[illegible] of Corn Objective Yield Survey

Procedures and Definitions

by

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Study of Corn Objective Yield Survey Procedures and Definitions

General:

A comprehensive study of corn objective yield procedures was carried out under the supervision of the Research and Development Branch in two Maryland corn fields in the fall of 1968. The purpose of the study was to detect any field procedures which could have been responsible for biases in the objective yield estimates of corn observed in earlier validation surveys. This study was part of an overall SRS effort to detect probable sources of bias in the corn objective yield survey procedures.

Major findings of the study were:

(1) The estimated number of ears per acre in these two fields as determined by regular objective yield counts and measurements was about 2.2 percent less than the average number of ears per acre physically counted in these same fields. This difference was significant at the five percent level.

(2) The average weight of grain per ear for the third and fourth ears in Row 1 of each sample unit was slightly less than the average weight of grain per ear from a large systematic sample of ears from the entire field. This difference was not significant at the five percent level.

(3) Estimated row widths based on measurements taken by enumerators were not significantly different from the average row widths computed by dividing the surveyed widths of field by the number of rows.

(4) Delaying the post-harvest gleaning operation until 33 days after harvest would have resulted in a 3.8 bushel per acre underestimate of the amount of grain not harvested by the farmers (harvesting loss). This would occur largely through the disappearance of shelled grain from the field, primarily in the first two weeks after harvest.

(5) The field acreages computed from the same measurement procedures as used in previous validation surveys overstated the net acreage in corn about 0.9 percent as compared with the acreage determined by measuring the length of each row and multiplying the total row length by the average row width.

(6) The average number of ears per acre counted in the 6 foot row sections at either end of the fields was slightly larger than in the remainder of the field. These row sections normally would not be included in the area of the field sampled by the regular objective yield procedures.

Field Procedures:

Two fields in Prince Georges County, Maryland were selected for this project. Operations carried out in these fields were as follows:

(1) Each row was measured and divided into 45 foot count units. The first count unit started at a point six feet into the field from the first plant in each row. The last count unit ended six feet into the field from the last stalk in the row. The length of the last count unit (always less than 45 feet) was recorded. The ends of the count units were marked with florist stakes. Also, the first and last stalks in each unit were marked with plastic flagging tape. (The 6.0 foot section at the end of each row would have corresponded approximately to the border area where the sample objective yield units normally would not be located.)

(2) The number of ears in each count unit and in the six foot end sections were recorded by a team of 2 people. Each individual made his own counts of ears. Any differences were to be reconciled by recounting. The team members also tagged every 50th ear in the row after a random start for laboratory weight and moisture determinations. In objective yield surveys, an ear is defined as being a cob, not in the tassel, which has at least one kernel.

(3) Final pre-harvest objective yield (Form B) observations, using regular survey procedures, were taken in 80 sample units in each field. A sample unit is two adjacent fifteen foot row sections. The location of the unit was determined by counting over a random number of rows across the end of the field and then walking into the field a random number (at least one) of paces, starting 1/2 pace in front of the first stalk in either row. The unit starts 5.0 feet from the point determined by the last pace.

Each of the four principal corners of each field served as the starting point for locating 20 sample units. The approximate distribution of the sample units within the fields are shown in Figures 1 and 2.

Observations taken for each unit included:

(a) Measuring the distance across 4 row spaces

(b) A count of the ears in each 15 foot row section

(c) The weight of the unshelled ears found in row 1 of the sample unit

In addition, the third and fourth ears in row 1 of each sample unit -- and all ears in row 1 for one-fourth of the sample units -- were individually tagged and saved for ear weight and moisture determinations.

Figure 1: Approximate location of objective yield sample plots within Field No. 1 (scale: 1 inch = 100 feet)

