AN INVESTIGATION OF THE ACCURACY OF TWO POSTHARVEST GRAIN LOSS ASSESSMENT METHODS

by

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INTRODUCTION

The problem of postharvest grain loss assessment has been known for some time but has become increasingly important during the past five years. Many different methods have been developed for estimating loss, all with various levels of applicability and accuracy. Some of these methods are: the Count and Weigh Method, the Standard Volume/Weight Method and the Converted Percentage Damage Method (Harris and Lindblad, 1978).

The Count and Weigh Method is one frequently suggested for estimating postharvest grain losses. Grains are separated into undamaged and damaged categories, and those in each category are counted and weighed. The resultant data are substituted into a formula which was developed by the French Commission for Evaluation of Losses (Anon., 1969). Adams and Schulten (1978) infer that this method will work well only at moderate levels of infestation. However, no indication is given as to what these infestation levels are or the true accuracy of the method at these levels.

Boxall et al. (1978) used the Count and Weigh Method in a study of farm-level food grain (paddy rice) storage losses in India and reported that reasonably reliable estimates were obtained. Results were compared to those achieved from a weight per standard volume method but inconsistencies were common.

Adams and Harman (1977) evaluated several loss assessment methods, including the Count and Weigh Method. Their results were not significantly correlated with observed weight losses in maize. Discrepancies were mainly at low and high levels of loss, the intermediate range giving an approximate estimate.

Mr. J. Mervyn Adams (personal communication) indicated the Count and Weigh Method underestimated observed loss and results were less reliable than when conversion factors were applied to the formula for specific grains.

Another common method is the Standard Volume/Weight Method for damage by insects and microorganisms (Adams and Schulten, 1978). This method is called the bulk density method by some. A graph is prepared using an undamaged sample of a specific lot or type of grain to relate dry weight of a given volume of the grain to moisture content. Samples of the same grain can be taken from storage later, weighed in the same volume container, and the weight loss estimated from the graph. Adams and Schulten (1978) indicated the Standard Volume/Weight Method is presently the most reliable method of loss determination.

This method was used to evaluate actual in-field losses of wheat grains due to insect infestation by Aboul-Nasr et al. (1973). Boxall et al. (1978) used the same method to evaluate paddy rice storage losses at the farm level in India. In only one instance was the estimate of loss obtained by the Standard Volume/Weight Method actually compared to the observed weight loss. In that case Adams and Harman (1977) said, "The comparison of constant volumes of grain (maize), when corrected for moisture content, gave excellent results for losses within 1% of the observed values."

Even though these two methods seem to have been accepted and have been used in various parts of the world, relatively little information exists as to how accurately they measure losses. To determine the capability of the Count and Weigh Method and the Standard Volume/Weight Method to measure losses, estimates obtained by the two methods were compared to actual measured losses caused by various levels of infestation of the maize weevil, *Sitophilus zeamais* (Motschulsky) in wheat, sorghum, maize, and rough rice.

MATERIALS AND METHODS

Grains

The various cereal grains differ in their size, shape and other characteristics. Wheat, sorghum, maize and rough rice were selected to determine whether the type of grain would affect the estimates of loss given by the two loss assessment methods selected for evaluation.

Wheat used was Early Triumph, a variety of hard red winter wheat. The yellow dent maize and red sorghum were both of unidentified variety. The rough rice was the variety NATO, a medium grain rice.

Eighteen jars (3.785 liters) were used for each type of grain, 1,200 g of grain per jar. Each jar was closed with a threaded jar ring with brass screen (60 mesh/in.) and white filter paper inserts.

Moisture contents of the grains were determined at the time they were put into jars and ranged between 12.7 and 13.7% (wet basis).

