RANDOM VARIATION IN MEASUREMENT OF CORN GRADE FACTORS

T. E. Elam
Department of Agricultural Economics
University of Illinois
Urbana-Champaign

L. D. Hill
Department of Agricultural Economics
University of Illinois
Urbana-Champaign

Submitted for the
Contributed Papers Session
1976 Summer Meetings of the
American Agricultural Economics Association
August 15-18, 1976
The Pennsylvania State University

RANDOM VARIATION IN MEASUREMENT OF CORN GRADE FACTORS

Abstract

The U.S.D.A. grain grading system has drawn considerable attention due to allegations of misgrading. An analysis of the potential role of random error in the grading system is presented. It is concluded that random variation may be a major cause of changes in grain grades under conditions of repeated sampling.

The General Accounting Office (GAO) recently released a report on its investigations of the U.S. grain grading system. Contained in this document are findings to the effect that the current grain marketing system is susceptable to fraud and cheating. Numerous instances of shortweighing, deficiencies in examinations of grain hauling vessels, incorrect sampling procedures, and errors in determining correct grades under U.S.D.A. standards (pp. iv-v). The purpose of this paper is to explore certain aspects of difficulties encountered in determining grain, and particularly corn, grades under current U.S.D.A. regulations.

Current U.S.D.A. Grade Standards for Corn

As shown in Table 1, U.S.D.A. (1975) has established five factors which determine the grade of corn. Also shown in this table, there are a number of other factors which would result in classifying a sample of corn as "sample grade." There are similar standards for all U.S. grains which are traded in any significant quantity.

Test weight was introduced into the standards as a measure of grain density and the numerical values are based on the weight of a Winchester bushel. Actual determination of test weight uses a standard 1 quart container in conjunction

Table 1: Grades and Grade Requirements for Corn

Grade	Minimum test weight per bushel	Maximum limits of-- Moisture	Broken corn and foreign material	Damaged kernels: Total	Heat-damaged kernels
	Pounds	Percent	Percent	Percent	Percent
U.S. No. 1----	56.0	14.0	2.0	3.0	0.1
U.S. No. 2----	54.0	15.5	3.0	5.0	.2
U.S. No. 3----	52.0	17.5	4.0	7.0	.5
U.S. No. 4----	49.0	20.0	5.0	10.0	1.0
U.S. No. 5----	46.0	23.0	7.0	15.0	3.0
U.S. Sample grade.	U.S. Sample grade shall be corn which does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 5, inclusive; or which contains stones; or which is musty, or sour, or heating; or which has any commercially objectionable foreign odor; or which is otherwise of distinctly low quality.				

Source: U.S.D.A, The Official United States Standards for Grain, December, 1975, p. 2.3.

with a scale calibrated to read in pounds per bushel. Because this measure is greatly affected by packing characteristics of the corn kernels, it is not a reliable measure of kernel density. Research has demonstrated a lack of correspondence between test weight and feeding value and there is no published data indicating that test weight is related to value of end products in the wet milling industries. (Hill and Hall)

Moisture meters that measure electrical properties of corn are approved by the U.S.D.A. as an acceptable substitute for the more reliable, but slower, oven method. Moisture is important as an indicator of storability (Hill and Shove) and as a means of adjusting total weight of corn and water to a weight and value based on a standardized moisture. The 15.5 percent base used in the grain trade is generally not a safe storage level, but since No. 2 corn at 15.5 percent is the basis for price blending of different moistures it is frequently used to maximize income.

Broken corn and foreign material (BCFM) is determined by passing corn over a screen of specified size. All particles passing through the screen plus any foreign material hand picked off the top are weighed against the original, unscreened, sample to determine percentage BCFM. This factor is quite important to corn processors since many corn-based products cannot be manufactured from corn particles below a certain size. Also, broken kernels are more susceptable to disease and insect attacks. However, since cracked corn is included with all other types of foreign material, this factor does not provide a reliable measure of value.