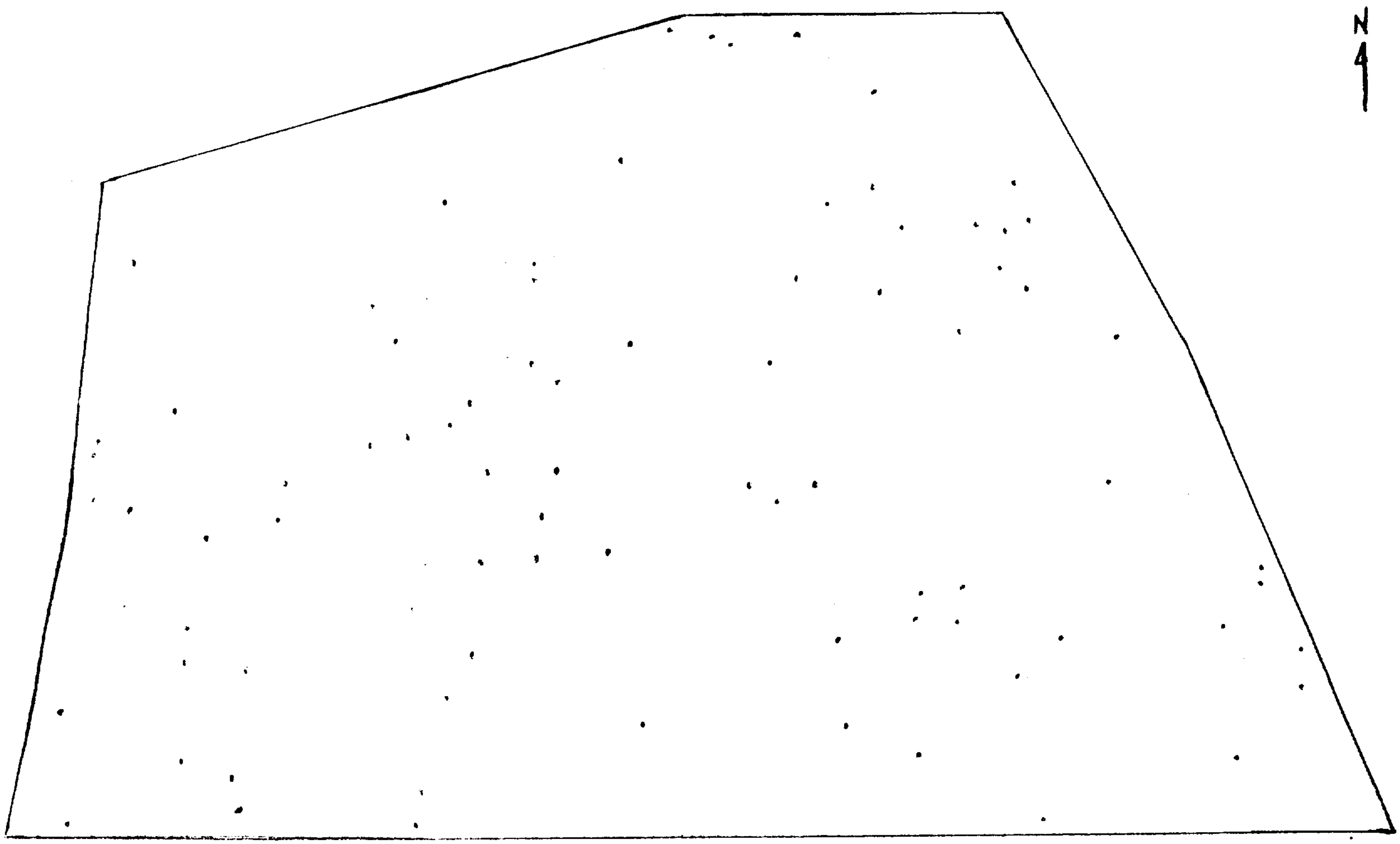
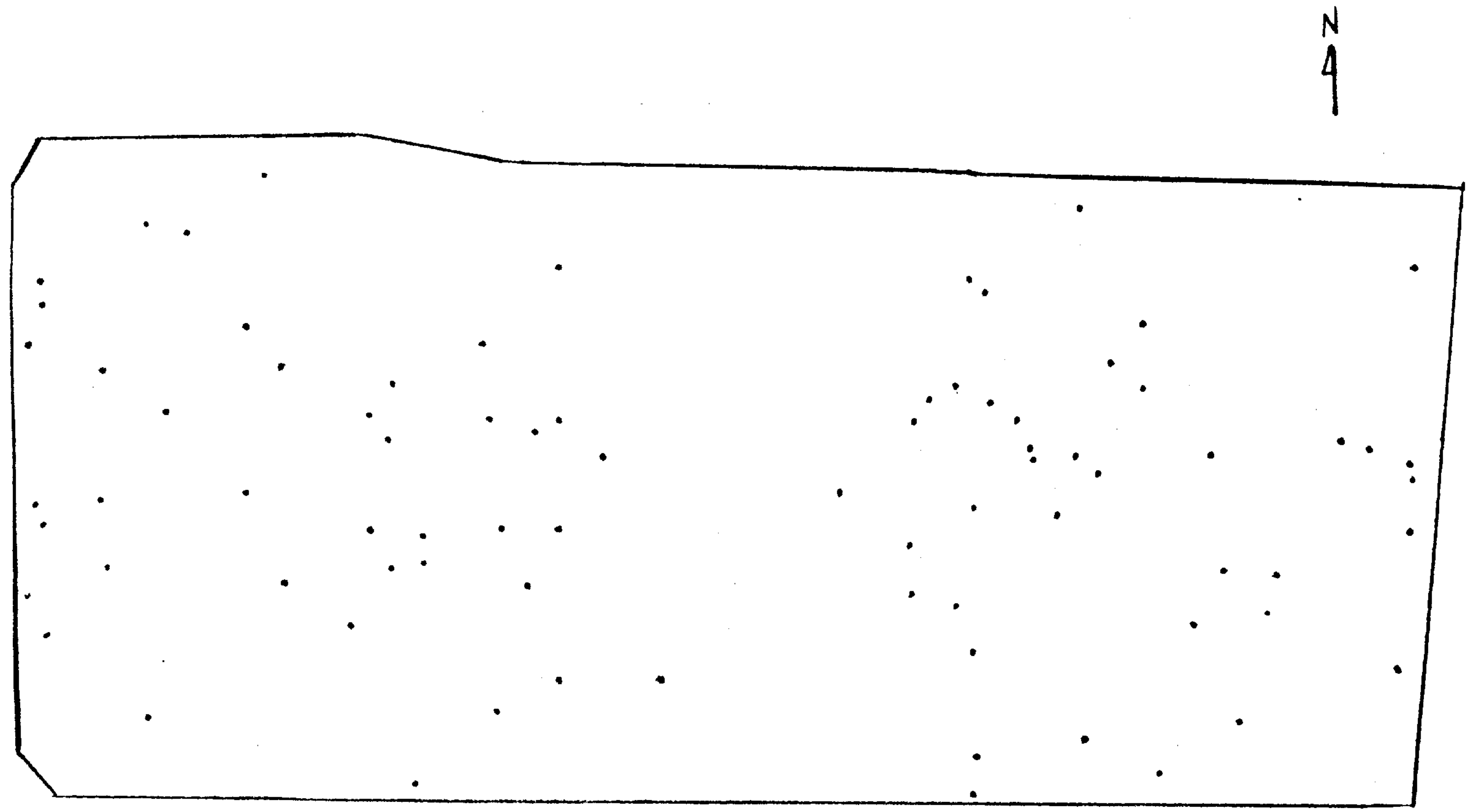


Figure 2: Approximate location of objective yield sample plots within Field No. 2 (scale: 1 inch = 100 ft.)