Insects

To provide various degrees of loss in each of the grains, *Sitophilus zeamais* (Motschulsky) was used to infest samples at various levels. Parent weevils were obtained from stock cultures of a Mexican strain of *S. zeamais* maintained on wheat in the Kansas State University Department of Entomology at 27 $\pm$ 1^{o}C and 63 $\pm$ 3% r.h. When used for infestation, parent weevils were from 7 to 21 days old.

Infestation

Three jars of each grain were infested at each of six levels; 0, 20, 40, 60, 80 and 100 insects per 100 g of grain. Parent weevils were allowed to oviposit for five days and then were removed by sieving. Samples were replaced in a darkened room maintained at 26 $\pm$ 2^{o}C and 68 $\pm$ 5% r.h. for development of progeny.

Emerged adult progeny were removed by sieving every 48 h. U.S. Standard sieves were used; 10 mesh/in. for maize, rice and sorghum; 12 mesh/in. for wheat. Sieving of samples ceased after emergence of all adults or just before the expected emergence of any possible second-generation progeny.

Loss Measurement Methods

Three methods were used to determine the extent of dry matter weight loss. An actual or observed loss was determined on all grain samples to serve as a reference to compare estimates made by the Count and Weigh Method and the Standard Volume/Weight Method described by Adams and Schulten (1978).

1. Observed Weight Loss. To obtain the actual or observed weight loss caused by the insects, jars of grain were weighed at the beginning of the infestation period and at the end of the infestation period using a Sartorius Model 2353 scale accurate to 0.1 g. Moisture contents were determined by drying 35 g whole

grain samples in an air oven. Sorghum and wheat were dried at 130°C for 18 and 19 hours, respectively (Hart et al., 1959). Rough rice was dried at 130°C for 22 hours (Kososki, 1977). Maize was dried 72 hours at 103°C (AACC, 1976). All losses were converted to a dry weight basis.

2. Count and Weigh Method. In this method a sample is separated into undamaged and damaged portions, each is counted and weighed, and the percentage weight loss calculated using the following formula:

$$\%\ \text{weight loss} = \frac{(UNd) - (DNu)}{U\ (Nd + Nu)} \times 100$$

where U = weight of undamaged grains

Nu = number of undamaged grains

D = weight of damaged grains

Nd = number of damaged grains

Adams and Schulten (1978) recommended a sample size of 100 to 1,000 kernels. Small samples needed for the Count and Weigh determinations were obtained by passing the grain sample through a Boerner grain divider (Figure 1) several times until a sample of approximately 1,000 kernels for rough rice, sorghum and wheat and 500 kernels for maize was reached. One thousand and 500 kernels were counted from each sample for data tabulation.

3. Standard Volume/Weight Method. Since this method is based on differing weights per unit volume for different levels of loss, it is necessary to develop a baseline curve representing

Figure 1. Boerner grain divider used for dividing samples into equal size subsamples.

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the weights per unit volume for each specific grain at various moisture contents which may be encountered during the sampling period. Baseline curves, based on dry matter, were developed for each type of grain using 1,000 g samples at approximately 10, 12, 14, 16 and 18% m.c.

