Analysis of 2013-2019 NTEP data regarding proposed Handbook 44 tolerances for grain moisture meters—a very preliminary report

Presented 8/11/2020 Grain Analyzer Sector meeting, USDA
By Gordon Elliott
Bravo Scientific
Overland Park, KS
gelliott@csisc.cc
913-642-8400

ABSTRACT

Regarding potential changes to “Handbook 44” tolerances for Grain Moisture Meters, seven years of NTEP test data (2013-2019) are examined. This data (taken at room temperature and under controlled conditions) is useful in estimating potential effects of such a tolerance change. This is especially valuable due to the sheer volume of individual moisture meter test recorded (in excess of 100,000 measurements across fifteen grain types). Individual and aggregate errors of measurement deviations from “Air Oven” standard measurements are studied (“bias” when referring to aggregate measures), and several means of analysis are presented. Potential mechanisms for errors that will affect field tests and meter calibration tests are also discussed. UGMA and NIR meters appear to have a low frequency of measurements that exceed the new tolerances, and non-UGMA dielectric moisture test equipment will have a somewhat increased rate exceeding those tolerances. Other potential mechanisms for measurement error are discussed, may produce increased events of exceeding the new tolerances, even for UGMA meters.

DISCLOSURE

Mr. Elliott designs grain moisture test technology and analyzes grain moisture calibrations and calibration data. He is associated with the Steinlite Corporation of Atchison Ks., a manufacturer of equipment involved in this study.

ACKNOWLEDGMENTS

I wish to thank Cathleen Brenner and Jason Jordan of USDA, AMS, FGIS, and Ms. Gloria Diane Lee of NIST, for their enormous help in separating out the raw data, answering an endless stream of questions, and for many helpful suggestions. Without them this report would simply not be possible.

1 INTRODUCTION

The Federal Grain Inspection Service of USDA, in concert with National Institute of Standards and Technology, are considering changes to “Handbook 44” regarding tolerances for Grain Moisture Meters as compared to Air Oven method of testing (AOM). These changes would decrease tolerances for field testing of Grain Moisture Meters used in trade, and would also affect “NTEP” testing, the ongoing program to keep Grain Moisture Meters certified in calibration. Current HB 44 field testing tolerances are 0.7% in moisture content, or 0.8% for corn and certain other grains and seeds, with an increasing tolerance at higher moisture ranges. The proposed change would decrease this tolerance to 0.5% for all grains (again with an increasing tolerance at higher moisture ranges). NTEP certification testing uses a value of one-half of the field test tolerances, with an additional margin for statistical error, and these tests certifying meters and calibrations would also be affected by the proposed change. The proposed change is of the greatest degree (ratio of decrease in tolerance) for corn, oats, rice, sorghum, and sunflower grains and seeds, precisely commodities that have shown higher levels of deviation from the AOM standards in most measurement technologies.

The purpose of this study is not to recommend policy changes, but rather to do the best job I can do at scientifically analyzing the potential effects of the proposed changes. I will speculate on possible mechanisms that require additional data to analyze, as well as show analysis from the massive volume room temperature test data.

2 TECHNOLOGY

Three different underlying technologies are used in the equipment studied.

1. UGMA algorithm (and certification) dielectric meters: These use a radio frequency signal in the range of 149 to 150 MHz, passing into a measurement cell containing a grain under test. The dielectric properties of that grain depend in large measure on the moisture content. The mechanics of the cell, dropping of grain and “strikeoff” level at the top of the cell, the characteristics of the conversion from RF to dielectric measurement, and even the grain calibrations are established by USDA standards for the “UGMA” meter program. Calibration updates are provided by USDA, with only limited adjustment parameters allowed for manufacturers to correct calibrations to individualized character of their equipment type. When deviations from AOM testing occur, they tend to be repeatable or track the same on (both of) the UGMA meter types, so when systematic errors occur they tend to be similar from meter to meter regardless of manufacture origin.
2. Non-UGMA Dielectric meters: These also use radio frequency signal to a cell with a plate, typically in range of 2 to 20 MHz. Both technology and calibrations are provided by the

manufacturers—certified in the NTEP testing program at the USDA. Since the underlying mechanics and algorithms differ from manufacturer to manufacturer, systematic deviations may not match other meter types, even if they occur in a regular manner on the same meter type.

3. NIR (Near Infra-Red) meters which test multiple grain characteristics: These meters use reflection of infra-red radiation from the grain under test as a major component of the sensing method, and provide additional information about the grain such as protein content at the same time. These meters tend to take longer to perform their tests (30 seconds typical as compared to 10 second range for the dielectric testers.) The longer test time is accepted by the customer because of the importance of the other measurements that are provided—and this increased testing period may contribute to a greater regularity in measurements observed in this study. Technology and calibrations are provided by the manufacturer—certified in the NTEP testing program at the USDA.

3 MECHANISMS OF MEASUREMENT DEVIATION

All the mechanisms used to measure grain moisture content in the machines under consideration use a "proxy" for the actual moisture content. Even the "AOM" standard is not an exact chemical measurement of the fraction of mass in the whole grain that is water, because the drying method tends to expel other volatile chemicals along with the water. Even slower but more accurate methods have been developed for such analysis (in which even the AOM test may take an entire day), and the AOM tests are optimized such that the mass of additional volatiles lost is balanced with the amount of water remaining in the grain. Likewise, other components of the grain (differing in local regions and time periods in potentially systematic ways) contribute to the dielectric reading on dielectric meters (both non-UGMA and UGMA based), and may similarly affect reflectance in NIR test meters.

Appendix 1 – *Additional causes of deviations in moisture testing* will list potential means for variation of samples from original AOM test results, as could potentially occur in the field, differing from in office testing with temperature and humidity controls as is applied to the NTEP data analyzed here. These include sample deterioration beyond that occurring in the controlled environment, localized sample characteristics with systematic measurement errors on a given equipment type, temperature related variations in both sample and equipment, all of which contribute to increased measurement deviations.