(4) A systematic sample of every fiftieth ear (ears tagged as described in (2)) was picked for laboratory weight and moisture determinations.

(5) A quality check, particularly of ear counts and of Form B row space measurements was made by the project leader.

(6) After all sample ears and ears from the plots had been taken, the farm operators used a two row corn picker to harvest the fields. All ears were trucked to a commercial grain elevator where the corn was shelled, weighed and tested for moisture.

(7) Post-harvest gleanings of ears and of shelled grain were made for 20 sample units per field within 2 days of the farmer's harvest. Ten additional sample units were gleaned on each of three later occasions.

(8) All sample ears taken from the field were individually shelled. The shelled grain from each ear was weighed and tested for moisture. All shelled grain weights were then adjusted to a common 15.0 percent moisture level.

(9) Field areas were computed from measurements made after the fields were harvested. These measurements were taken by people who had measured field areas on previous corn yield validation projects.

Survey Results:

Actual production, acreage, and yields for these two fields are given in Table 1. Also in this table are estimates of the weight of grain per ear from the sample of every fiftieth ear; and the average number of ears per acre, weight of grain per ear, and harvest loss computed from observations in the objective yield sample plots.

(1) Acreage - The net acreages of corn in each field, computed using the total of the measured row lengths and the average row width (measured as part of the objective yield observations), were 7.04 acres for Field 1 and 6.00 acres for Field 2.

(2) Number of Ears - A total of 142,304 ears were counted, 76,770 ears in Field 1 and 65,534 ears in Field 2. The average number of ears per acre was 10,911 for Field 1 and 10,915 for Field 2. The objective yield estimates for number of ears per acre was significantly less, at the 5 percent level of probability, then the actual numbers (see Table 2).

(3) Weight of Grain per Ear - The average weight of grain per ear in the two fields was 182.82 grams for Field 1 and 149.76 grams for Field 2. These estimates are based on a 2 percent sample (every fiftieth ear) of ears from these fields. The sampling error of these estimates are 1.61 grams for the first field and 1.84 grams for the second.

All weights are adjusted to 15.0 percent moisture content.

The average weights of grain per ear for ears picked from the Form B sample units were computed using the averages of ears 3 and 4 from row 1 of a subsample of three-fourths (60) of the sample units and the average weight of grain of all ears in row 1 of each of the other 20 sample units. These averages, 177.35 grams for Field 1 and 148.82 grams for Field 2, were respectively, 3.0 and 0.6 percent less than the average weight of grain per ear from the 2 percent sample for these fields. These differences are not large enough to be statistically significant at the five percent level. The difference in mean weights of grain per ear in the two sets of sample units (i.e., all ears in row 1 for 20 units and ears 3 and 4 of the 60 units) in Field 1 was not significantly different ($t = 1.21$). Computing the mean weight of grain per ear using only the data from ears 3 and 4 rather than all ears for the 20 sample plots would have resulted in a very small change in the estimated mean and would have produced a less precise estimate.

(4) Yield - The average yield of corn harvested by the farmer was 69.65 bushels per acre for Field 1 and 56.75 bushels per acre for Field 2 (Table 1). Both objective estimates of net yield, 67.12 and 55.38 bushels, were below the actual yield. The magnitude of these differences was small enough that they could reasonably have been expected to occur as a normal result of the sampling process.

The gross or biological yields estimated as the product of the average number of ears counted per acre and the average weight of grain per ear estimated from the large sample of every fiftieth ear are higher, but not significantly higher, than the corresponding objective estimates (Table 1). This difference reflects the objective yield underestimate of ears per acre.

(5) Row Width Measurements - The distance measured across 4 row spaces at the starting point of each sample unit and the length of the sample plots were used to expand the objective ear and stalk counts to estimated numbers per acre.

Errors in measurement can be classified as gross and minor. An example of a gross error in measurement would be measuring over 3 or 5 row spaces rather than 4. Most corn is planted in 36 to 40 inch rows so gross errors of this type are usually obvious to whoever reviews the finished work. The four enumerators who made the regular objective yield observations in the 160 sample units in these 2 fields apparently did not make any gross errors in measuring row spaces.

Minor errors would include such variations in procedure as in not measuring across the entire 4 row spaces or not measuring straight across, i.e., in a perpendicular line to the rows. For example, failing to measure the last tenth of a foot (about the width of a

Table 1.--Summary - acreage, production and yield of corn, Maryland, 1968

Production, acreage and yield from elevator weights and survey measurements

	Field 1	Field 2	Total
Weighed production (bushels)	494.815	343.683	839.498
Measured area (acres)	7.10	6.06	13.16
Derived net yield (μ) (bushels)	69.65	56.75	63.79

Ear counts, weight of grain per ear and gross yield from population counts and systematic ear weight sample

	Field 1	Field 2	Total
Total ears (number)	76,770	65,534	142,304
Net area (acres)	7.036	6.004	13.04
Ears per acre (number)	10911	10915	10913
Weight of grain per ear - Mean (grams)	182.82	149.76	167.62
S.E. (grams)	1.61	1.84	1.24
Gross yield - Mean (bushels)	78.53	64.35	72.01
S.E. (bushels)	.69	.80	.53

Objective estimates from sample plots

	Field 1	Field 2	Total
Ears per acre - Mean (number)	10591	10759	10668
S.E. (number)	146.6	164.3	109.4
Weight of grain per ear - Mean (grams)	177.35	148.82	164.28
S.E. (grams)	5.24	6.04	3.97
Gross yield - Mean (x) (bushels)	73.95	63.08	69.07
S.E. (s) (bushels)	2.41	2.73	1.81
Students 't' 1/	1.83	.84	1.61
Harvest loss - Mean (bushels)	6.83	7.70	7.23
S.E. (bushels)	1.09	.93	.73
Net yield - Mean (x) (bushels)	67.12	55.38	61.84
S.E. (s) (bushels)	2.65	2.89	1.95
$\zeta = \frac{x-\mu}{s}$ 2/	-.96	-.47	-1.00

1/ Student's "t" is significant at the five percent level for values less than -2.0 or larger than +2.0.