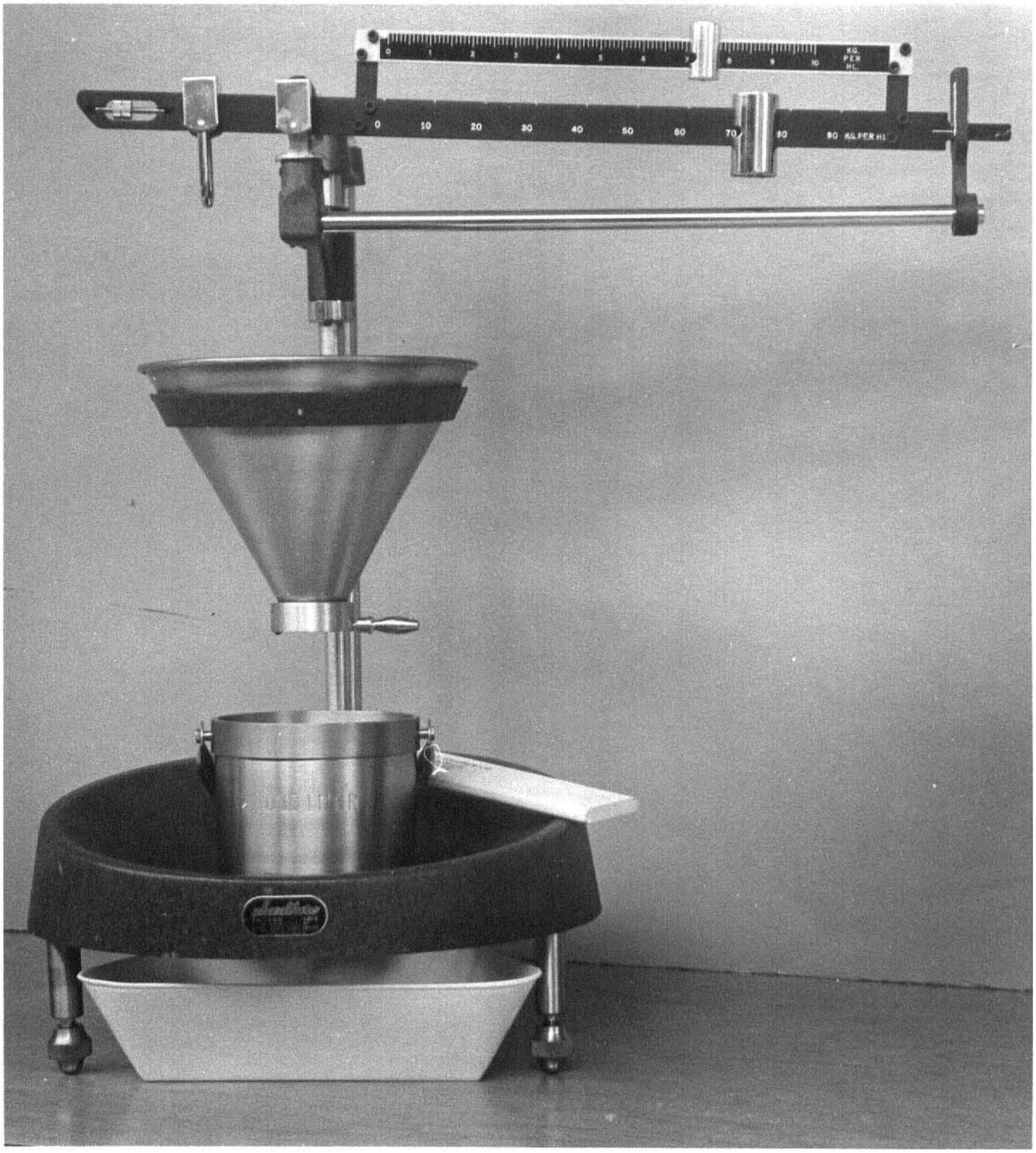
The total grain sample (after sieving to remove all insects and dust) was used with an official Boerner weight per bushel apparatus, (metric model with kilograms per hectoliter)(Figure 2) to determine the volume/weight of each sample. Moisture content determined for each sample was used for the calculation of dry matter remaining after the storage period and also for comparison of the sample dry matter with that of the baseline dry matter at the same moisture content. Thus, if the sample dry matter was less than the baseline dry matter quantity, a calculation of the dry matter loss could be made. (Adams and Schulten, 1978).

Weekly Weight Loss in Wheat

Five species of stored product insects develop internally in grain and consume a portion of the grain during this development. Each of the two methods being evaluated also was used to determine its effectiveness in estimating this hidden type of loss. Wheat was selected for this evaluation.

Wheat was infested with Mexican Sitophilus zeamais (Motsch.) weevils at the rate of 40 insects per 100 g. Three one-gallon jars (3.8 liters) containing 1,200 g of wheat each were used for

Figure 2. Boerner weight per bushel apparatus (metric model with kilograms per hectoliter) used to determine the volume/weight of each sample.


