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# Tips on Examining the Accuracy of On-Farm Grain Moisture Meters

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## Introduction

Grain moisture content affects decisions in grain harvesting, drying, storage, handling and marketing. Using a properly calibrated moisture meter is essential to grain producers as a deviated reading would profoundly affect the choices and judgments related to this grain.

Grain moisture meters are an invaluable tool for both producers and buyers, ensuring the accurate weight and price of grain at the point of sale. This article explores several methods of measuring grain moisture, the importance of calibrating grain moisture meters, as well as some possible economic ramifications of using inaccurate or uncalibrated meters.

Water content is key to grain stability during harvest, handling, storage, and shipment, and is typically referred to as the "grain moisture content." The moisture content affects the grain's physical properties, chemical properties, dielectric characteristics, grain quantity and biological processes, as well as "storability": wet grain deteriorates faster than dry grain, due to the growth of mold.

Typically, both sellers and buyers are interested in the moisture content of the grain, because it affects weight: 50 tons of wet grain weighs the same as 50 tons of dry grain — at least at the point of sale. But this obviously spells bad news for the buyer down the road, once that grain dries out. Adhering to standardized grain moisture standards keeps the marketplace fair, for all parties involved.

Given the sheer quantities of grain being bought and sold around the world, ensuring the accuracy of grain moisture meters, as well as the use of correct metering techniques and standards, is essential. Even a small error, multiplied over hundreds of bushels, can be the difference between profit and loss.

## Methods of Measuring Grain Moisture Content

Over the past century, several methods have been developed to measure the moisture content of grains and their products. They essentially fall into one of two categories: direct methods and indirect methods (see Fig. 1).

Direct methods include the Karl Fischer technique, oven drying, vacuum, microwave drying, halogen, infrared and

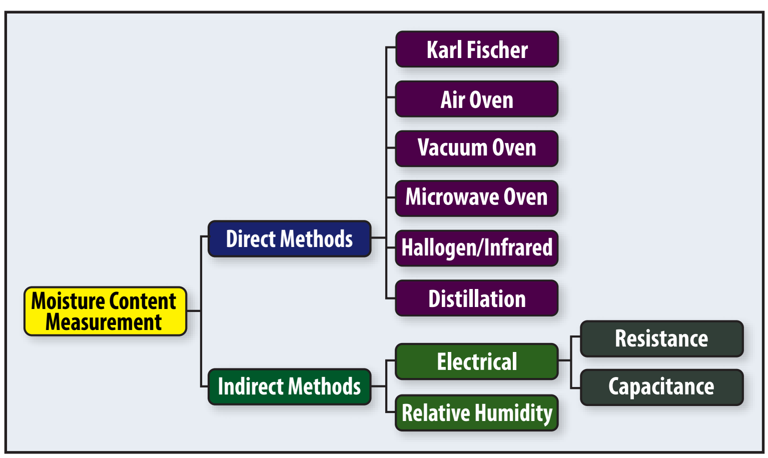


**Figure 1. Classification of some moisture content measurement methods.**

distillation methods. Indirect methods include electrical methods and the relative humidity method. These methods are described in the following section.

### Direct Methods

Direct methods usually determine the amount of water in the grain by evaporating the moisture or by a chemical reaction when water is removed, assuming the material consists only of dry matter and water. They have been used extensively in laboratories.

#### *Karl Fischer Technique*

The Karl Fischer method is the most prevalent chemical method for grain moisture determination. It can be used on virtually all solid or semi-solid materials. It has been used as the standard method against other techniques. The Karl Fischer method requires sample grinding, mixing with anhydrous methanol, filtration and titration to an endpoint with "Fischer" reagent, which contains iodine, pyridine and sulfur dioxide.

#### *Air Ovens*

The most straightforward methods of determining moisture under the grain standards of the United States are oven methods. These methods are empirical and may be subject to errors owing to decomposition.

All USDA oven methods have been intended to provide results that agree with those obtained by the Karl Fischer methods, because the Karl Fischer method gives the actual moisture content of grain.

Oven methods evaporate the water from the grain, and the moisture content is determined by the amount of weight loss. This method uses whole kernels (no grinding), in which samples of known weight are placed in a forced convection oven for a prescribed period. ASAE Standard S352.2 outlines the proper procedure for grains and oilseeds.

#### *Vacuum Oven*

Vacuum oven methods remove water from whole kernels or ground samples under very high pressure and temperature. Vacuum drying has no advantages over the air oven for cereal grains.

