# Rapid Proximate Method for Determining Moisture Content of Single Kernels of Corn[1]

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**ABSTRACT**

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An instrument for determining the moisture content of single kernels of corn was designed and built. The instrument, like the Tag-Heppenstahl moisture meter, uses the principle of electrical conductance, but it is equipped with smaller rolls designed for passage of single kernels and has a more sensitive electrical system. Tests show that ammeter response and moisture content determined by oven drying are significantly related (r = 0.97 and syx = 0.89). Using the instrument, we showed that moisture in blends of low and high moisture corn equilibrated in two to three days. In corn inoculated with *Aspergillus flavus*, rate and amount of mold growth were greater in blends with high than in blends with low mean moisture contents.

Presently available instruments for determining the moisture content of grains require large samples (eg, 250 g) and yield values that are necessarily averages for all kernels in a sample. Conductance type moisture meters are based on the conduction of an electrical current through the grain. For example, with the Tag-Heppenstahl moisture meter, the grain is passed through a pair of steel grinding rolls and the voltage measured is directly related to the moisture content of the grain. This instrument was used by the U.S. Department of Agriculture as a standard procedure for measurement of grain moisture before the adoption of the Motomco meter, which is based on the measurement of the electrical capacitance of the grain.

Christensen and Kaufmann (1974), who reviewed grain storage and the role of fungi in deterioration of grain, considered high moisture content to be the chief cause of the contamination of grains by molds. Johnson et al (1969) showed that levels of aflatoxin were high in some samples and nonexistent in other adjacent samples of corn. Such scattered pockets of contamination could occur if equilibration of mixtures of high and low moisture corn proceeds slowly enough to allow molds to grow on high-moisture corn.

Preliminary single-kernel moisture determinations conducted by R. M. Johnson at the Agricultural Research Center, Beltsville, MD, 1957 revealed that the Strand sedimentation mill had limitations possibly related to kernel size and that results were inaccurate above 20% moisture content. The Battelle Memorial Institute, Columbus, OH, was awarded a contract to design and develop, to our specifications, an instrument capable of measuring moisture content to approximately 40% in single kernels of corn.[3] The instrument is based on the measurement of electrical conductance.

We report the design and accuracy of the instrument and the results of experiments on equilibration of moisture in corn.

[1] Mention of a trademark name or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply approval to the exclusion of other products that also may be suitable.

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[3] J. M. Harris, J. S. Glasgow, J. R. Thompson, and C. A. Watson. Unpublished data, 1969. Development of a moisture content instrument to measure moisture content and distribution in a grain sample. Contract No. 12-19-100-8948(51) with Market Quality Research Division, ARS, USDA, and Battelle Memorial Institute, Columbus Laboratories, Columbus, OH.



## MATERIALS AND METHODS

In preliminary studies the Strand mill was connected to a high-speed recorder and was supplied with sufficient power from a regulated source to give a reading of 100 units for corn kernels with 25% moisture content. When kernels with moisture content lower than 25% passed through the rolls, they resisted the flow of current and current peak height dropped proportionately. The roll speed was 30 rpm and the single kernels of corn were dropped through the rolls at 0.10-in. intervals. Twenty-six samples of field corn with natural 10–25% moisture were shelled and 42 kernels were randomly selected from each sample to evaluate the above system. Peak ammeter response for each kernel was recorded and compared with oven moisture content. Each kernel was then placed in an oven at 103°C for 72 hr; oven moisture thus obtained was correlated with peak ammeter response. To determine if kernel size affected the instrument measurements, kernels were separated into two groups (large and small) and tested.

Through a contract with Battelle Memorial Institute, a conductance type meter similar to the Tag-Heppenstahl device, but designed to test single kernels, was built (Fig. 1). The rolls are about one-third the size of those of the Tag-Happenstahl; ie, 2 in. in diameter and 1.25 in. long, and the idler roll is attached by a spring that gives the rolls freedom to adjust to different size kernels. The rolls are connected to a logarithmic amplifier that converts the natural logarithmic response into a more useful linear response. The schematic of the instrument is shown in Fig. 2. The 100 V passing through the rolls is reduced by a series of resistors so that the signal reaching the recorder is 100 mV, and when the rollers are shorted, the peak ammeter response is 100 units. Subsequent tests showed that the response reached this for kernels with about 25% moisture.