Measurement of the corn, oats, rice, sorghum, and sunflower grains and seeds will experience larger deviations in moisture meters because of mechanical difficulties in transport of those commodities within the measurement mechanism. Since the proposed tolerance changes include simplification to a single tolerance for all grain types, the variations of these specific types from the standard relative to the tolerance will be a noticeable effect of this change.

A basic standard deviation (basic randomness of measurement due to mechanical, electronic, and commodity effects in the individual grain test drops) will contribute to the measurement error.

Calibrations "drift" relative to the local and aggregated character of the grain samples from year to year (and sometimes in a systematic way on a local area basis). Though average machine characteristics could drift over time, this is mostly a variation seen in aggregated behavior of the commodity itself in a shorter time span. This can be described as a "non-stationarity" of the data, but with aperiodic cyclic nature which tends over time to return to a general long-term mean. For example, at the Steinlite

Corporation we have seen overall stability of the NTEP calibration data relative to machine characteristics over a 20 year time span, but local 3-5 year variations that tend one or another directions but eventually return to cross a central mean. If a field machine requires a three-year maintenance schedule, but crop characteristics change within the first years, that “drift” may appear on the local machine using to local grain samples, while national averages with up-to-date calibrations have smaller aggregate deviations.

4 WHAT CAN WE TEST WITH THE NTEP DATABASE?

The NTEP data is taken at room temperature and cannot be used to check for field characteristics like temperature variations in the sample or equipment, or sample variations due to age or re-use of the sample.

It does provide a huge database for analyzing the essential variations from sample to sample, such as fundamental sample standard deviation of individual grain measurement, over various commodity and moisture ranges and samples from all over the US.

Calibrations are always developed or checked against the prior three-year time span. So, calibrations will always be about one season out of date (if any changes were required at all). Beyond the random character of commodities, we may be able to see systematic variations.

The NTEP data experiments here do not provide information about a large variety of meters of the same type. Rather all tests are performed on two examples of each meter type, and those meters are calibrated yearly with extra care to most accurately represent the idealized standard of that meter type. This analysis is about the variability of the response of those meters to the grain characteristics, not the variability across meters of the same type.

5 RESULTS

5.1 UGMA TYPE CONSISTENCY OF READING

The suggestion of updating the tolerances is based in part upon the emergence of new technology, specifically the “UGMA” meter standard. Figure 1 UGMA meter tracking, minimum and maximum values shows the close tracking of the minimum and maximum values for corn measurements (in a narrow moisture range). This is graphed in order of increasing moisture and is not a time series. Furthermore, this graph does not represent two meters, rather shows the maximum and minimum simultaneous values from two meter types (without regard to which produced that extreme). Connecting graph lines often may switch meters or meter manufacturer and may also span years of time difference.

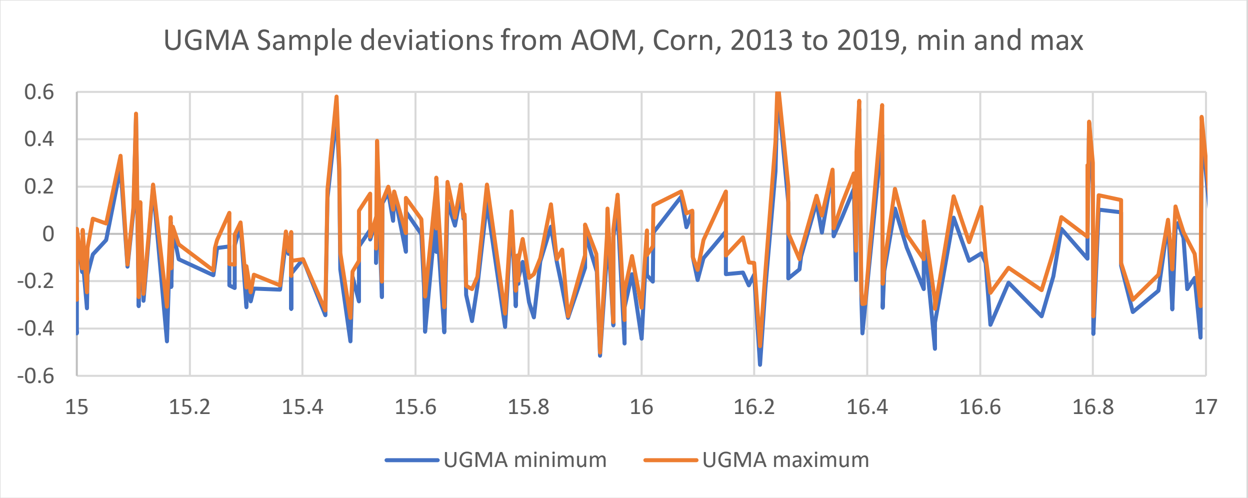

Figure 1 UGMA meter tracking, minimum and maximum values

Compare this to the same chart, showing the range for the non-UGMA meters in Figure 2 Non-UGMA moisture meters (both Dielectric and NIR), minimum and maximum values. While there is some tracking or similarity across the same sample with different machines, even a relationship to the UGMA machine readings, the variation between machines is often larger than the deviation from the AOM.

One aspect demonstrated here is that systematic deviations from AOM occur in individual samples. Though the deviations are greater and are have more variation from machine to machine type even in home-office non-UGMA moisture meters, there is a high degree of repeatability of the deviation of individual samples across machines. This means that one can easily (by accident) pick a corn sample with a "bias" such that it consistently tests out of range of the proposed standard. The fact that the individual sample has a known "AOM" reference value does not tell us with complete accuracy where it fits in the range of testing on electronic moisture meters, even on UGMA meters, even though the UGMA meters especially have a very narrow average response range to conditions averaged across all US crops.