#### *Microwave Oven Technique*

The microwave oven technique is recommended for fast measurement of moisture in reliable food products. The sample is heated at a certain intensity for a specified time. The optimum drying time and temperature for different samples have to be determined by experimentation. This method has one major disadvantageous as the microwave energy focuses on the center of the oven, some portions of the sample may burn (oxidation) while other potions may be under dried.

#### *Halogen and Infrared Moisture Analyzers*

Grain moisture content could be determined using halogen and infrared analyzers based on the thermogravimetric principle. The sample is heated in these analyzers by an intense halogen or infrared light. The loss of moisture is displayed continuously. The advantages of these analyzers include the faster rate of heating grain and the shorter drying time than conventional or microwave drying ovens. On the other hand, the results of these analyzers are affected by the sample size, the drying temperature and the drying time.

#### *Distillation Method*

The distillation method involves removing moisture by heating sample material in a liquid solvent. The liquid solvent must have a higher boiling point than water and must be immiscible in water (meaning it won't dissolve or blend with the water). A sample material is heated in an apparatus with a hydrocarbon oil until a temperature of 190°C is reached. A 100g sample is ground in a blender, then submerged in vegetable oil and heated to 190°C. Evaporated moisture is condensed and measured in a graduated cylinder. The moisture content is calculated.

### Indirect Methods

Indirect methods measure a property of the grain that is related to moisture content. These methods have been used in the grain trade.

#### *Electrical Methods*

Electrical conductance and capacitance of grains are primarily dependent upon the moisture content of the grains, and all electronic moisture testers or meters are based on this characteristic. An electrical current element, either resistance or capacitance, is measured and then changed into moisture content reading. The meter measures the electrical resistance of grain when a current is applied between two electrodes. Grains are placed in a constant and known volume.

#### *Resistance Methods*

Electrical resistance techniques use the principle of resistance to electrical conductance. The sample is compacted by two surfaces made of a conducting material, and the conductivity of the sample has a positive relationship with the moisture content. This method has been more commonly used for forages (hay, silage) than grain.

There are some practical difficulties related to the resistance method. Low moisture content in grain has a small change in conductance readings. Increases in the grain moisture content above 23 percent result in only a small increase in conductivity. Additionally, the moisture content of the grain surface layer could determine the reading, regardless of the moisture in the interior of the grain, because the moisture distribution within the kernel is uneven.

#### *Capacitance Methods*

In the electrical capacitance technique, the grain is placed between two plates or concentric metal cylinders, and acts as a dielectric material. The capacitance method depends on the significant difference between the dielectric constants for water and dry components. Changes in the moisture content affect the capacitance reading of the meter, which could be translated to grain moisture content.

This method is not affected by the distribution of water within the grain kernels. Accordingly, it is commonly used on farms and in the grain trade, as well as for sensors of moisture-based dryer controllers. Furthermore, they can be operated over a greater moisture range and are less sensitive to the degree of physical contact with the material.

Most modern moisture meters use the capacitance principle. Capacitance meters achieve relatively uniform bulk density during loading, and automatically compensate for temperature effects. Calibration charts must be customary for each grain category. It means that a meter must be calibrated separately for all grains to obtain accurate measurements.

In this method, temperature alterations are required for accurate measurements. Fortunately, most moisture meters are equipped with temperature correction software. Accordingly, accurate measurements are obtained within a range given by the manufacturer. Outside of this range, readings have no meaning.

Several moisture meters on the market today are not capable of accurately testing grain above 90°F. So, if the grain was harvested in a cold climate, bring the sample up to ambient room temperature in a sealed container before testing. It is an important step, as condensed surface moisture causes high readings in electronic testers.

On the other extreme, excessively dry outer layers of hot grain kernels that have not yet reached ambient room temperature typically cause low readings in electronic testers. Thus, cool the sample, slowly, in a sealed container before testing.

Several factors can contribute to capacitance meter inaccuracy, relative to the air oven method of determining moisture:

1. Cracked or broken corn can lower moisture readings (drier) than sound corn by a range of 0.7 and 1.0 point under a low level of moisture content (14-16 percent).
2. Cracked or broken corn can results in higher moisture readings (wetter) than sound corn by a range of 0.7 and 1.0 point under the high level of moisture content (greater than 25 percent).
3. Various hybrids of corn can provide different moisture reading under the same cracked or broken levels.
4. The existence of mold can increase the moisture meters' readings.
5. Meter measurements can shift up to 0.7 points, compared to the oven, from one year to the next.
6. Extremely cold samples can result in lower moisture readings, and warm samples can result in higher moisture readings, except if the measurement is temperature-compensated.
7. For meters with external scales, a one-gram weighing error can produce a 0.10 – 0.15 point test error; large samples read wet and conversely.
8. Grain samples colder than room temperature can experience condensation and provide inaccurate moisture readings.