To determine the accuracy of the instrument, we tempered 100-g samples of well-blended, dockage-free corn lots with 12–26% moisture at 2% increments and allowed them to equilibrate for five days in a refrigerator. Samples were brought to room temperature, and 10 kernels from each were chosen at random and dropped into the moving rolls of the device. Plastic gloves were used when touching the kernels, and a plastic rod was used to aid passage of the largest kernels through the rolls. Each kernel was then placed in a weighed crucible and the moisture content determined by the air-oven method of 103°C for 72 hr.

To study the rate of moisture equilibration in a mixture of low and high moisture corn, we selected 10 kernels from each moisture level (80 kernels total) and enclosed them in an airtight container. The samples were shaken and stored in a refrigerator. From each mixture, 10 kernels were tested on days 0, 1, 2, 3, 4, 7, and 8.

We prepared approximately 3,000-g samples of four blends, in duplicate, of white and yellow corn as shown in Table I. Blends 1 and 2 each had moisture contents of about 16%; blends 3 and 4, 18%. The samples were stored at 28°C, and after each 24-hr storage period, a portion was separated into white and yellow components.

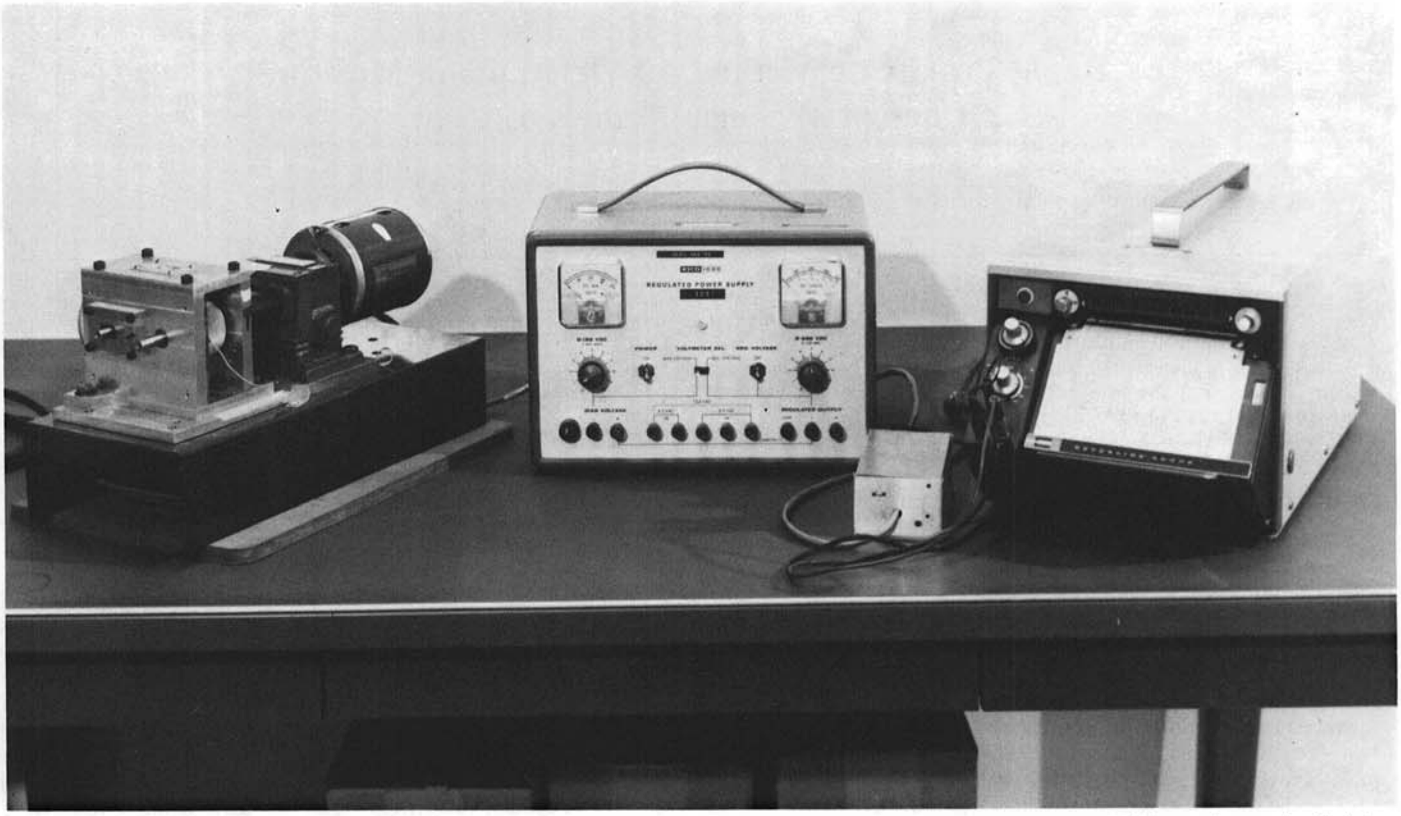

Fig. 1. Instrument for determining moisture content of single kernels of corn with rolls (left), power supply (center), and high-speed recorder (right).

