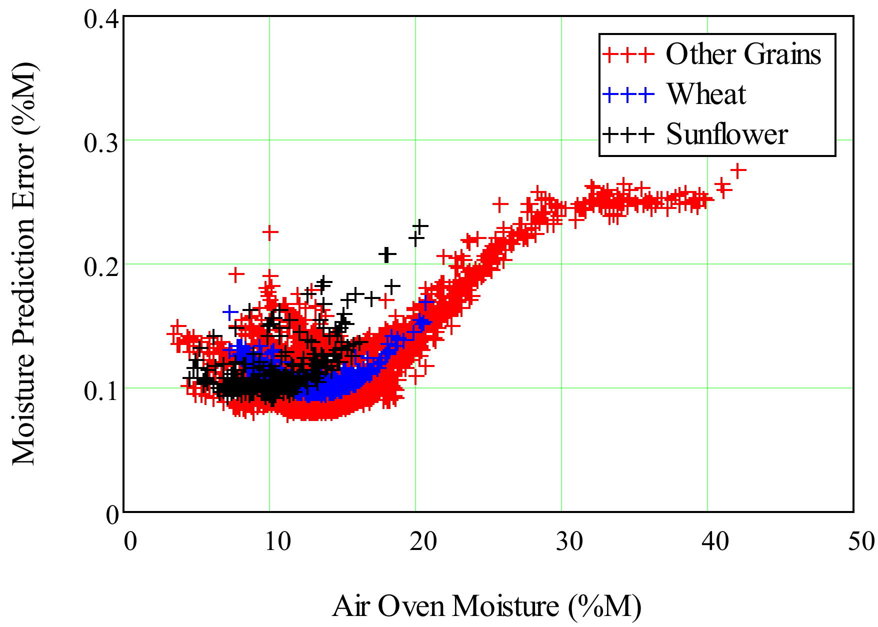



***Figure 23***. Moisture prediction error caused by a simulated 0.1 ohm resistance inserted in the connection between the source-end connector and the center test cell center electrode for grains tested in 2008, 2009, and 2010 Calibration Studies with the FGIS Master UGMA system. (Note: This sensitivity is dependent on instrument design.)

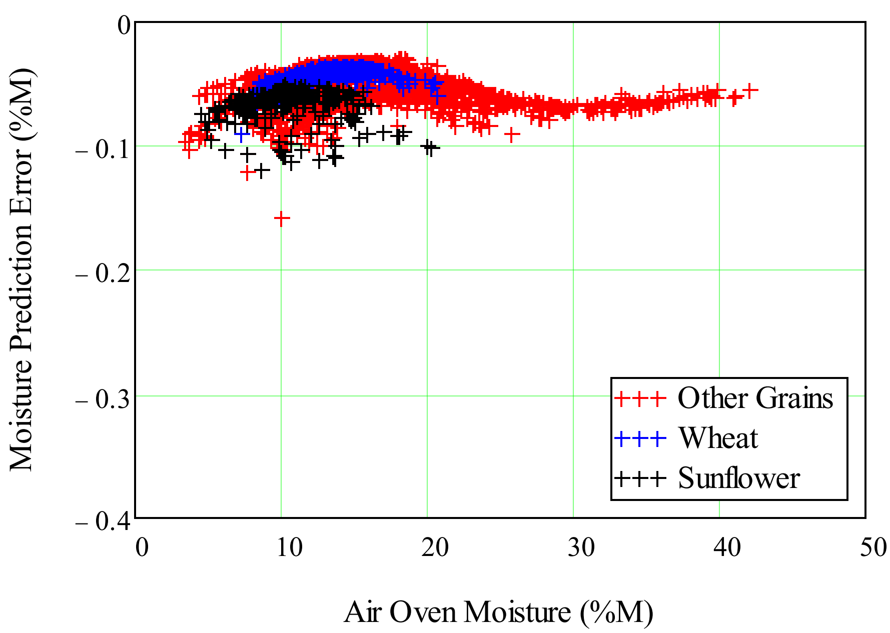



***Figure 24***. Moisture prediction error caused by a simulated 0.1ohm resistance inserted in the connection between the connector to the 50-ohm load and the center test cell center electrode for grains tested in 2008, 2009, and 2010 Calibration Studies with the FGIS Master UGMA system. The polarity of the change is opposite to that shown in Fig. 23. (Note: This sensitivity is dependent on instrument design.)