2/ "ζ" is significant at the five percent level for values less than -1.96 or greater than +1.96.

Table 2.--Number of ears - enumerated and objective sample estimates for corn
Maryland, 1968

Population Counts

	Field 1	Field 2	Total
Total ears (number)	76,770	65,534	142,304
Acres in field (number)	7.04	6.00	13.04
Ears per acre - (μ)	10,911	10,915	10,913
Objective estimates from sample plots			
Ears per acre - (X)	10,591	10,759	10,668
Standard error of X - (s)	146.6	164.3	109.4
$z = \frac{(X - \mu)}{s}$ 1/	-2.21	-0.95	-2.24
Relative difference between objective estimate and actual number of ears	-2.9%	-1.4%	-2.2%

1/ "z" is significant at the five percent level for values less than -1.96 or greater than +1.96.

Table 3.--Weight of grain per ear for corn, Maryland, 1968

	Field 1	Field 2	Total
Systematic sample of every fiftieth ear			
Number of ears analyzed	1435	1260	2695
Mean weight of grain per ear at 15.0 percent moisture (grams)	182.6	149.8	167.6
Standard error of estimate (grams)	1.61	1.84	1.21
Coefficient of variation (percent)	0.88	1.22	0.72
Objective yield sample estimates			
Mean weight of grain per ear (grams)			
From row 1, ears 3 and 4 only (60 units)(grams)	180.8	149.1	166.2
From all ears in row 1 (20 units) (grams)	166.9	148.4	158.4
Average of all units (grams)	177.4	148.9	164.3
Standard errors of estimated weights (grams)			
From row 1, ears 3 and 4 only (60 units)(grams)	6.06	7.57	4.78
From all ears in row 1 (20 units) (grams)	9.76	8.52	6.57
From all units (grams)	5.17	6.04	3.94
Tests for significant differences in estimated mean weights of grain per ear			
Difference in estimated weight of grain per ear (grams)	5.4	0.9	3.3
Standard error of difference (grams)	5.24	6.31	4.12
Student's "t" 1/	1.03	.14	.80

1/ Student's "t" is significant at the five percent level for values less than -2.0 or larger than +2.0.

Table 4.--Row width measurements, Maryland, 1968

Survey Measurements	Field 1	Field 2	Total
Width of field (feet)	487.12	351.71	838.83
Number of rows	152	112	264
Average row width (feet) - μ	3.205	3.140	3.177
Objective Measurements			
Number of measurements	80	80	160
Average row width - Mean (feet) - $\bar{x}_1$	3.187	3.172	3.180
S.E. (feet) - s_1	.007	.008	.0053
$z = \frac{\mu - \bar{x}_1}{s_1}$ 1/	2.57	-4.00	-.57
Quality Check			
Number of measurements	22	19	41
Average row width - Mean - (feet) - $\bar{x}_2$	3.199	3.169	3.185
S.E. - (feet) - s_2	.009	.005	.0051
Student's "t" $\frac{x_1 - x_2}{s_d}$ 2/	1.05	.32	.68

1/ "z" is significant at the five percent level for values less than -1.96 or greater than +1.96.

2/ Student's "t" is significant at the five percent level for values less than -2.0 or larger than +2.0.

stalk) across 4 normal width row spaces would result in an upward bias in the estimated yield of about three-fourths of one percent. Also, measuring to a point on the last row one foot away from the perpendicular would result in a downward bias in the estimated yield of about three-tenths of one percent. Measuring to a point 2 feet away from the perpendicular would result in a downward bias of about 1.2 percent.

The average distance between rows within each field was computed by dividing the field width (derived from acreage survey measurements) by the number of rows in the field (Table 4). Because of the odd-shape of the fields, this distance was computed only for one end of the field. These distances were significantly different from the objective yield estimate in each field. The differences were not consistent, one was significantly smaller and the other significantly larger. There was no discernible difference when the two fields were combined.

A second estimate of row spacing comes from the quality check work by the project supervisor. He measured the distance across 12 rows at 41 different randomly selected locations in the two fields. His measurements did not differ significantly from those of the enumerators.

(6) Harvest Losses - Post-harvest gleaning of ears and shelled grain were completed for 20 sample units in each field within 2 days after the respective fields had been harvested. (The fields were picked Oct. 21 and 22; the gleanings were made Oct. 22 and 23). Ten additional sample units were gleaned in each field during each of the following periods: Nov. 9-11, Nov. 16-17, and Nov. 23-24. The original plans had called for gleanings to be taken approximately 1, 2, 3, and 4 weeks from harvest. However, we failed to get the necessary supplies to the enumerator in time for the first visit.

There was some disappearance of grain on ears during the 33 day period (Table 5). However, shelled grain disappeared at a highly significant rate, particularly during the first 19 days after harvest. This disappearance probably can be attributed to feeding activities of various types of wildlife, sprouting and erosion.

(7) Measured Field Acreages - The net acreages of corn in the two fields were 7.036 and 6.004 acres. These acreages were computed from the average row length and average row width. The length of a row was defined as the distance between points one and a half feet before the first and after the last stalk in each row. The average row width was computed from the Form B row width measurements.