Total and heat-damaged kernels are determined on the basis of visual inspection and judgement. Whole kernels classified as damaged and heat-damaged are weighed against the original sample to determine the percent of damaged and heat-damaged kernels. Heat-damaged kernels are included with other damaged kernels in determining the percent of total damage. Damaged kernels are indicative of a number of possible problems with corn, while heat-damage generally can be taken as an indication of corn which has been stored without proper drying or dried at excessively high temperatures. Both total and heat-damage detrimentally affect the nutritional quality of corn. Also, heat-damage is quite serious for both wet and dry millers and distillers due to the dark color of corn kernels that have been exposed to excessive heat.

Potential Sources of Grain Grading Errors

There are a number of sources of error in determination of grain grades under U.S.D.A. sampling and measurement standards. There is the possibility of outright fraud--purposefully recording false information on measurements of grade factors. There are, however, well established, inexpensive, and often-used avenues for appeal of grade determination. These appeal rights mitigate against the likelihood of blatantly fraudulent grade determinations.

Secondly, there is the possibility of clerical errors in recording measurements on grade factors from the thousands of grain samples graded annually. Again, the right of appeal should mitigate against this type of error as a serious source of problems in the grain industry.

Also, there is the possibility of inaccurate calibration of weighing and moisture measurement devices which might affect grade determination. In addition, the determination of damaged and heat-damaged kernels is to an extent a subjective matter, depending in borderline cases on the judgement of the inspector.

Finally, there is a variability in the grade determination process which is independent of any of the above-mentioned factors. Namely, there is a problem of variability inherent in any procedure which bases the determination of population characteristics on measurement taken on a sample from that population. Such variability is definitely present in U.S.D.A. grain grading procedures.

Considerations of efficiency require that nowhere near the total U.S. grain crop inspected for sale be actually examined by an inspector. Determination of grade is, under ordinary circumstances, made on the basis of a quite small sample. In a typical truckload of 20 tons of corn, five probes of 400-600 grams each might be taken for purposes of inspection. The probes are composited and randomly reduced 1000 grams which is actually inspected. This 1000 gram sample is further reduced to 250 grams for determination of moisture and damage, for a sampling rate of .00138 percent. With a sampling rate of this magnitude, it would not be surprising if there were some variability in grade determination based on sampling variability alone. As the following portions of this paper will show, this is indeed the case.

Sampling and Random Variability in Determination of U.S.D.A. Corn Grades

Sampling variability arises from two distinctly different sources, sampling errors and random variation. In order to be an unbiased representation of the population characteristics, a sample must be drawn on a random basis. In addition, if the rate of sampling is low, as in grain inspection procedures, the population must be fairly homogeneous if samples are to accurately refect population characteristics.

However, even assuming that samples are taken on a random basis from a homogeneous population, there remains a degree of pure randon variability. This latter source of variability is directly related to the amount of variation in the population and inversely related to the sampling rate. Thus, even under ideal circumstances, repeated sampling from a homogeneous population of corn (or any grain for that matter) on a random basis with accurate measurement and reporting of grade factors, will not necessarily result in identical measurements on those factors.

Random Variation in the Corn Heat-Damage Factor

To illustrate the degree to which measurements of U.S.D.A. grade factors are subject to random variation, a simulation was run on heat-damage in corn. This particular factor was chosen primarily because of a high degree of randomness relative to grade requirements associated with its measurement and because the range between grades is quite small.

Thus, results discussed below should not be taken as representative of the degree of random variation in all corn grade factors. U.S.D.A. estimates of the amount of randomness in determination of all corn grade factors are discussed in the next section of this paper.

The simulation was run under the assumption of a random sample drawn from a population containing a uniform distribution of heat-damaged corn kernels. Under U.S.D.A. guidelines such a sample would be drawn in three stages. First, a master sample is taken using one of two methods--by probing or a random sampling device which diverts a portion of the corn as it is being transferred into or out of an elevator. Secondly, the master sample is randomly divided into a 1000 gram sub-sample. This 1000 gram sub-sample is further divided into a 250 gram sub-sample on which the measurement of heat-damage is based.

Thus, an element of random variation enters at two points--where the master sample is drawn and at the point of further division into a 250 gram sub-sample. The appropriate sampling distribution for the master sample is the binominal, while the hypergeometric distribution is appropriate for the smaller sub-sample (Lapin) (See Appendix).