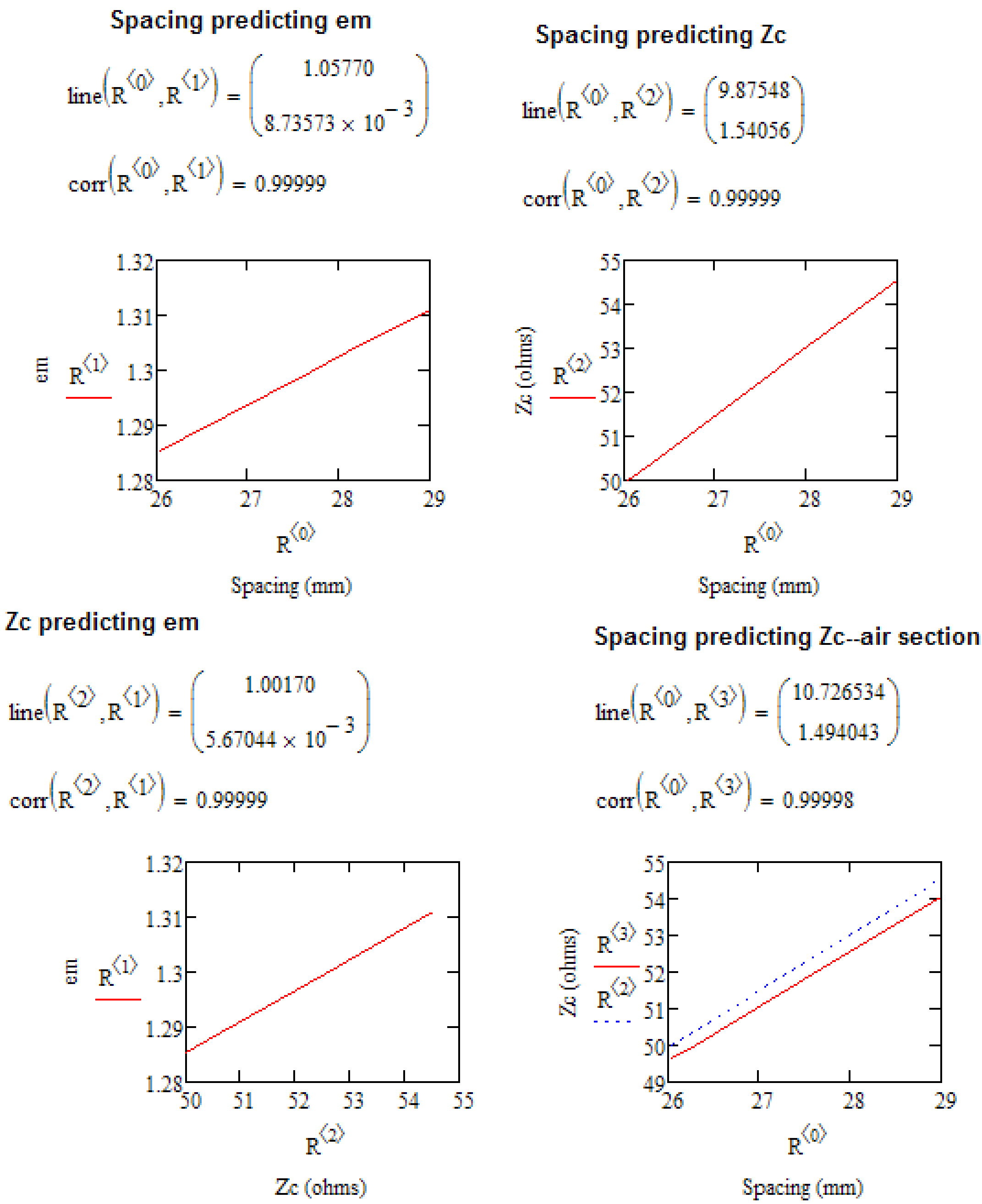



***Figure 25***. Relationships between test cell plate spacing, characteristic impedance, and filling factor. The relationships are highly linear. These results are from finite element analysis using the dimensions of the FGIS "New Master" (NM) test cell. Note that the "Spacing Predicting Zc—air section" analysis is based on a finite element model that includes the presence of the metallic base plate in the NM test cell, whereas the "Spacing Predicting Zc" analysis excludes the effects of the base plate. For the latter case, the effects of the base plate and the