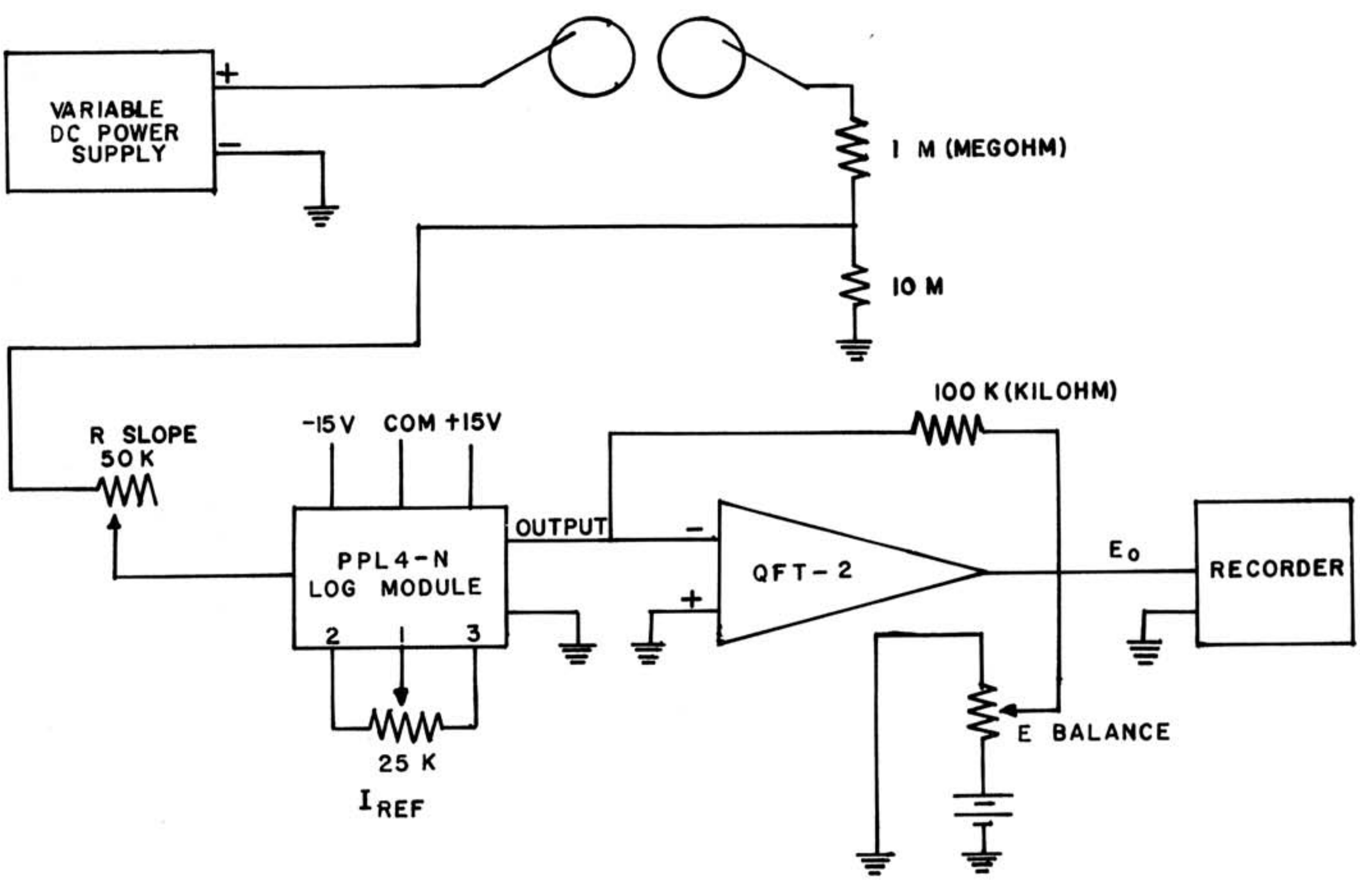


Fig. 2. Electrical schematic of the instrument for determining moisture content of single kernels of corn. The PPL4-N log module and the QFT-2 are manufactured by Teledyne Philbrick.

We analyzed 10 kernels selected at random from each component, first on the conductance meter and then by the oven method. We inoculated portions of the blends with spores of *Aspergillus flavus*, incubated them at 28°C, and examined them daily for several days.

## RESULTS AND DISCUSSION

We compared the moisture contents of 1,092 single kernels of corn as determined by the ammeter response of the Strand sedimentation mill and by oven drying. The coefficient of correlation was 0.93 and the standard error of estimate 1.55%. A plot of the data showed that kernels with more than 20% moisture read higher per unit ammeter response than those less than 20% moisture. We attributed this to limitations in the electrical system of the device. When kernels were separated by size into two groups (large and small) and then tested, the difference in peak ammeter response vs. moisture content determined by oven drying between the size groups was significant.

Considerable research was done before the design of the instrument described above and shown in Fig. 1 was finalized. The variable roll-spacing effect was incorporated to reduce errors caused by various sized kernels. Originally, the system used a multiple channel recorder that counted the number of kernels within predetermined moisture ranges. However, we incorporated the electronic system described that provides moisture data on individual kernels, but we recognize the electrical limitations of the system.

The accuracy of this system is much better than that of the system using the Strand Mill and was therefore used in all subsequent studies. Data on 60 single kernels of corn comparing peak ammeter response with oven moisture content at 16–26% moisture levels in 2% increments gave a correlation coefficient of 0.97 and a standard error of estimate of 0.89%.