Probabilities for identification of U.S.D.A. grades on the heat-damage factor in corn for both a 1000 gram master sample and a 250 gram sub-sample given initial conditions of various percentages of heat-damage are shown in Tables 2 and 3. Entries in Table 2 are interpreted as probabilities of an entire 1000 gram master sample from a homogenous population of corn falling into U.S.D.A.

Table 2: Probability of Grade Variation on Heat Damage in a 1000 Gram Master Sample of Corn Due to Random Chance [a/]

Percent of heat damage in the Population	Actual Grade	Probability that a 1000 g. master sample will be graded on the basis of heat-damage					
		No. 1	No. 2	No. 3	No. 4	No. 5	Sample
.05	1	.928	.071	.001	.000	.000	.000
.10	1	.626	.336	.038	.000	.000	.000
.15	2	.318	.494	.188	.000	.000	.000
.20	2	.135	.441	.424	.001	.000	.000
.25	3	.050	.296	.648	.006	.000	.000
.30	3	.017	.164	.791	.028	.000	.000
.35	3	.006	.080	.831	.084	.000	.000
.40	3	.002	.035	.779	.184	.000	.000
.45	3	.000	.014	.662	.324	.000	.000
.50	3	.000	.005	.513	.481	.000	.000
.55	4	.000	.002	.366	.630	.001	.000
.60	4	.000	.001	.242	.752	.005	.000
.70	4	.000	.000	.086	.880	.034	.000
.80	4	.000	.000	.024	.850	.125	.000
.90	4	.000	.000	.006	.695	.299	.000
1.00	4	.000	.000	.001	.478	.521	.000
1.50	5	.000	.000	.000	.006	.993	.001
2.00	5	.000	.000	.000	.000	.999	.001
2.50	5	.000	.000	.000	.000	.996	.004
3.00	5	.000	.000	.000	.000	.491	.519
3.50	sample	.000	.000	.000	.000	.058	.942
4.00	sample	.000	.000	.000	.000	.001	.999
5.00	sample	.000	.000	.000	.000	.000	1.000

[a/] Based on an average kernel weight of .323 grams per kernel or 3096 kernels in a 1000 gram sample.

grades 1-5 on the basis of heat-damage, given various percentages of heat-damaged kernels in the population. Thus, if the population contains .15 percent heat-damage, the midpoint of the #2 range of .1 to .2 percent, there is a .494 probability of the master sample grading #2 and a .516 probability of a grade other than #2.

Entries in Table 3 show the probabilities for a 250 gram sub-sample of the 1000 gram master sample falling into U.S.D.A. grades 1-5 on the basis of heat-damage. Thus, if a 1000 gram sample were to contain .161 percent (or 5) heat-damaged kernels, a percentage which would place the sample approximately in the center of the #2 grade range, the probability of a 250 gram sub-sample grading #2 is .396. Thus, in this instance there is a .614 probability that the 250 gram sub-sample would be assigned a different numerical grade on heat-damage than would the entire 1000 gram sample.

Obviously, the relevant question concerns the degree of randomness inherent in the overall process. To measure this, it was assumed that the 250 gram sub-sample actually graded was drawn directly from a homogeneous population of corn. Thus, the binomial distribution was used for the determination of these probabilities. Results are shown in Table 4. As would be expected, for a given amount of heat damage in the population, the overall probability of correct grade identification on the basis of heat damage falls between the probabilities shown in the preceding two tables.

Examining Tables 2-4, two conclusions are obvious. For grades 1-3, determination of correct grade for the heat-damage factor in corn on the basis of a 250 gram sample is at best risky. This is a function of both the small size of the sub-sample and the extreme narrowness of the grade definitions. Secondly, as would be expected, near the break points of all five of the grades, determination of grade on the basis of heat-damage could as well be done by flipping a coin as by grading the sub-sample. This particular feature is not peculiar to

Table 3: Probability of Grade Variation on Heat-Damage in a 250 Gram Sub-Sample of a 1000 Gram Master Sample of Corn Due to Random Chance[a/]