After the fields were picked, a team of statisticians from the Data Collection Branch and Statistical Methods Staff arrived at estimates of 7.104 and 6.056 acres for these fields. Their procedure, used to determine field areas on previous validation surveys, requires

Table 5.--Post-harvest gleanings by field, date of gleaning and type of loss for corn, Maryland, 1968

Date and type of loss	No. of samples per field	Days from harvest	Field 1		Field 2		Both fields	
			Mean	S.E.	Mean	S.E.	Mean	S.E.
			-------------	bushels per acre	-----------			
October 22-23	10	1						
Grain on ears			3.78	.84	5.71	.87	4.67	.60
Shelled grain			3.05	.84	1.98	.33	2.56	.48
Total			6.84	1.19	7.70	.93	7.23	.77
November 9-11	5	19						
Grain on ears			5.12	1.03	6.49	1.67	5.75	.95
Shelled grain			.26	.10	.60	.28	.42	.14
Total			5.39	1.03	7.10	1.69	6.17	.96
November 16-17	5	26						
Grain on ears			2.48	1.62	5.06	2.53	3.67	1.45
Shelled grain			.18	.08	.60	.29	.37	.14
Total			2.66	1.62	5.65	2.55	4.04	1.46
November 23-24	5	33						
Grain on ears			3.34	1.34	3.11	1.91	3.23	1.14
Shelled grain			.09	.05	.25	.08	.16	.01
Total			3.43	1.34	3.36	1.91	3.39	1.14

an alidade to measure the angles between the "sides" of the fields, and a surveyors chain to measure the length of the sides. (An alidade is a large protractor, with markings in half degrees, and an aiming stick). Minor arbitrary adjustments in the measured angles were made to get the figure to "close".

The average distance from the first stalk at each end of each row to the field boundary used by the survey team was 3.013 feet in Field 1 and 3.459 feet in Field 2. This space between the survey boundary and the first plants in the row could have occurred for one or both of the following reasons. One, the corn picker bent the stalk outward as it emerged from the field. The survey team normally did not measure through these bent over stalks. Also, the row ends did not form a straight line. The survey team attempted to keep the "sides" of the field as long as practical with the result that some non-productive area was included in the "surveyed" area.

Since 1.5 feet of the distance between the first stalk and the boundary is already included in the "net acreage" in corn, only the residuals at both ends of the field would introduce any bias in the measured acreage. This bias amounted to only .03 acres in each field, about half as much as would be needed to wholly explain the difference (.06 and .07 acres) between the "net" and "measured" acreages. The effect of this bias would be to reduce the farmer's yield (derived from production and acres) by about one-half of one percent, or about one fourth of a bushel.

The remaining difference in the two acreage estimates may have resulted from (1) sampling error in the objective estimate of average row spacing, or (2) lack of precision in measuring the angles between the sides of the fields.

(8) Moisture Testers - This phase of the project was not intended to be a test of equipment used in the State laboratories. However, our experiences with moisture testers may be of interest.

The laboratory equipment used in the weight and moisture determinations on the sample ears was obtained from States (West Virginia and New Jersey) which had been phased out of the corn objective yield program. The first moisture tester received and which was used throughout the project was a battery-powered Model 200 Radson. A second moisture tester, a 110 volt Model 300 Radson, was received after about eighty percent of the ears had been processed. At this point we discovered that there was a consistent, and highly significant, difference in the level of the moisture readings from the two testers. For 144 samples having moisture contents ranging from about 10 to 24 percent, readings taken on the Radson Model 200 averaged 1.35 percentage points higher than those taken on the Model 300 but only .06 percentage points higher than on a Motomco tester from Grain Division, C&MS at Beltsville. Moisture readings on all ears analyzed after that date

Table 6.--Acreage determinations, Maryland, 1968

Item	Unit	Field 1	Field 2
Total length of rows in field	feet	96174.8	82447.0
Average width per row space	feet	3.187	3.172
Derived acres		7.036	6.004
Measured acres		7.104	6.056
Difference	acres	.068	.052
Mean distance from field boundary to first stalk in row	feet	3.7875	3.1106
Mean distance from last stalk in row to field boundary	feet	2.2384	3.8069
Mean distance from field boundary to first stalk in row - both ends	feet	3.013	3.459
Derived acres in end area	acres	.034	.032

were taken on both Radson testers.

After the laboratory analysis was completed, readings from four samples were taken on the two Radson testers and the moisture tester at the elevator where the corn from the field was shelled and tested for moisture. The samples left on hand at that time were comparatively dry -- moisture content less than 20 percent, so two samples were artificially moistened to bring them above the 20 percent range.

Table 7.--Comparison of moisture readings with different moisture testers for corn, Maryland, 1968

Sample	Moisture Tester		
	Elevator	Radson 200	Radson 300
	(Percent)	(Percent)	(Percent)
1	17.81	15.82	16.95
2	19.17	17.70	18.76
3	25.74	23.32	25.02
4	27.82	28.84	27.72
Mean	22.64	21.42	22.11

On this test, the average reading from the Radson 200 was 0.69 percentage points below the Radson 300 and 1.22 percentage points below the elevator tester. Almost immediately after this test was made, the Radson 200 stopped working. The cause of the difficulty was not determined.

(9) Quality Check - The project supervisor quality checked the field work in a systematic sample of 41 count units. Items checked were the accuracy of the row measurements and the ear counts.

The ends of the measured 45 foot count units were marked by small stakes at the time of the original measurement. Distances between these stakes were remeasured. None of the second measurements varied from the original by more than 0.3 feet. The mean difference of .0175 feet was too small ($t = 0.7$) to support the alternative hypothesis that substantial errors were made in measuring the row length.