0 1 2 3 4 5 6 7 8 9 10 KG. PER HL.
0 10 20 30 40 50 60 70 80 90 KG.PER HL

each week of the experiment. Control jars were the same jars of wheat used for the main experiment.

Insects were introduced into the jars and allowed to oviposit for 5 days. They were then sieved out of the jars, using a U.S. Standard sieve, 12 meshes/in. One week later the first set of jars was taken out of store, sieved, weighed, moisture content determined, and then analyzed by the Count and Weigh and the Standard Volume/Weight Methods. This continued at weekly intervals for 5 weeks, not counting the 5 day oviposition period.

RESULTS AND DISCUSSION

Observed Weight Loss

Means of observed weight losses at each of the 6 levels of infestation (3 replicates at each level) were analyzed using Duncan's multiple range test (Table 1). The range of weight changes in this experiment went from a gain of 0.43% in rice to a loss of 9.13% in sorghum. Maize weevils produced a wide range of loss means in sorghum and wheat at the 6 levels of infestation, increasing as the level of infestation increased. However, there were no significant differences among the means in maize. Loss measurements in rice, along with frequent observations of the jars during the experiment, suggested that *Sitophilus zeamais* (Mots.) was unable to develop in rough rice. This agrees with Hsieh and Hwang (1978) who determined that *Sitophilus zeamais* (Mots.) was unable to oviposit in rough rice with intact husks. Since there was essentially no loss in the rough rice, further data for rough rice will not be discussed.

Count and Weigh Method

Duncan's multiple range test indicated that maize losses estimated by the Count and Weigh Method at varying levels of infestation (Table 2) had only slight differences among means, although the means were higher than the observed weight loss means. In sorghum, generally, estimated dry matter weight loss means were similar to the observed weight loss means. Estimated loss means for wheat generally agreed with but were usually less

Table 1. Percent Observed Weight Loss Caused by Various Levels of Maize Weevils in Maize, Rice, Sorghum and Wheat[1]

Percent Observed Weight Loss (- values signify loss; + values, gain)

Infestation Rate/100 g	MAIZE	RICE	SORGHUM	WHEAT
0	-0.37^{A}	-0.17^{BC}	-0.30^{A}	$+0.30^{A}$
20	-3.87^{B}	$+0.30^{A}$	-2.50^{B}	-2.87^{B}
40	-4.87^{B}	$+0.43^{A}$	-5.83^{C}	-5.63^{C}
60	-3.30^{B}	$+0.30^{A}$	-7.40^{D}	-6.37^{CD}
80	-4.17^{B}	$+0.17^{AB}$	-7.83^{DE}	-7.53^{D}
100	-4.20^{B}	-0.40^{C}	-9.13^{E}	-8.87^{E}

[1]Duncan's Multiple Range Test. Alpha level = 0.05 (d.f.) = 12 for maize, rice and wheat; (d.f.) = 11 for sorghum.
Means with the same letter in columns are not significantly different.

Table 2. Percent Weight Loss Caused by Various Levels of Maize Weevils in Maize, Rice, Sorghum and Wheat Estimated by the Count and Weigh Method[1]

Percent Observed Weight Loss (- values signify loss; + values, gain)

Infestation Rate/100 g	MAIZE	RICE	SORGHUM	WHEAT
0	0.00^{A}	0.00^{A}	0.00^{A}	0.00^{A}
20	-6.43^{BC}	-0.90^{B}	-2.50^{B}	-3.03^{B}
40	-5.57^{B}	-0.23^{A}	-6.00^{C}	-4.40^{BC}
60	-6.83^{BC}	-0.33^{A}	-6.83^{C}	-5.40^{C}
80	-7.23^{BC}	-0.27^{A}	-8.13^{D}	-5.37^{C}
100	-8.13^{C}	-0.40^{AB}	-9.20^{D}	-7.87^{D}

[1]Duncan's Multiple Range Test. Alpha level = 0.05 (d.f.) = 12 for maize, rice and wheat; (d.f.) = 11 for sorghum.
Means with the same letter in columns are not significantly different.

than those for observed weight losses (Table 1).