Percent of heat damage in the 1000 Gram Sample	Actual Grade of 1000 Gram Sample	Probability that a 250 g. sub-sample will be graded on the basis of heat-damage					
		No. 1	No. 2	No. 3	No. 4	No. 5	Sample
.032	1	.750	.250	---	---	---	---
.097	1	.422	.422	.156	---	---	---
.129	2	.316	.422	.258	.004	---	---
.161	2	.237	.396	.352	.016	---	---
.194	2	.178	.356	.429	.037	---	---
.291	3	.075	.225	.535	.165	.000	---
.323	3	.056	.188	.533	.223	.000	---
.386	3	.031	.126	.491	.348	.003	---
.484	3	.013	.066	.381	.522	.017	---
.581	4	.006	.034	.266	.639	.056	---
.743	4	.001	.010	.125	.668	.196	---
.969	4	.000	.002	.035	.477	.486	.000
1.486	5	.000	.000	.001	.079	.920	.000
1.970	5	.000	.000	.000	.007	.984	.009
2.487	5	.000	.000	.000	.000	.870	.130
2.972	5	.000	.000	.000	.000	.556	.444
3.973	sample	.000	.000	.000	.000	.059	.941
4.974	sample	.000	.000	.000	.000	.001	.999

a/ Based on an average kernel weight of .323 grams per kernel or 774 kernels in a 250 gram sample.

Table 4: Probability of Grade Variation on Heat Damage in a 250 Gram Sample of Corn Due to Random Chance[a/]

Percent of heat damage in the Population	Actual Grade	Probability that a 250 g. sample will be graded on the basis of heat-damage No.1	No. 2	No. 3	No. 4	No. 5	Sample
.05	1	.679	.263	.057	.001	.000	.000
.10	1	.461	.357	.174	.008	.000	.000
.15	1	.313	.364	.293	.030	.000	.000
.20	2	.212	.329	.387	.071	.000	.000
.25	2	.144	.279	.445	.130	.001	.000
.30	3	.098	.228	.470	.202	.003	.000
.35	3	.066	.181	.466	.281	.007	.000
.40	3	.045	.140	.441	.360	.014	.000
.45	3	.030	.107	.403	.434	.026	.000
.50	3	.021	.080	.358	.498	.043	.000
.55	3	.009	.060	.310	.548	.067	.000
.60	4	.004	.044	.264	.584	.098	.000
.70	4	.002	.024	.182	.610	.180	.000
.80	4	.001	.012	.119	.584	.282	.000
.90	4	.000	.006	.075	.521	.396	.000
1.00	4	.000	.003	.046	.440	.510	.001
1.50	5	.000	.000	.003	.103	.866	.027
2.00	5	.000	.000	.000	.013	.773	.214
2.50	5	.000	.000	.000	.001	.527	.422
3.00	5	.000	.000	.000	.000	.160	.840
4.00	sample	.000	.000	.000	.000	.007	.993
5.00	sample	.000	.000	.000	.000	.000	1.000

a/ Based on an average kernel weight of .323 grams per kernel or 3096 kernels in a 1000 gram sample.

the heat-damage factor in corn, but is indigenous to one degree or another to the entire U.S.D.A. grain grading system.

Estimates of Sampling Variability for All Corn Grade Factors

U.S.D.A. (1974) has published estimates for standard deviations associated with measurement of all grade factors for corn inspected under approved procedures. These estimates are presented in Table 5.

As is obvious from this table, there is considerable sampling variability associated with grade factors for this important grain. The role of this variability is magnified when it is realized that a standard management practice in the industry is to blend grain as close to the upper limits of grade factors as possible. Thus, it is not overly surprising when review of grade determinations, such as that conducted by GAO, finds an original inspection to be at variance with a reinspection.

Indeed, one would begin to be suspicious of the integrity of the grain grading system if repeated sampling of loads of grain did not turn up differences in grade on a fairly regular basis.

From a preliminary examination of grade changes on appeals of officially determined corn grades filed at the Peoria office of AMS, random variability is an important factor in grade alteration upon reinspection. During fiscal year 1975, several hundred appeals of corn grade determinations were filed with the Peoria AMS. Of those lots of corn appealed, 68 were changed in grade. However, of those whose grades were changed, only 61 of the lots were altered on the basis of specific grade factors. The remaining 7 were changed to or from sample grade on the basis of odor.