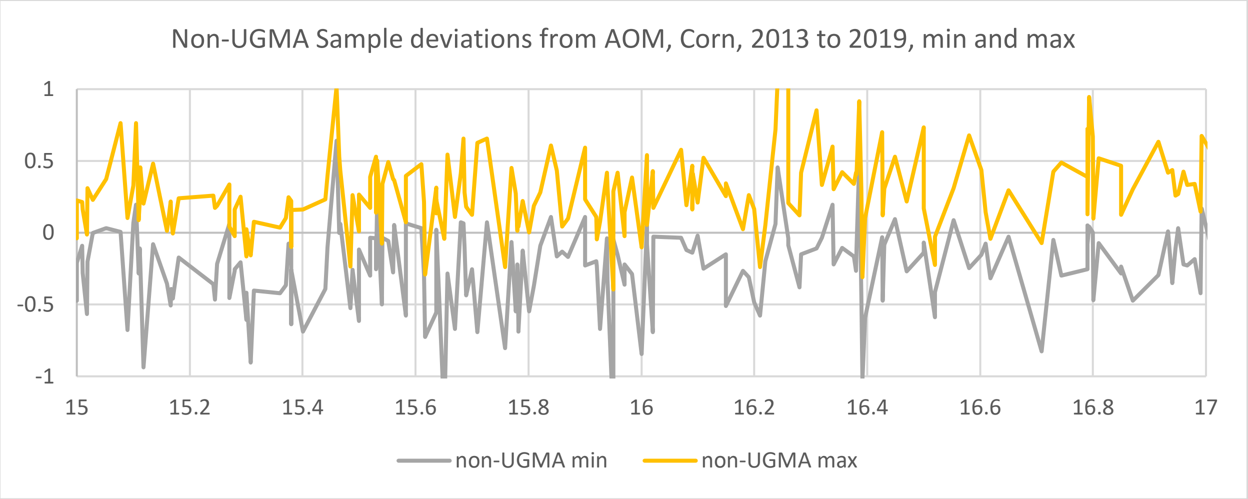

Figure 2 Non-UGMA moisture meters (both Dielectric and NIR), minimum and maximum values.

5.2 STANDARD DEVIATIONS OF THE INDIVIDUAL MEASUREMENTS

Appendix 3—*methods used to determine individual sample standard deviation* discusses the analysis methods for standard deviation of individual sample measurements. The basic standard deviation of individual moisture measurements on the various machines is derived from pairwise measurements with the same sample. In other words, this represents the expected variation in individual samples one gets by repeating the same sample on the same test unit.