The project supervisor was unable to confirm the recorded ear counts for 14 of the 41 count units checked. Observed differences were both positive and negative. For the 41 count units, the project supervisor found an average of .29 or 0.9 percent, fewer ears per count unit than did the original counting teams. Again the difference was not significantly different from zero, ($t = 1.45$) when compared with the original counts.

Estimating Procedures:

(1) Estimating the Net Weight of Grain per Ear

(a) Definitions

$\overline{W}$ -- the combined weight of all ears found in row 1 of each of two sample plots (weighed in the field) divided by the number of ears weighed.

X -- the weight of a subsample of ears, the third and fourth ears from row 1 of each sample plot, (weighed in the laboratory).

Y -- the weight of the shelled grain from the subsample of ears adjusted to standard moisture (weighed and tested for moisture in the laboratory).

(b) Current Objective Yield Estimation Procedures

The procedure currently used to estimate the net weight of grain for mature samples is as follows:

(i) All ears in row 1 of each of the two sample plots in the sample are picked and weighed in the field. This gives the value "$\overline{W}$" defined above.

(ii) The third and fourth ears in each row 1 were tagged as the ears were picked. After all of the ears were weighed in the field, the third and fourth ears are placed in a plastic bag (or bags) and sent to the state office laboratory. At the laboratory, these ears are reweighed in the plastic bag(s). The factor "X" is computed by subtracting the weight of the same number of new bags of the same size from this weight.

(iii) The grain shelled from these four ears is weighed and tested for moisture. The factor "Y" is then obtained by adjusting the weight of the shelled grain to a standard moisture content.

(iv) A ratio estimator ($R = Y/X$) is used to convert the gross ear weight from row 1 of both sample units to an estimated weight of shelled grain per ear at standard moisture.

Using a ratio estimator necessarily results in a biased estimate of the net weight of grain per ear. The amount of this bias is influenced by several factors. These factors are (1) the amount of correlation (r) between the variables used in computing the ratio, (2) the number of observations used in computing the ratio, and (3) the closeness of the y-intercept of the linear regression of Y on X to the origin. An approximation of the probable bias relative to R from the use of this procedure was computed from the formula:

$$\frac{E(R-\hat{R})}{R} = \frac{1-f}{n\,\overline{XY}} \left(\hat{R}\, S_x^{\,2} - r\, S_y\, S_x\right), \quad \text{Cochran (6.14)}$$

Using variances and means ($\bar{X}$, $\bar{Y}$, S_y, S_x & n) from the 2 percent sample of ears and assuming that the ratio is computed from a subsample of 4 ears (e.g. the third and fourth ears from row 1 of each unit), the relative bias in the estimated ratio was found to be approximately 0.1 percent in Field 1 and 0.05 percent in Field 2. The expected relative sampling error of this estimated ratio for an individual sample was approximately 4.8 percent for Field 1 and 3.2 percent in Field 2. The effect of the bias on the estimate for an individual sample then is quite small compared with the sampling error. Even for a State with 150 to 200 samples, the sampling error of the mean ratio estimate (R) at the state level would still be four to five times as large as the indicated bias.

(c) Alternate Methods of Estimating Average Weight of Grain per Ear

The next step was to compare the efficiency of various ways of estimating the net weight of grain per ear, at some standard moisture, based upon a subsample of 4 ears per sample. The procedures tested were:

(i) The unbiased estimate, $\bar{Y} = Y/4$, where Y is the total weight of shelled grain from the 4 ears adjusted to a standard moisture content as defined previously.

(ii) The ratio estimate presently used in the regular objective yield procedure and described in (1)(b).

(iii) The regression estimate $\hat{Y}_{lr} = a + b\,\bar{W}$ where a and b are least - squares estimates of the linear regression coefficients computed from Y_i and X_i for the subsample of 4 ears from each sample and $\bar{W}$ is the average weight per ear of all ears picked and weighed from row 1 of both units as defined in (1)(a).

Note: Procedures (2) and (3) make use of double sampling where a subsample of size n (n = 4) is drawn from a larger sample of size (n + n').

Formulas used in computing the variance of these estimators are as follows.

The unbiased estimate

$$S_{\bar{y}}^2 = \frac{S_y^2}{4}$$

The ratio estimate (Cochran, 12.33 and 6.10)

$$S_{\bar{y}}^2 = \left[1 + \frac{3\,C_{xx}}{n} + \frac{6\,C_{xx}}{n}\left\{\frac{r^2\,C_{yy} + C_{xx} - 2\,C_{xy}}{C_{yy} + C_{xx} - 2\,C_{xy}}\right\}\right] \times \left[\frac{S_y^2 - 2\,R\,S_{xy} + R^2\,S_x^2}{n}\right] + \frac{2\,R\,S_{xy} - R^2\,S_x^2}{n'}$$

where the terms C_{xx}, C_{xy}, C_{yy} represent

$\frac{S_x^2}{\bar{X}^2}$, $\frac{S_{xy}}{\bar{X}\,\bar{Y}}$, and $\frac{S_y^2}{\bar{Y}^2}$ respectively, and $r^2 = \frac{(S_{xy})^2}{S_x^2\,S_y^2}$.