test cell gate are separately included in the test cell model as a constant offset term in the dielectric measurement. In actual instruments, the effects of conductors near the test cell may be significantly more complex and problematic because of the potential for resonances at or near the measurement frequency.

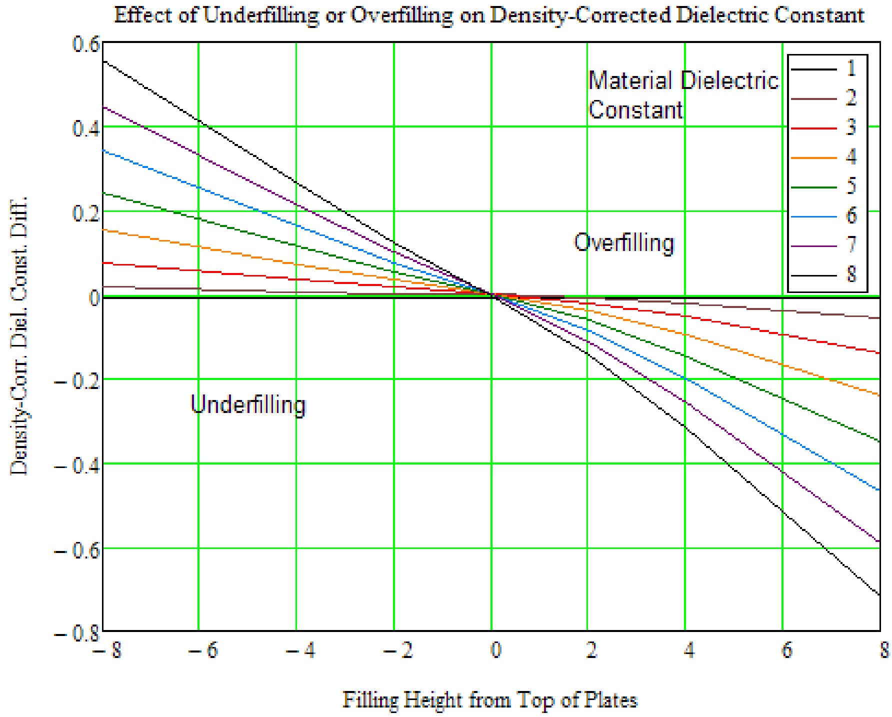



***Figure 26.*** Estimated effects on density-corrected dielectric constant of overfilling and under-filling of the test cell (as a function of filling height in mm). These results are based on finite element analysis of the "New Master" test cell.