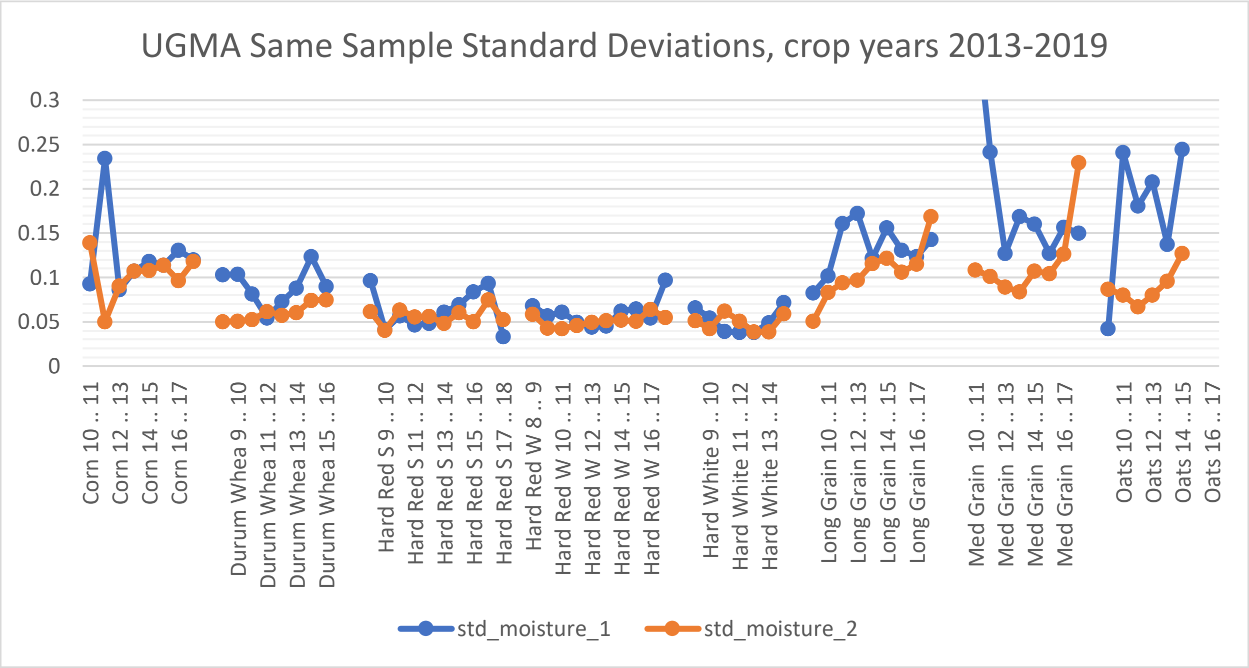

Figure 3 xx

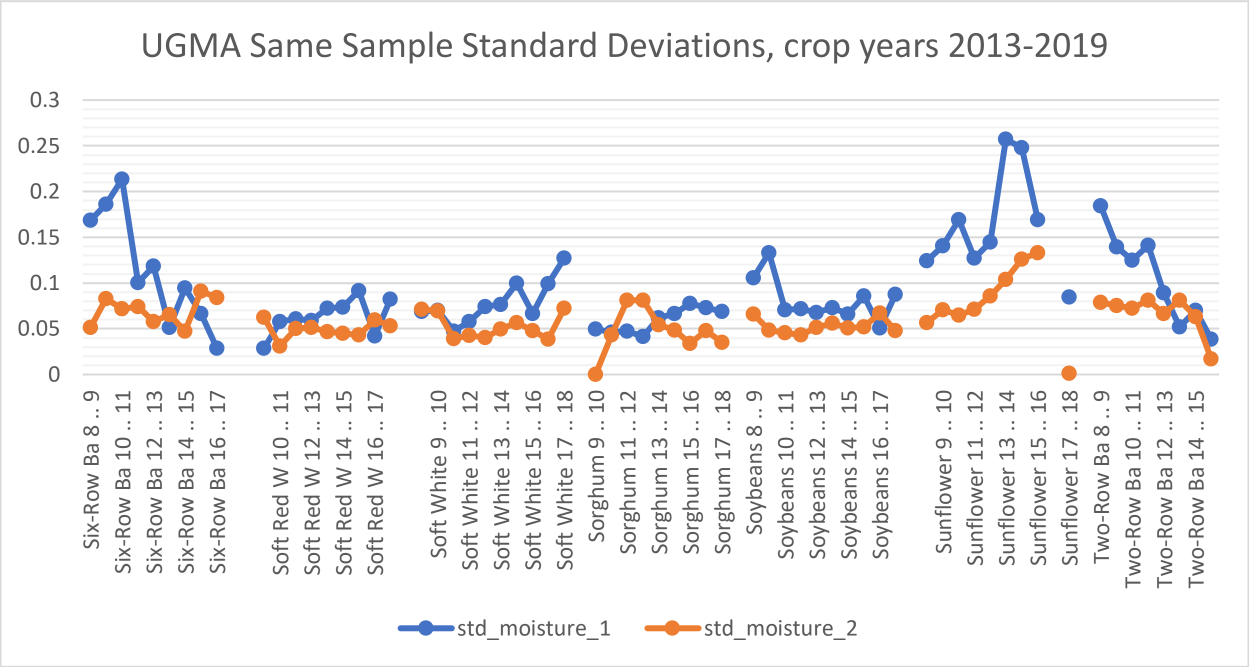

Figure 4 xxx

A problem occurred with finding the standard deviation on NIR machines in that the NTEP testing did not use two tests in a row on the same unit with the same sample. So a different method used was verified to work when variations were small and taken across two machines. These are consistent with similar tests on the other machine pairs. Off char readings should be considered “bad data”.