The regression estimate (Cochran 12.29a)

$$S_{\bar{y}lr}^2 = S_{y.x}^2\left[\frac{1}{n} + \frac{(\bar{W} - \bar{X})^2}{\sum (X_i - \bar{X})^2}\right] + \frac{S_y^2 - S_{y.x}^2}{n'}$$

where $S_{y.x}^2 = \frac{n-1}{n-2}\,,\; S_y^2\,(1 - r^2)$, and

$$E\left[\frac{(\bar{W} - \bar{X})^2}{\sum (X_i - \bar{X})^2}\right] \text{ reduces to } \frac{n + n'}{(n)^2\,n'}$$

The parameters required by these formulas and shown in Table 8 were computed from a 2 percent sample of all ears in each of the two fields. The analysis assumes n' = 21 and that both stages of sampling are equivalent to simple random sampling at that level. Since the first stage of sampling is

Table 8.--Relative efficiency of ratio and regression estimators for estimating weight of grain per ear in double sampling, for corn, Maryland, 1968

Parameters	Field 1	Field 2	Combined
$\overline{X}$ (grams)	234.60	187.39	212.54
$\overline{y}$ (grams)	178.58	149.76	164.99
s_y^2 (grams)	3615.8	4280.78	4144.90
s_{yx} (grams)	4527.0	5286.49	5217.87
s_x^2 (grams)	6253.4	6700.59	7018.33
R	.76121	.79917	.77631
a (grams)	8.7485	1.9130	6.9750
b	.72392	.78896	.74346
r^2	.90636	.97431	.93591
$s_{y.x}^2$ (grams)	338.83	110.038	265.72
Estimated Variances			
$s_{\overline{y}}^2$ (grams)	903.95	1070.2	1036.2
$s_{\overline{y}_R}^2$ (grams)	249.86	230.25	261.06
$s_{\overline{y}lr}^2$ (grams)	265.96	234.31	270.92
Coefficients of variation of sample estimates			
C.V. ($\overline{Y}$) (percent)	17.2	21.9	19.5
C.V. ($\overline{Y}_R$) (percent)	8.85	10.1	9.8
C.V. (Y_{lr}) (percent)	9.13	10.2	10.0

a cluster sample (2 clusters per sample), the variances shown in Table 8 probably under estimate the mean sampling error which would be obtained in practice.

The computed estimate of variance for the ratio model was slightly lower than for the regression model for both fields. This may have resulted from the omission of terms involving $1/n^2$ for the approximated variance formula. Both the regression and ratio models were approximately twice as efficient as the direct expansion for this size subsample. There is no apparent gain in efficiency from using the regression model in place of the ratio model. Since the cost, i.e., the amount of work required to make weighings of the individual ears and shelled grain from those ears, is higher for the regression model, the ratio model should continue to be used.

(2) Other Estimating Procedures - Additional checks on the validity of computational procedures used in arriving at the estimated weight of grain per sample on the corn objective yield surveys involved the computation of linear correlations between the following variables. (Table 9)

(a) Net weight of shelled grain per ear at 15 percent moisture.

(b) Weight of the unshelled ear, no adjustments for moisture.

(c) Weight of shelled grain per ear, no adjustments for moisture.

(d) Shelling fraction = (c)/(b).

(e) Moisture content

(f) Length of ear (measured over husk)

As expected, the highest correlation for each field was between (a) and (c), shelled grain adjusted for moisture and not adjusted for moisture. The coefficient of correlation (r) was over .99 in each field with over 1200 observations. The correlation between the weight of the unshelled ears (b) and the weight of shelled grain adjusted for moisture (a) was also quite high.

In these two fields there was a positive linear correlation between the shelling fraction (ratio of weight of shelled grain to ear weight) and weight of shelled grain per ear. That is, the shelling fraction increases with the weight of grain per ear. There was no consistent correlation between the shelling fraction and the weight of the unshelled ears. There was no appreciable correlation between the amount of shelled grain adjusted to 15 percent moisture and the moisture content of the shelled grain.

The linear correlation of the length of ear measured over the husk with both gross ear weight and with weight of shelled grain per ear was also quite high (between .75 and .80). This would indicate that the length of ear should be a good forecast estimator of ear weight. It is used in the present forecasting model. For mature samples, the use of the ear length as a second covariate, or a double ratio estimator with gross ear weight, in estimating weight of grain per ear, would add very little to the efficiency of the present estimating procedure. Using only the length of ear to estimate weight of grain would result in approximately the same total cost and a somewhat poorer estimate of weight of grain per ear.

Table 9.--Linear coefficients of correlation (r) between weight of unshelled ears, weight of shelled grain per ear (with and without adjustment to standard moisture), shelling fraction, moisture content, and the length of the ear measured over the husk.

Dependent variable	Independent variable	Field 1		Field 2	
		n	r	n	r
Weight of shelled grain per ear at standard moisture	Weight of unshelled ear	1435	.9520	1260	.9871
	Weight of shelled grain per ear not adjusted for moisture	1435	.9920	1260	.9956
	Shelling fraction	1435	.0984	1260	.3891
	Moisture content	1435	.0057	1260	-.0243
	Length of ear over husk	126	.7684	126	.7882
Weight of unshelled ear	Shelling fraction	1435	-.0428	1260	.2449
	Moisture content	1435	.1364	1260	.0203
	Length of ear over husk	126	.7737	126	.7701

Note: With 1000 observations, a "r" as large as .062 would occur by chance five percent of the time, a "r" as large as .081 would occur by chance one percent of the time. With n = 125, a "r" as large as .174 would occur by chance five percent of the time and as large as .228 one percent of the time.

(3) Selection of Sample Ears - The expected weight of grain per ear at standard moisture, because a ratio type estimating model was used was shown to be quite small with respect to the sampling error. Non-random selection of larger, smaller, or better-filled ears for the computation of the ratio used, could introduce additional bias in the estimated ratio. The procedure in use on the corn objective yield survey guards against this possibility by specifying that the ears within the row are always to be counted in a certain order and that the third and fourth ears counted would be used for computing the estimated ratio.