### *Relative Humidity Methods*

Several categories of hygrometers are used to quantify the relative humidity of the air surrounding the grain. The relative humidity in the air is dependent on the grain moisture content. These meters require one to two hours to reach equilibrium before dependable measurements can be obtained. The correctness of moisture determination measurement requires the even distribution of moisture through the sample.

## On-farm Grain Moisture Meters

On the farm, typically four types of grain moisture meters can be found including:

- **Yield monitor:** moisture meters typically included in yield monitors to adjust grain yield.
- **Portable units:** This type looks typically like a cup (Fig. 2) that could be easily carried; however, these units are not the most reliable. Portable capacitance meters, like those used on farms, are about 1.5 to 2.0 times as variable as tabletop meters used in trade, at the same moisture content.

**Figure 2. DICKEY-john Mini GAC® 2500**


**Figure 3. DICKEY-john GAC 2100**


**Figure 4. Perten AM 5200-A**


**Figure 5. Perten Inframatic 8800 NIR**

**Figure 6. Digistar Moisture Tracker**

**Examples of On-farm Grain Moisture Meters**

- **Tabletop units:** Several types of these units are available in the market (Figs. 3 and 4). These types compete in their accuracy and features used by commercial grain companies. It should be mentioned that the moisture content readings are affected by grain packing density and temperature.
- **Portable NIR units:** These units allow greater flexibility for use. Fig. 5 illustrates an example of one such unit. Some NIR units, are designed to be used for various forages and coproducts but are not yet calibrated to be used for whole grains (see Fig. 6). Accordingly, it is therefore crucial to making sure that moisture meter is calibrated for the intended grain.

## Accuracy and Precision of Grain Moisture Meters

Accuracy is defined as "the degree of the nearness of value to the correct or accurate value," whereas precision denotes to the repeatability of a measure. Both are important in evaluating the results of moisture determinations.

A device's bias often represents its accuracy; i.e., the mean of the differences between the measured values and the real value. Bias is often interpreted to represent a constant systematic error that is not expected to change. More than 90 percent of random variations are caused by the grain, not the meter. Better circuitry in meters will only add user features, not reduce errors or improve accuracy.

## Suitable Grain Sampling

Producers regularly sample their grain for moisture content determination since it is typically unreasonable to analyze an entire lot. The accuracy of any moisture determination is first dependent upon having a representative sample — i.e., one that possesses the same properties as the lot from which it is drawn. "Hand-grab" or "scoop" samples are rarely representative, although samples taken by hand can be representative if a suitable sampling method is used.

Three things should be considered to ensure that any sample is representative: (1) appropriate equipment, (2) multiple samples and (3) careful sample handling. Hand or mechanical probes are used to draw a pure "core" from the material at rest. Hand or automatic (mechanical) diverters are used to collect samples at intervals from flowing material. Subdividing samples should be done with a Boerner divider or other similar mechanical device so that the sub-samples are also representative.

A single drawn sample cannot fairly represent the entire lot, especially if there is moisture variability throughout the lot. Combining multiple samples helps overcome this variability throughout the lot. Combining multiple samples helps overcome and average this variability. A random sampling at different locations and intervals also helps eliminate systematic biases. Sample handling procedures should deliver the sample unchanged for analysis — rough handling can cause sample degradation or loss.

Clean and appropriate containers should be used, and storage conditions should minimize changes in moisture due to microbial respiration, or exchange of moisture with the surrounding environment. For safe storage, it is essential to know the highest moisture content in any portion of the stored grain mass, at any location, and at any given time. Additionally, both insects and fungal activity can significantly increase the moisture content of stored grain over time.

## Instructions to Maintain, Inspect and Calibrate Grain Moisture Meters

One of the principal concerns when measuring grain moisture readings is to make sure that the meter is calibrated, so you get accurate readings. When a meter is not calibrated, producers may get erroneous results—and being just one or two percentage points off can have a significant impact on the quality of your work. Therefore, being able to check moisture meter calibration and ensuring accuracy is crucial. Since not all moisture meters are the same, it is essential to know about the different methods of checking available meter calibration. As mentioned earlier, moisture meters are the devices of the trade, employed to determine quantities in a legal sense.

Like all equipment, moisture meters are subject to failure and wear. Therefore, inspection and certification programs are needed to maintain accuracy, even for well-calibrated meters. These programs are managed by either federal or state agencies. Their purpose is to identify defective, out-of-service meters and to assure that meter operators are using the latest calibrations.

Moisture meters owned by the Federal Grain Inspection Service (FGIS) or its licensed designates are calibrated, maintained and inspected by FGIS. Calibration is done at a central laboratory. Inspections of meters in field service are made with a set of standard samples. FGIS field offices check meters used by their licensed designates using the certified field office meter as the reference.