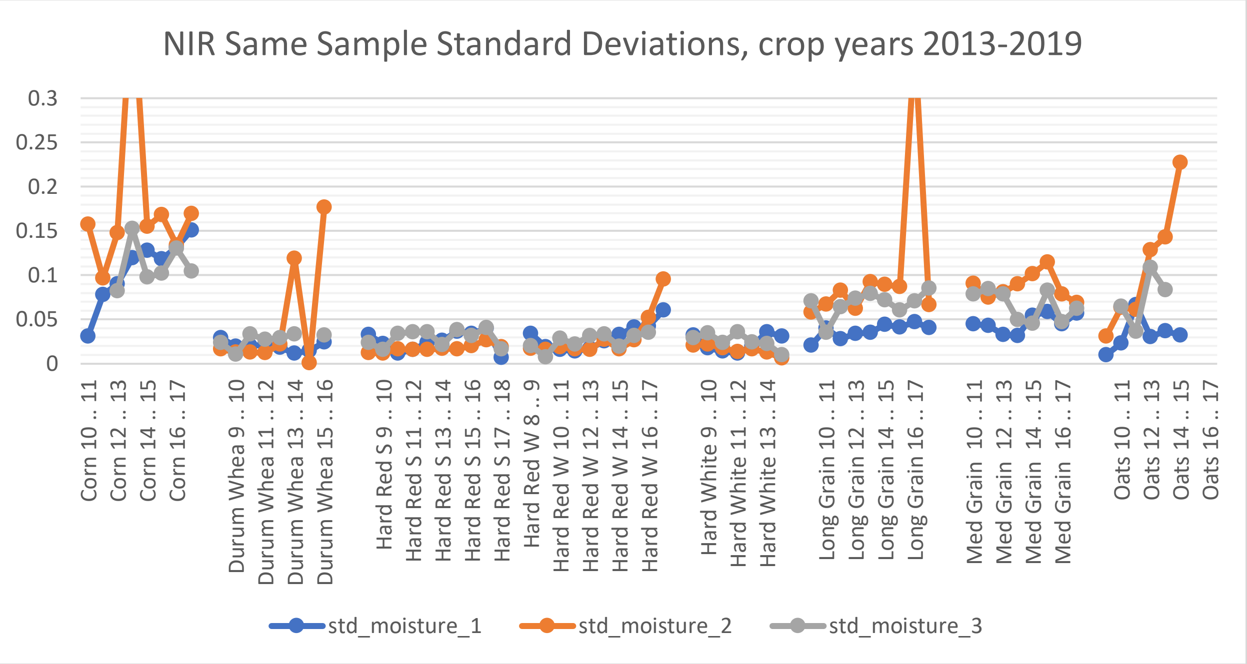

Figure 5 xxx

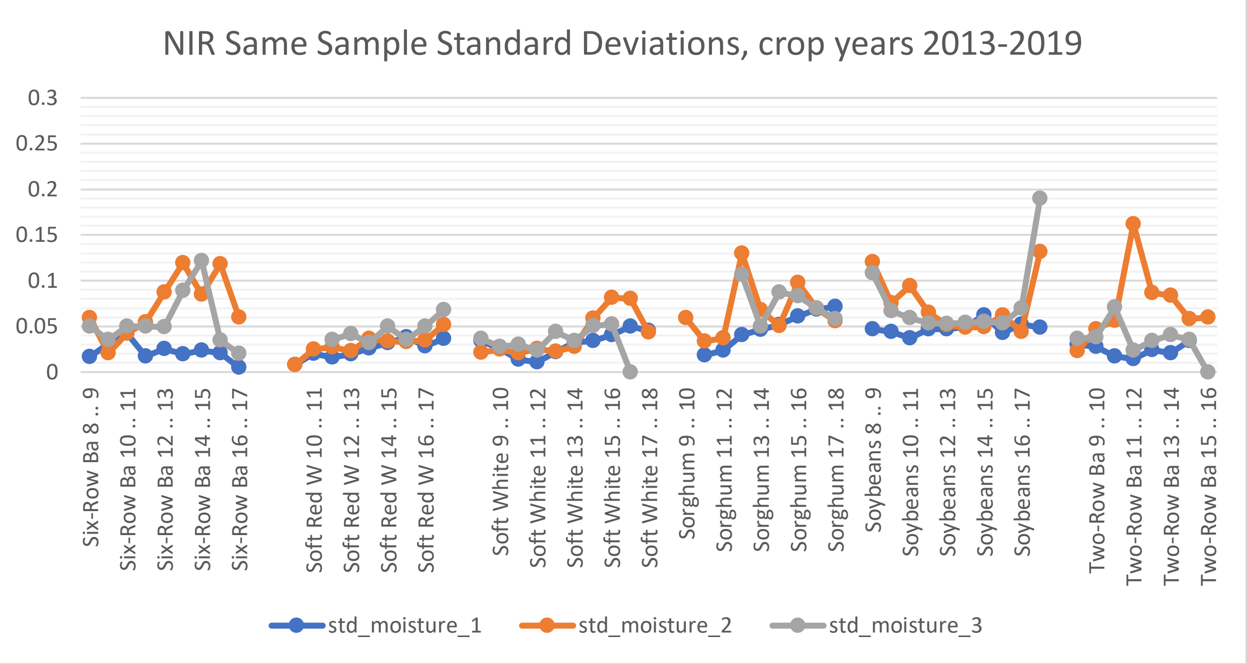

Figure 6 xxx

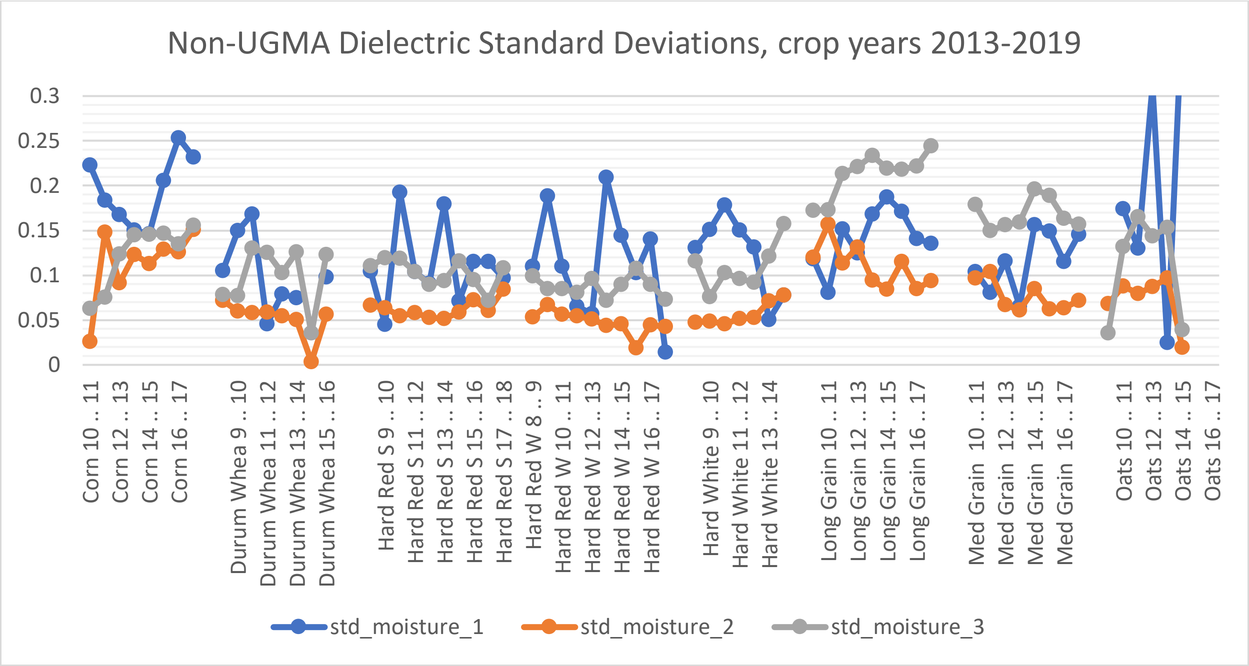

Figure 7 xxx

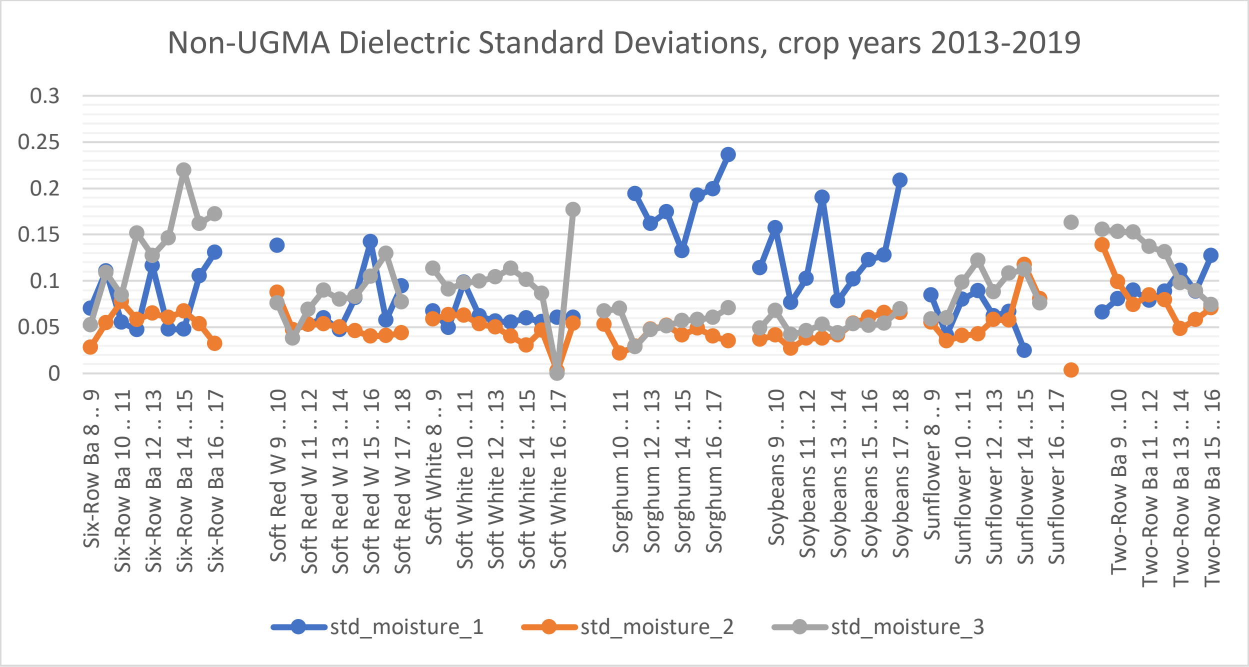

Figure 8 xxx

To estimate the standard deviation of the average of three readings—as are used in field testing—take the standard deviation of the individual reading estimated from similar conditions from the graph, and divide by sqrt(3), which is approximately 1.73. From this one can estimate probabilities that just due to sample measurement randomness with a specific grain in a specific moisture range, that the measurement will add to the errors from other sources. This randomness can be in either direction and may help or hurt the degree of error from AOM, with equal probability.

From the graph the standard deviation of individual samples of corn is about 0.12% in moisture. There is about a 16 percent chance that 0.07% in moisture will be added to increase the error from other sources—that is the error occurs in the same direction as those other sources of error (positive "tail"). That is a relatively small fraction (14 percent) of that 0.5% in moisture (minimum) tolerance allotted—but errors from every cause add up. NIR moisture meters seem to have about the same randomness-based response to corn measurements. Non-UGMA dielectric meters may have a slightly higher randomness response to corn and other hi variance grains, but only by a small degree and this source of errors does not explain all the differences between the meter categories.