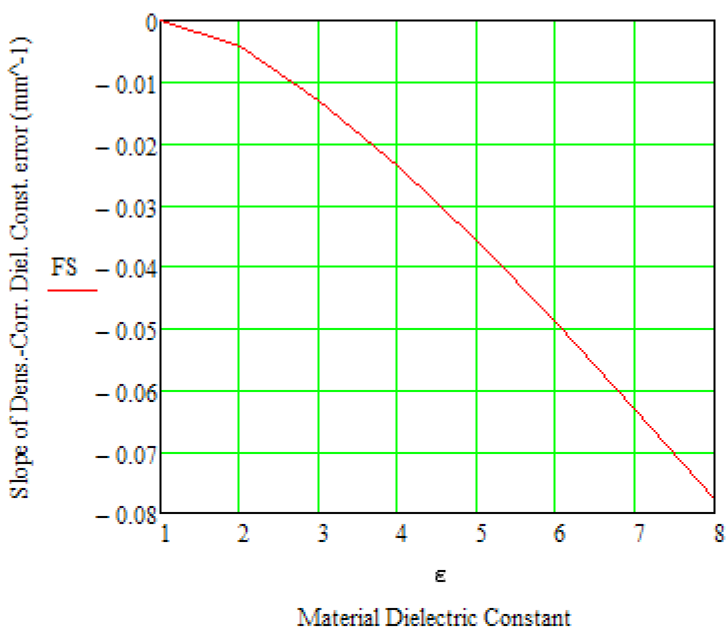



***Figure 27***. The slope of the density-corrected dielectric constant change with filling height (dielectric constant units per mm) based on finite element analysis of the New Master test cell. These are the slopes about the center point of Figure 25 (at the top of the plates).

Over-filling causes the measured dielectric constant to be lower; thus, the sign of the slope is negative.

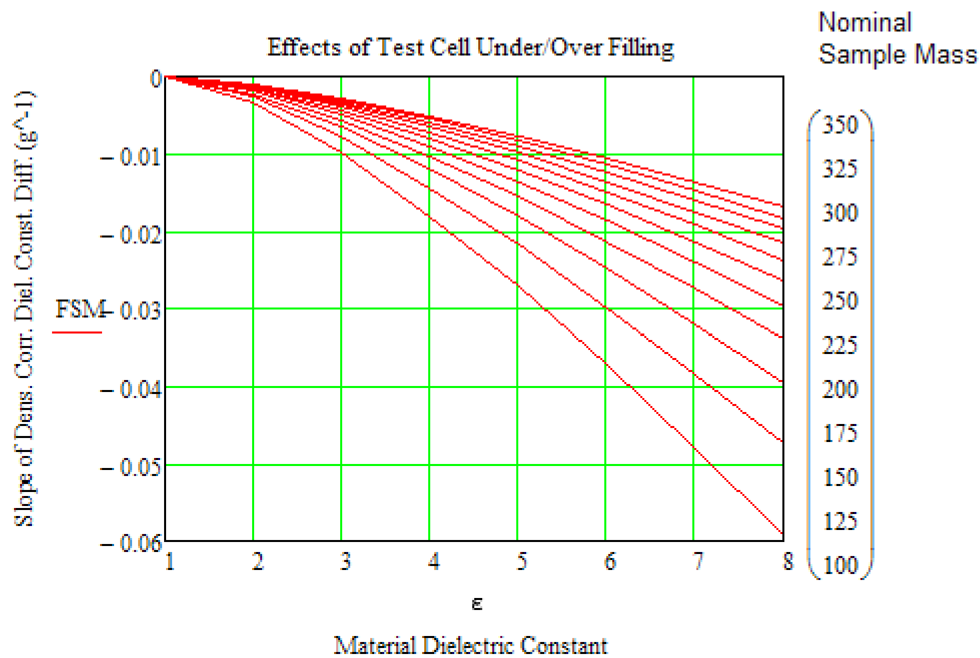



***Figure 28.*** Plot of the slopes of density-corrected dielectric constant per gram of cell over-filling (or under-filling) for different nominal full-sample masses. These results, like those of Figs. 24-26, are based on finite element analysis of the New Master test cell and assume "rectangular" sample cross-sections. These are the slopes about the "full" point corresponding to the center point of Figure 25. Over-filling causes the measured dielectric constant to be lower; thus, the sign of the slope is negative.

For further information, please refer to the USDA-AMS website (www.ams.usda.gov/) or by mail or phone to the address below.

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