Of the 61 grade changes on the basis of numerical grade factors, in 36 or 59 percent of the cases the difference in measurement between original and revised factors determining grade not significant at the 95% level. Thus, if one accepts the U.S.D.A. estimated standard deviations for corn grade factors, a

Table 5: U.S.D.A. Estimates of Standard Deviations for Measurement of Corn Grade Factors[a/]

Factor	Portion Size	Standard Deviation Grade 1	2	3	4	5
Test Weight	1-1/8 to 1-1/4 qts.	.23	.23 (8.7)	.23 (8.7)	.23 (13.0)	.23 (13.0)
Moisture	250 g. (Motomco)	.20	.20 (7.5)	.20 (10.0)	.20 (12.5)	.20 (15.0)
Broken Corn and Foreign Material	1-1/8 to 1-1/4 qts.	.20	.20 (5.0)	.20 (5.0)	.30 (3.3)	.30 (6.7)
Total damage	250 g.	.56	.68 (2.9)	.80 (2.5)	.93 (3.2)	1.12 (4.5)
Heat damage	250 g.	.09	.14 (0.7)	.23 (1.3)	.32 (1.6)	.56 (3.6)

a/ Source: U.S.D.A., "Shiplot Inspection for Grain," Washington, D.C., Sept., 1974 (mimeo).

b/ Numbers in parentheses are widths, in estimated standard deviations, of the ranges for each factor for each grade lower than U.S. No. 1.

considerable number of these grade changes can be accounted for by random chance alone.

Further Research Needs.

The entire system of U.S.D.A. grain grading practices and standards needs to be intensively studied. Increased accuracy of grade determination under current standards is possible, but only at the cost of requiring the inspection of larger samples. What these costs would be, and the resulting increase in accuracy, are far beyond the limited aims of this paper.

More importantly, however, we need to be asking questions relative to the economic role of grain standards. As Ladd and Martin have recently pointed out, the optimal grain grading system would likely not rely on assignment of a single numerical grade, but would rather be based on purchase by specification of characteristics important to grain users. The current system of assignment of a single grade number based on a number of different factors is inefficient for both buyers and sellers, since there is a considerable amount of information lost in a system which assigns a grade on the basis of the highest grade on any one factor. Additional research is required to identify the potential benefits and costs of conversion to a scheme which would preserve information on all grading factors considered important by grain users, including the costs for varying degrees of accuracy in measurement which could be achieved with such a system.

BIBLIOGRAPHY

General Accounting Office, Assessment of the National Grain System and Certain Related Matters, Washington, D.C., Feb., 1976.

Hall, Glenn and Lowell D. Hill, Test Weight as a Grading Factor for Shelled Corn, Urbana, University of Illinois, Department of Agricultural Economics, Agricultural Experiment Station, AERR 124, Sept., 1973.

Hill, Lowell D. and Gene C. Shove, Drying Corn at the Country Elevator, Urbana, University of Illinois Cooperative Extension Service, Circular 1053, 1972.

Ladd, George W. and Marvin B. Martin, "Prices and Demands for Input Characteristics" AJAE, 58: 1, Feb., 1976, pp. 21-30.

Lapin, L. L., Statistics for Modern Business Decisions, New York, Harcourt Brace Jovanovich, Inc., 1973.

U.S.D.A. (1974), Shiplot Inspection Plans for Grain", Washington, D.C., Sept., 1974 (mimeo).

U.S.D.A. (1975), The Official United States Standards for Grain, Washington, D.C., U.S. Government Printing Office, Dec., 1975.

APPENDIX

Binomial Distribution

$$P\,[k_1^* \leq k \leq k_2^*] = \sum_{i=k_1^*}^{k_2^*} \frac{n!}{k_i\,!\,(n - k_i)\,!}\,\Pi^{k_i}\,(1-\Pi)^{n-k_i}$$

n = sample size, no. of kernels

k*= no. of damaged kernels in "n"

Π = proportion of damaged kernels in the population

Hypergeometric Distribution

$$P\,[k_1^* \leq k \leq k_2^*] = \sum_{i=k_1^*}^{k^*} \frac{C^{s}_{k_i}\;C^{N-s}_{n-k_i}}{C^{N}_{n}}$$

s = no. of damaged kernels in the population

N = population size

n = sample size (<N)

k*= no. of damaged kernels in the sample