5.3 OUT OF TOLERANCE EVENTS

Groups of four tests are done on all the dielectric moisture meter types (UGMA and non-UGMA). When averaged together, these could fall outside of the proposed tolerances. Two important grain types for analyzing problems include Corn and Long Grain Rough Rice. The NIR meters use only two samples. Tolerances were established by an algorithm that uses the highest end limit of the 2% moisture bin and increases according to the new rule above 0.5% when above 0.03 of the moisture content at the top of the bin. Rounding of both tolerance and moisture value to one tenth digit makes the rule apply as it would in the field.

Figure 9 xxx shows the fraction of measurement sets for a sample in the typical range of 12% to 18% which might be used for field testing of moisture meters. There are almost no sample measurement sets falling outside the new tolerance, with 95% to 99% falling in tolerance in 12% to 18% moisture for UGMA meter type.

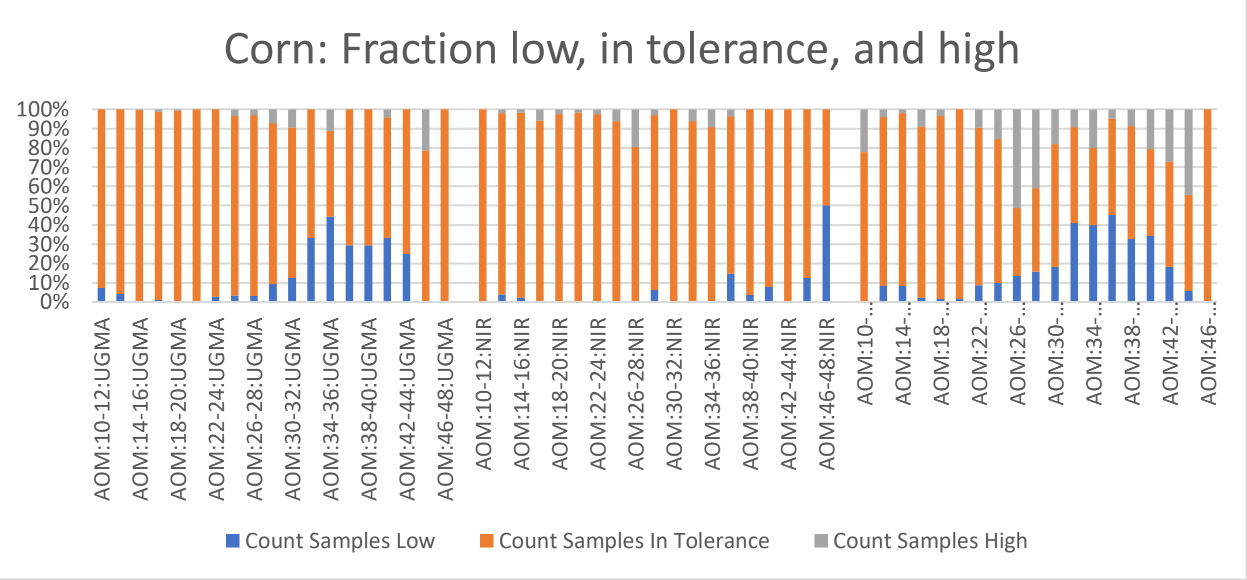

Figure 9 xxx

NIR meters show similar performance, and non-UGMA Dielectric meters (right) having somewhat higher rates of falling outside the new tolerance ranges.