Data on the rate of equilibrium of moisture in a blended corn sample comprising 10 kernels at 12, 14, 16, 18, 20, 22, 24, and 26% moisture content are shown in Table II. Among the eight days, mean moisture content ranged from 21.2 to 22.7% by oven drying and from 21.7 to 23.4% by the conductance method. Both the standard deviation and coefficient of variation for peak ammeter response declined until day 4 and then stabilized, indicating that the moisture in the blend had reached equilibrium.

Data for the yellow and white corn blends after 1 and 6 days of equilibration are shown in Tables I and III. On day 1, the high and low moisture components had much different moisture contents (Table I), but by day 6 they had converged. There was close agreement of moisture contents as determined by the two methods. The coefficients of correlation (Table III) of moisture content determined by the two methods were highly significant, and the standard deviations of peak ammeter response were low. Equilibration took place fairly rapidly and was essentially complete on day 2.

Mean moisture content of blends varied somewhat from the intended 15 and 17%. Rate and extent of mold invasion were most closely related to actual mean moisture content of the blend rather than to the initial moisture contents of the components. For example, corn with an initial moisture content of 11% in a blend with an average moisture content at equilibrium of 17% had more mold growth than corn with an initial moisture content of 24% in a blend with an average moisture content at equilibrium of 16%. Thus, rapid equilibration in uniformly commingled low and high moisture corn apparently offsets the vulnerability of high moisture kernels.