The Count and Weigh Method overestimated the loss in maize, when compared to the observed weight loss means, the largest difference being 3.93%. This method accurately estimated losses in sorghum, with more overestimations than underestimations, with a maximum difference of only 0.57%. In wheat, the Count and Weigh Method generally underestimated loss with the largest difference being 2.16%. For such a relatively simple loss assessment method, it seemed reasonably accurate. However, the experimental conditions were artificial and tests under actual storage situations are needed. The greatest amount of damage in maize was at the 40 insects per 100 g level while at the 100 insects per 100 g level for the other grains.

The General Linear Models Procedure in SAS (Barr et al., 1979), otherwise known as Proc GLM, was used for regression analysis to compare the Count and Weigh Method to the Observed Weight Loss (Figure 3). The regression equation used was:

$$Y_c = 1.0803 + 1.3347X$$

where Y_c = % weight loss estimated by Count and Weigh Method

X = % Observed Weight Loss

The predicted regressions of the Count and Weigh Method versus the Observed Weight Loss were compared to a hypothetical regression line representing a perfect relationship, i.e. one unit of Observed Weight Loss equals one unit of loss measured by the Count and Weigh Method. The hypothetical regression is

Figure 3. Relationship between percent weight loss estimated by the Count and Weigh Method and the percent Observed Weight Loss produced in maize by *Sitophilus zeamais* (Mots.) at 26 $\pm$ 2°C and 68 $\pm$ 5% r.h. $R^2 = 0.5966$

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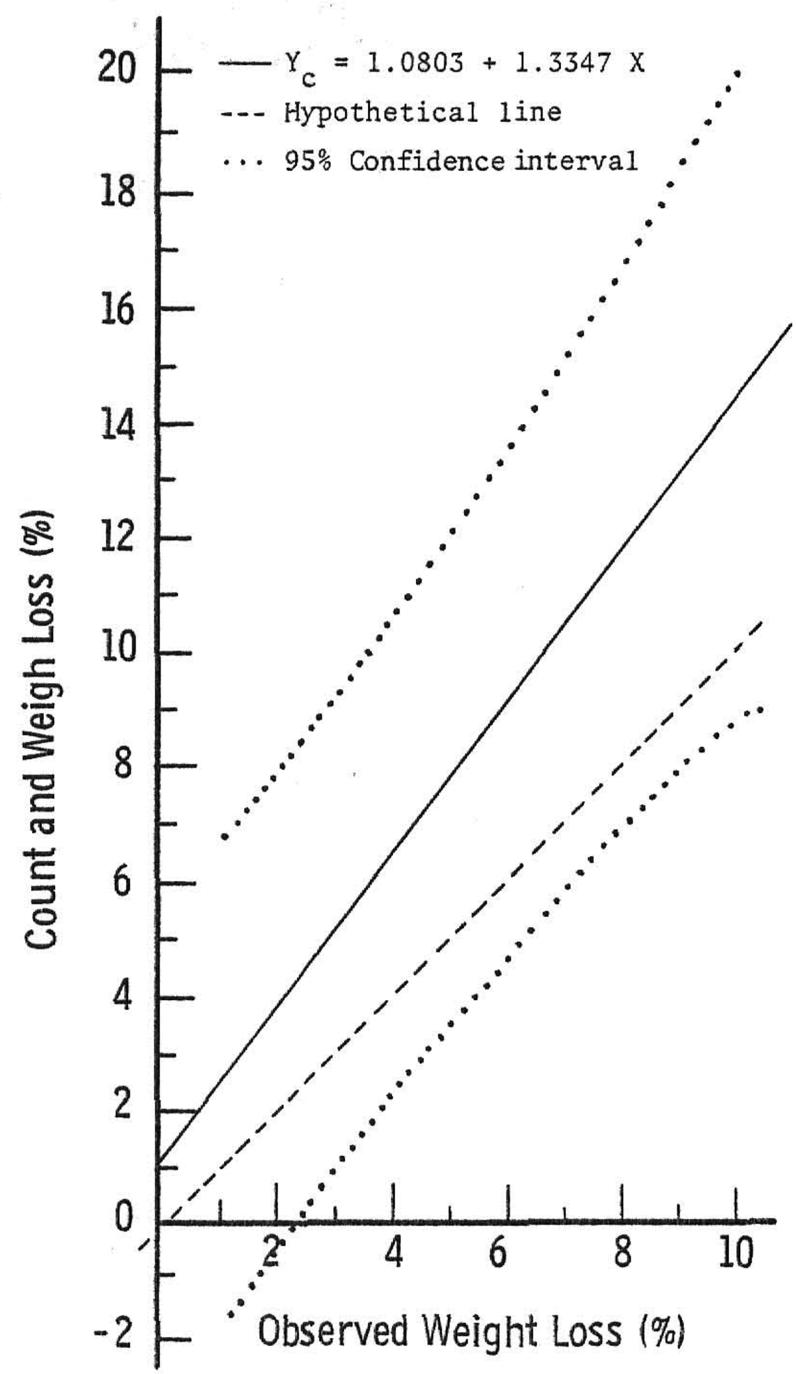