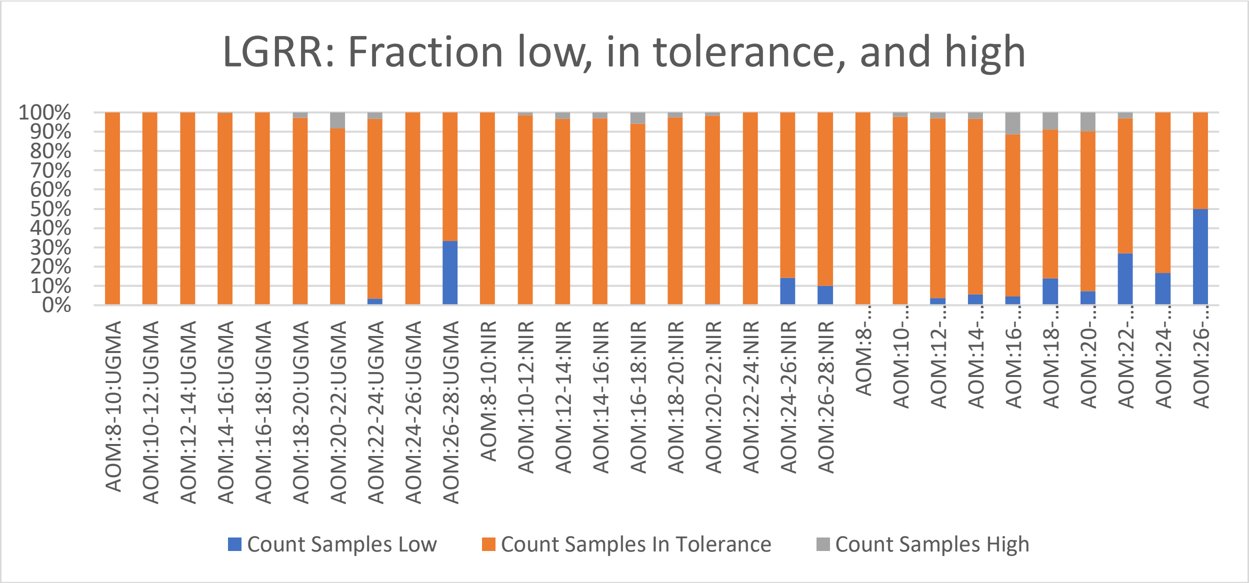

Figure 10 xxx

The Figure 10 xxx shows virtually no out of tolerance samples for UGMA meters in the 10% to 20% range. Performance on NIR meters was similar, and slightly higher out of tolerance events show on non-UGMA Dielectric meters (right).

5.4 NEAR MARGIN EVENTS

Field testing may qualify samples for comparison testing, for example to fall within 0.3% of their original AOM reading when tested on a UGMA reference meter.

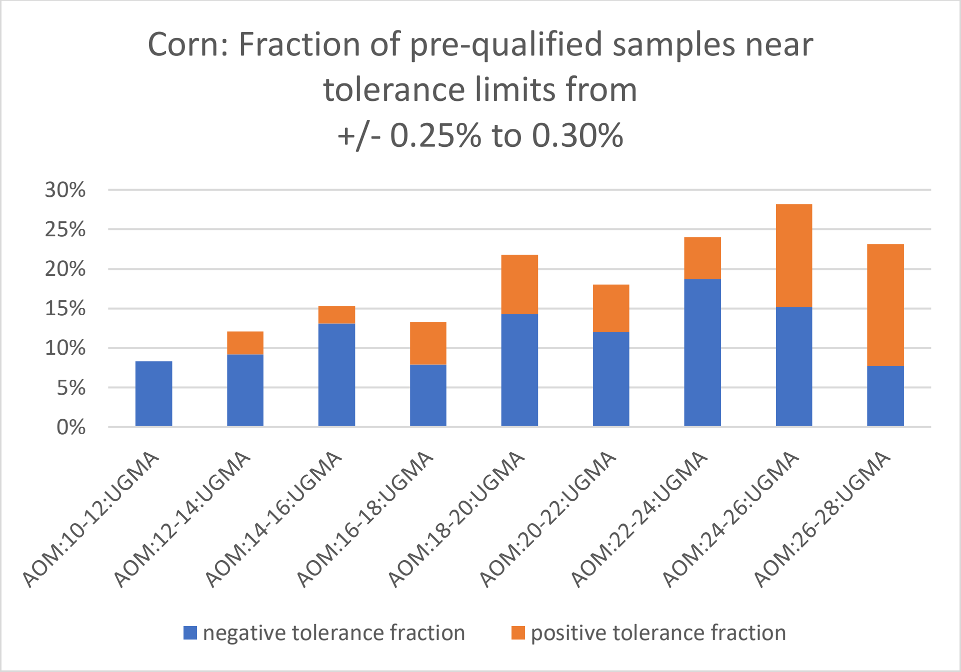

Figure 11 xxx

UGMA meters tend to have a consistent response to a given sample—in other words samples tend to have a UGMA specific “sample bias.” (Across the samples from all areas and over time periods these biases average out so that the UGMA meter is highly accurate in overall performance.) But a sample may sow such a “sample bias” that will repeat on each UGMA machine on which it is tested.

The question arises, how close will such a “sample bias” cause a UGMA to UGMA machine comparison error toward a sample tolerance limit (either low or high)?

Figure 11 xxx shows that from 12 to 15% of those pre-qualified corn samples (the percentage of those samples passing the pre-qualification test of +/- 0.3% of moisture difference from AOM on reference UGMA machine) could fall within 0.05% of moisture from that 0.3% boundary. In other words this fraction of samples will show at least a 0.25% of moisture deviation from AOM on all UGMA machines with identical calibration to the reference machine.

UGMA machines for normal distribution are calibrated to within 0.15% of AOM before leaving the factory, according to UGMA guidelines (stricter than NTEP standards). Assuming that the reference machine was high by 0.15%, and then the testing of the sample showed a “sample bias” for UGMA machines of +0.3% *relative to the reference machine used*, then we have a “stacked tolerance” of 0.45% of moisture from the AOM as would occur on a (hypothetically) highly accurate home office UGMA machine that happened to show 0% average bias.

The “standard deviation” randomness of the basic measurement process (some 8 percent of the time in the positive direction or positive tail), will cause a positive 0.07% of moisture deviation (of the average of three readings) from the mean value of a large number of such identical measurements. This probabilistic measurement error could have occurred on the reference machine when pre-qualifying the original sample. Then another such random error of 0.07% could also happen on the UGMA machine device under test, for a total of an additional 0.14%. Thus the “stacked tolerances” are up to some 0.6% of moisture, and not all factors have been considered. That all these errors occur in the same direction is becoming improbable. Assuming that the sample itself does not drift in character; we have at least the possibility that just these stacked tolerances all aligning in the same direction could cause a UGMA to UGMA sample out of tolerance event. (Sample drift in the field is a subject recommended for study, and would provide additional stacked tolerance errors.) A complete probability study, with all stacked tolerances including others not evaluated yet would be required to analyze the probability of such out of tolerance events in the field.