Ear and grain weights were obtained for all ears picked from row 1 from 20 sample units in each field. For the first 5 ears in each of these units, paired comparisons were made between the ratios of shelled grain at 15 percent moisture to total ear weight computed from the third and fourth ears, from the two largest (heaviest) ears, and from the two smallest (lightest) ears of the five. These comparisons (Table 10) show that if the enumerators had purposely selected the two largest of the first five ears, the ratio and the net yield for these fields would have been under-estimated by almost two percent. However, if the enumerators had consistently selected the two smallest ears, the net yield for the two fields would have changed by less than .01 bushels.

The difference in the ratio computed from the larger ears possibly was associated with moisture content. Correlations computed for the two percent sample of ears indicate that while there was no consistent correlation between the ear weight and the shelling fraction, there was a slight significant positive correlation between ear weight and moisture content. This would indicate that large ears do not dry out as fast as small ears.

These findings cast some doubt on the validity of the "weighed production" obtained in previous validation studies. In those studies, ears used in computing the average weight of grain per ear for fields harvested as ear corn were not obtained in a truly random manner.

The method of selection used was to thrust your hand into a wagon-load of ear corn and to pull out the ear you happen to grab. The necessary assumptions for this procedure to yield the equivalent of a random sample would be:

(i) Ears of all sizes are distributed uniformly throughout the wagon.

(ii) Ears of different sizes at the same location would be selected with the same probability.

(iii) Any grain missing from the selected ear before its selection must be left in the field (to be counted as harvest loss) and not be in the wagon (to be counted as production).

The last assumption is false. The first two assumptions are questionable.

Table 10.--Ratios of shelled grain at 15 percent moisture to gross ear weight for ears 3 and 4, the two largest of the first five ears in the row, and two smallest with paired differences, Maryland, 1968

Field	Ears 3 and 4		Two largest ears			Two smallest ears		
	Shelling fraction	S.E.	Shelling fraction	Difference	S.E.(d)	Shelling fraction	Difference	S.E.(d)
1	.7017	.0146	.6970	+.0046	.0083	.7025	-.0008	.0177
2	.8132	.0073	.7893	+.0239	.0099	.8121	+.0011	.0081
Both	.7574	.0082	.7432	+.0142	.0064	.7573	.0001	.0099

Summary and Recommendations:

The application of regular objective procedures to a large number of samples in these two fields produced estimates of net and gross yields which were slightly below both the weighed net yield obtained by the farmer and the gross yield obtained from a complete ear count and an estimated weight of grain per ear from a comparatively large sample of ears. These differences were not significant at the 95% level and are negative. Differences observed in earlier surveys were positive. The objective field procedures used in 1968 did not produce any evidence of being biased in this project.

There are areas which are worthy of further consideration.

(1) Acreage - One assumption in the report on the 1965 Validation Survey was that the measured acreages obtained using the chain measure and alidade provided exact measures of the net acreage in corn. From our experience on this study, it appears that such a measured acreage will probably overstate the net acreage, thus introducing a small but downward bias in the derived yield. Any further validation studies should definitely include some type of quality control on the field measurement.

(2) Moisture testers - A calibration test between two Radson moisture testers such as are now used by most of our State laboratories resulted in a consistent and highly significant difference in their level of moisture readings of 1.35 percentage points. Even if this was an unusual difference, our experience still indicates that the laboratory equipment, particularly moisture testers, should not be taken for granted. In particular, it does not seem unreasonable to require that each state laboratory run a series of calibration tests with some nearby tester of greater reliability. These calibration tests should include samples of the full range of moisture content expected in the upcoming survey. The results of these tests would be used to construct calibration charts for the purpose of adjusting the Radson moisture readings. All battery powered moisture testers would be equipped with new batteries before the calibration tests began. Any further validation tests would include comparison of readings taken at the commercial elevators near the state laboratory.

(3) Harvest loss - The apparent harvest loss can be reduced considerably as a result of (a) wildlife feeding activity, (b) alternate freezing and thawing, rain or snow which acts to work shelled grain into the ground where it is not easily detectable, and (c) erosion due to rain, etc. The effect of these activities can be reduced by good coordination between the farmer and the enumerator which would permit the post-harvest gleanings to be made immediately after harvest. Alternatively, the post-harvest program should include a series of post-harvest observations taken over time in randomly selected fields so that the effect of delay in taking post-harvest gleanings can be determined.

Post-harvest gleaning units are presently located five rows and five paces farther into the field than the pre-harvest units. This procedure generally excludes the first five rows and the first 20 feet of each succeeding row and the turn rows from the area to be sampled. The effect of this exclusion should be included in any future studies of this type. There did appear to be an unusually large number of unharvested ears left in the excluded areas of these fields.

The size and shape of the sample plot for post-harvest observations should also be studied further. The present procedure requires the enumerator to glean shelled grain only from one of the two row middles. The multi-row harvesting equipment which has come into widespread use in recent years would tend to leave shelled grain only in one of two or more rows. There may be real advantages from the standpoint of sampling efficiency to use a post-harvest unit which is, say, 4 rows wide but only 5 or 7 1/2 feet long and gleaning shelled grain from the entire unit.

(4) Future studies - In the event of future validation of this type, the following changes in procedure would be desirable:

(a) The number of ears within each count unit should be counted by one person and recounted by another. These two would not work together and would not record their counts on the same form. Differences would be reconciled by a supervisor. Mechanical counting aids (hand counters) should be used.

(b) Ears selected for laboratory analysis should be marked with an ID slip fastened around the ear under the husk and with a piece of flagging ribbon wrapped around the shank of the ear. When the selected ears are picked, the number taken from each row should be checked against a record of the number tagged.