Moisture meters used and approved by the FGIS follow the guidelines and regulations in "Handbook 44," published by the National Institutes of Standards and Technology and must be NTEP (National Type Evaluation Program) certified. The requirements spelled out by Handbook 44 specifications can be summarized as follows:

- Only the National Type Evaluation Program meters can be used for commercial purposes after Jan. 1, 2003.
- The meter must be entirely automatic. Pre-weighing of the grain sample by the operator has to be avoided. No manual adjustment for temperature or density is permitted, and there shall be no manual balancing or calibrating of the meter before its usage.

- The meter must be capable of printing the ticket or recording the test results. This printed ticket can be handed to the customer.
- The meter must have the capability of being sealed so that its calibrations can only be accessed by permitted personnel.
- The meter must indicate that the moisture reading is beyond the operating range of the calibration and must not display any moisture reading at all.

Moisture meters used in trade, not subject to the U.S. Grades and Standards (e.g., meters at local elevators), are inspected by state governments. Individual states decide whether to follow the regulations in Handbook 44 or not. Users must rely on government inspection to keep meters accurate.

The two most prevalent state inspection programs are the natural grain and meter-to-meter inspections. A natural grain program compares the readings of the meter being tested with the air oven results. Natural grain programs typically use a tolerance of ±0.04 times moisture value for corn inspections.

"Tolerance" is the maximum difference between the inspected meter reading and the assumed moisture content. Whereas a meter-to-meter program compares the readings from the meter being tested to a calibrated meter used by the inspector, samples are typically re-tested in the inspector's meter at least daily. The meter-to-meter programs typically use a tolerance of ±0.5 points up to 22 percent moisture and ±1.0 point above 22 percent. Few inspections, by either method, can be made above 22 percent because samples cannot be preserved effectively.

## Remarks

- Water remains a vital constituent affecting grain stability during harvest, handling, storage and shipment.
- Grain moisture content affects grain storability because wet grain deteriorates faster than dry grain due to molding.
- Buyers seek to adhere to their set moisture standards for grains being contracted.
- It remains essential to quantify and correct any resultant errors through proper calibration of moisture meters to improve grain handling and management decisions and to ensure maximum returns to farmers and stakeholders.
- Most moisture sensors operate on the principle that electric resistance is directly correlated with moisture content.
- Any changes in plant material moisture content often affect sensor outputs through changes in volume and density. Such changes must be corrected through calibration, especially when measuring grain with lower moisture content.
- Performing accurate and fast moisture content measurements are of critical value to agricultural, manufacturing, processing, storage and shipping operations.
- A significant challenge is a need for calibration for different types of grain and the non-transferability of grain moisture content calibrations across instruments.
- It remains highly critical for grain handlers to know, fairly and within close margins, the MC of all portions of the grain matrix under their care.

## References


Broker, DB, FW Bakker-Arkoma, and CW Hall. 1992. *Drying and Storage of Grains and Oilseeds.* Van Nostrand Reinhold, New York, NY.

Csiba, M., Kovács, A. J., Virág, I., & Neményi, M. (2013). *The most common errors of capacitance grain moisture sensors: effect of volume change during harvest.* Precision agriculture, 14(2), 215-223.

Jafari, F., Khalid, K., Yusoff, W. D. W., & Hassan, J. (2010). *The analysis and design of multi-layer microstrip moisture sensor for rice grain*. Biosystems Engineering, 106(3), 324-331.

Kandala, C. V., & Sundaram, J. (2010). *Nondestructive measurement of moisture content using a parallel-plate capacitance sensor for grain and nuts.* IEEE sensors journal, 10(7), 1282-1287.

Nelson, S. O., Trabelsi, S., & Kraszewski, A. W. (1998). Advances in sensing grain moisture content by microwave measurements. Transactions of the ASAE, 41(2), 483.

Sauer, DB, editor. (1992). *Storage of Cereal Grains and Their Products*. Fourth edition. American Association of Cereal Chemists, St. Paul, MN.

Storage of Cereal Grains and Their Products: 5th Ed. (2020). The significance of Grain Moisture and Its Measurement Sammy Sadaka and Kurt A. Rosentrater.

Thompson, JF, and RG Mutters. (2001). *Maintaining Rice Quality after Harvest*. In: Annual Comprehensive Rice Research, University of California. Published by the California Rice Research Board.

Trabelsi, S., Nelson, S. O., & Lewis, M. (2008). *Microwave moisture sensor for grain and seed.* Biological Engineering Transactions, 1(2), 195-202.





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