Figure 12 xxx shows that for Long Grain Rough Rice that the occurrence of samples in the range of 0.25% to 0.3% of moisture (+/-) is lower than for Corn samples, but is still significant for the range of samples that might be used in field testing.

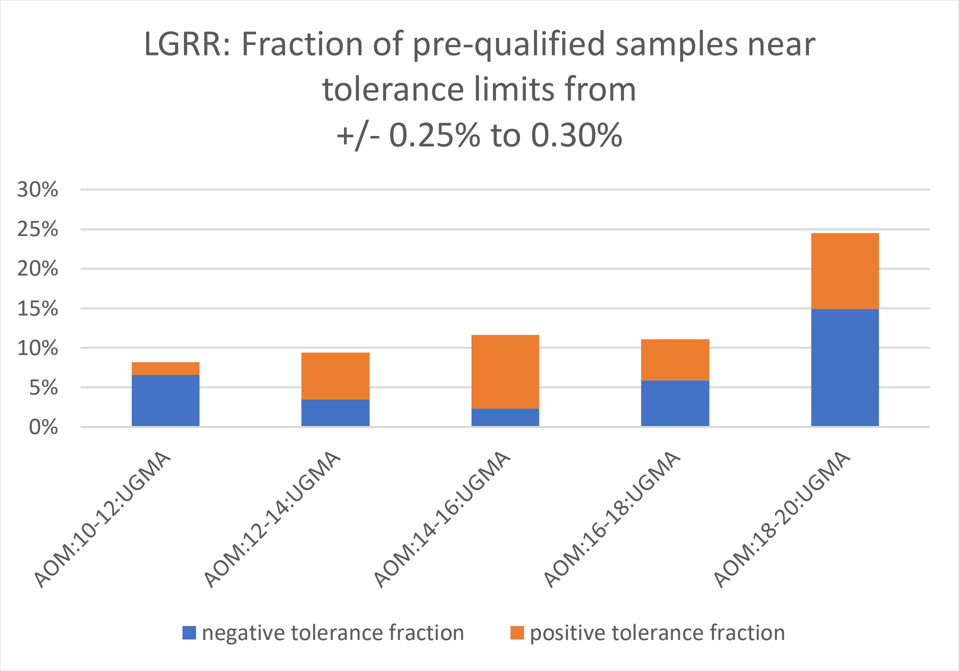

Figure 12 xxx

5.5 EFFECT ON NTEP METER TESTING

[TBD]

APPENDIX 1 – ADDITIONAL CAUSES OF DEVIATIONS IN MOISTURE TESTING

In the October 2019 Grain Analyzer Sector Summary, Ms. Diane Lee gave a quote from Dr. David Funk, whose extensive experience in the field provided a subject that the rest of us may not have thought about:

> At the temperature extremes errors in measurement are increased so the tolerances were set to account for an average error in these meters. As such, the task group should include a review of the measurements at varying temperature ranges.

Grain samples used in the field may drift in character by a small amount of moisture value. Some presentations have suggested that samples are used 10 times before retesting them.

UGMA machines have various characteristics that may drift slowly in field use. One of the two UGMA machines uses an RTD temperature sensor with large area, but that may be subject to a very slow drift. Recalibration during regular maintenance should remedy this—but the speed of drift should be analyzed to determine the required maintenance time. The other manufacturer uses an Infra-Red thermal sensor, which could be affected by accumulated material, and has taken measures to mitigate this problem. Field machines from either manufacturer may be subject to issues of accurate temperature measurement over time. A small drift in temperature error will cause a systematic bias error in moisture readings that is not observed in home office reference machines that are recalibrated every year.

Most of the dielectric moisture meters (including both UGMA meter types) use a metallic load cell to measure mass of the sample. These load cells are subject to damage if they are subjected to extreme vibration or mishandling of the equipment. The home office reference machines are kept in closely controlled conditions and are not subject to handling or vibration and are furthermore recalibrated yearly. Field machines might drift at a greater rate because of more extreme temperature and environmental conditions of regular use. The effects on UGMA tolerances may need to be evaluated by use of field collected data.

These (and other questions to be determined) may need to be evaluated to find a better estimate of the “stacked tolerances” which may occur in field testing. Then a probability analysis can show how likely those errors will “stack” in the same direction such that an out of tolerance event is caused by random variables other than the mean tolerance errors of the machines in question, and field results can show actual failure rates with the existing field conditions.

APPENDIX 2 – LIST OF GRAIN MOISTURE MACHINES IN THE NTEP DATA

All presentation of data in this report has been abstracted so that the detailed identification of specific machines has been removed. However public record shows that the eight machine types used in this study are as follows (with order completely unrelated to any data presentation):

1.	Dickey-john Corp. – GAC2500-UGMA	UGMA
2.	Dickey-john Corp. – GAC2000, GAC2100, GAC2100a and GAC2100b	Dielectric
3.	Perten Instruments Inc. - AM5200 and AM5200-A (UGMA)	UGMA
4.	Perten Instruments Inc. – IM9500 and IM9500 HLW/TW	NIR
5.	Foss North America – Infratec 1241	NIR
6.	Foss North America – Infratec Nova	NIR
7.	The Steinlite Corp. – SL95	Dielectric
8.	MTC Moisture Analyzers – MTC 999 ES	Dielectric

The GAC2500 is now listed under Foss North America in 2020 NTEP certificate, and all Perten Instruments machines are now listed under PerkinElmer Health Sciences Inc.

APPENDIX 3 – METHODS USED TO DETERMINE INDIVIDUAL SAMPLE STANDARD DEVIATION

[TBD (didn't have time)]