**TABLE I**
**Comparison of Moisture Contents Determined by Oven Drying and Conductance Method on the Components of Four Blends of Corn after One and Six Days of Equilibrium[a]**

| | | Equilibrated 1 Day | | | Equilibrated 6 Days | | |
|---|---|---|---|---|---|---|---|
| | | Conductance Method[b] | | | Conductance Method | | |
| Corn Blends | Moisture Content (%) | Range | Mean | Oven Method (%) | Range | Mean | Oven Method (%) |
| White | 24 | 15.8–21.3 | 17.9 | 18.9 | 14.9–17.3 | 16.6 | 16.8 |
| Yellow | 11 | 14.3–16.7 | 15.9 | 16.2 | 14.3–17.6 | 16.5 | 16.7 |
| Yellow | 24 | 15.7–21.6 | 18.7 | 18.9 | 15.6–18.4 | 17.6 | 17.6 |
| White | 11 | 14.3–17.3 | 15.5 | 16.5 | 14.8–17.7 | 16.3 | 16.9 |
| White | 18 | 15.6–18.6 | 17.1 | 17.8 | 15.4–17.8 | 16.9 | 17.4 |
| Yellow | 11 | 14.6–16.6 | 16.0 | 16.4 | 15.1–17.3 | 16.9 | 16.9 |
| Yellow | 18 | 15.6–18.1 | 17.1 | 17.3 | 15.6–17.4 | 16.9 | 16.9 |
| White | 11 | 14.4–16.4 | 15.2 | 16.3 | 14.6–16.8 | 15.9 | 16.5 |

[a] Average of replicates.
[b] Calculated from the regression equation as shown in footnote for Table II.

**TABLE II**
**Average Moisture Contents and Ammeter Responses for 10 Kernels of Corn Selected Each Day from a Blend Having Original Moisture Contents Ranging from 12 to 26%**

| | Time of Equilibration (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 7 | 8 | Av. |
| Average moisture (%) by oven method | 22.7 | 21.9 | 21.2 | 22.2 | 22.3 | 22.1 | 22.4 | 21.9 |
| Average moisture (%) by peak ammeter response[a] | 22.1 | 22.2 | 21.7 | 22.5 | 23.4 | 22.6 | 23.1 | 22.5 |
| Peak ammeter response | | | | | | | | |
| Mean | 61.9 | 63.2 | 58.3 | 65.2 | 73.2 | 66.3 | 71.2 | 65.6 |
| Standard deviation | 24.8 | 15.1 | 13.6 | 7.6 | 4.4 | 3.9 | 3.9 | 5.2 |
| Coefficient of variation | 40.1 | 23.9 | 23.3 | 11.6 | 6.0 | 5.9 | 5.5 | 7.9 |

[a] Derived from the regression equation $\hat{Y} = 15.3 + 0.11X$ where $\hat{Y}$ = moisture content and X = peak ammeter response.

**TABLE III**
**Statistics of Moisture Equilibration in Yellow and White Corn Blends as Measured by Oven Drying and Conductance Moisture Methods**[a]

| Statistic | Time of Equilibration (days) 1 | 2 | 3 | 6 |
|---|---|---|---|---|
| Peak height vs. oven moisture | | | | |
| n | 32 | 32 | 32 | 32 |
| r | 0.94** | 0.99** | 0.99** | 0.96** |
| syx (%) | 0.43 | 0.03 | 0.03 | 0.12 |
| Regression equation | $\hat{Y} = 14.3 + 0.14X$ | $\hat{Y} = 15.3 + 0.12X$ | $\hat{Y} = 15.3 + 0.11X$ | $\hat{Y} = 15.4 + 0.11X$ |
| Moisture content | | | | |
| Oven method | | | | |
| mean (%) | 16.4 | 16.1 | 16.2 | 16.3 |
| sd (%) | 1.2 | 0.8 | 0.7 | 0.6 |
| cv | 7.3 | 5.0 | 4.3 | 3.7 |
| Conductance method (peak height) | | | | |
| mean (%) | 14.5 | 11.9 | 11.7 | 11.5 |
| sd (%) | 3.4 | 2.8 | 2.6 | 2.7 |
| cv | 23.4 | 23.5 | 22.2 | 23.5 |

[a] n = number of samples (20 kernels tested per sample), r = coefficient of correlation, syx = standard deviation of regression, sd = standard deviation, cv = coefficient of variation, $\hat{Y}$ = oven moisture content, and X = peak height.

## SUMMARY


An instrument is described for determining the moisture content range in corn samples. Because of the speed with which a single determination is made, mean values for 10 or more kernels can be computed rapidly, thus providing an extensive data base quite rapidly. The instrument developed for laboratory research to obtain information on moisture ranges and equilibration rates in stored corn appeared to be adequate for these purposes.


### ACKNOWLEDGMENTS


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