— Y_c = 1.0803 + 1.3347 X
--- Hypothetical line
··· 95% Confidence interval
Count and Weigh Loss (%)
Observed Weight Loss (%)
20
18
16
14
12
10
8
6
4
2
0
-2
2
4
6
8
10

shown by a dashed line in Figures 3 through 11. The predicted population regression line for maize lies above the hypothetical regression line (Figure 3). If the Count and Weigh Method estimated loss perfectly, the predicted regression line would fall on the hypothetical line. Since the predicted regression line is above the hypothetical line, the Count and Weigh Method overestimated loss.

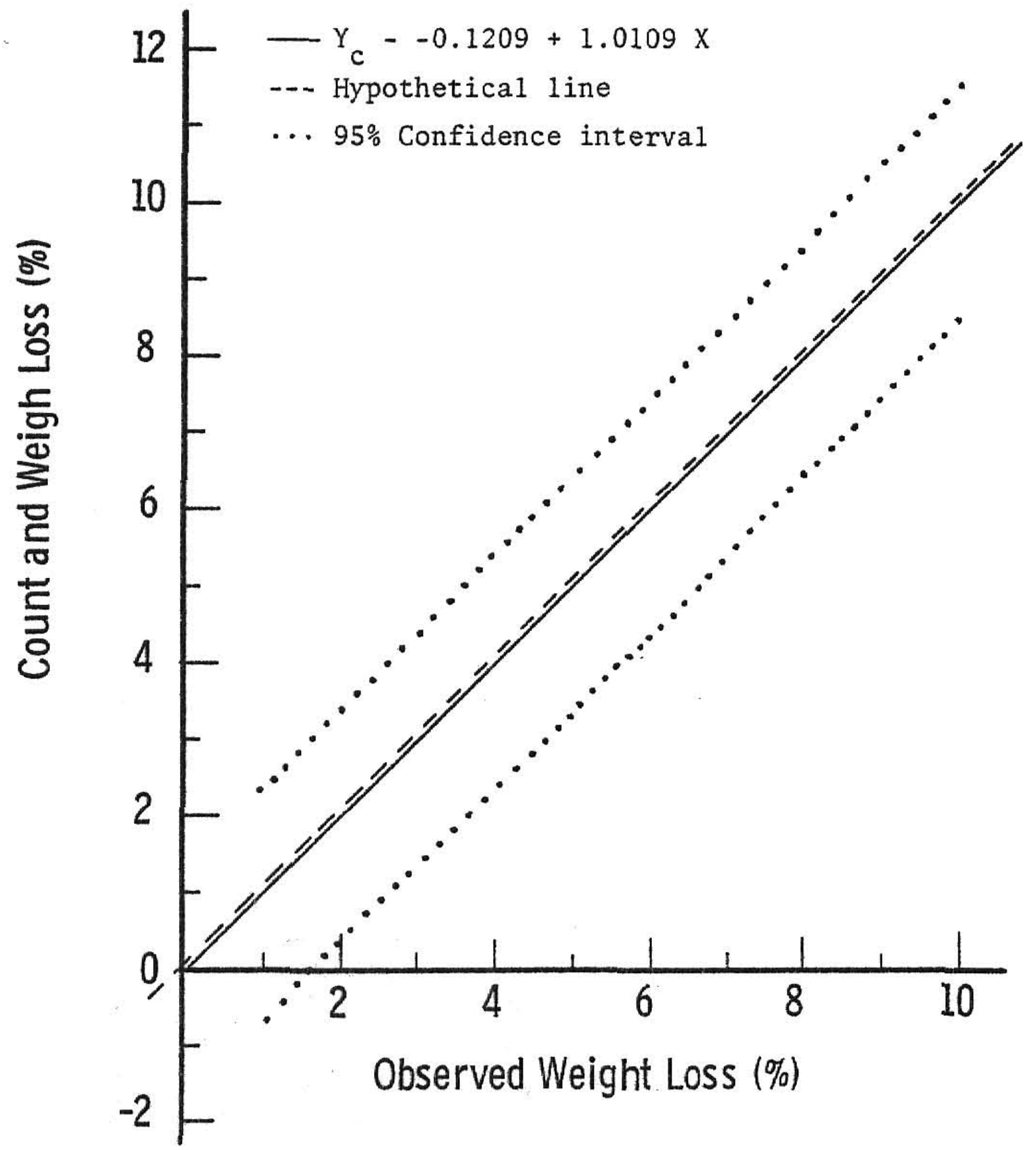
A further use of the regression analysis was to predict an individual value of Y for a new member of the population for which X was measured. This gives the 95% confidence interval shown by dotted lines in Figures 3-11. Thus, a prediction of the % Count and Weigh Loss at 5% Observed Weight Loss would fall in the interval $3.5\% \leq Y \leq 12\%$ for maize (Figure 3), unless a 1-in-20 chance had occurred in the sampling.

In Figure 3 the R^2 value for maize is 0.5966, indicating that 60% of the variance of Y_c is attributable to its linear regression on X, while 40% is the proportion free from X. If $R^2 = 1$, this would indicate that all the points of X and Y lie on the same line.

Positive numbers on the graphs for % Count and Weigh Loss and % Observed Weight Loss refer to a weight loss. Negative numbers for % Count and Weigh Loss and % Observed Weight Loss refer to a weight gain.

The predicted regression line for sorghum (Figure 4) lies slightly below the hypothetical line, which indicates that the Count and Weigh Method very accurately estimated the Observed

Figure 4. Relationship between percent weight loss estimated by the Count and Weigh Method and the percent Observed Weight Loss produced in sorghum by *Sitophilus zeamais* (Mots.) at 26 ± 2°C and 68 ± 5% r.h. R^2 = 0.9633.



— Y_c - -0.1209 + 1.0109 X
--- Hypothetical line
··· 95% Confidence interval
Count and Weigh Loss (%)
12
10
8
6
4
2
0
-2
2
4
6
8
10
Observed Weight Loss (%)

Weight Loss. The R^2 value of 0.9633 indicates that most of the points will lie on or close to the line Y_c and the narrow confidence interval shows this.

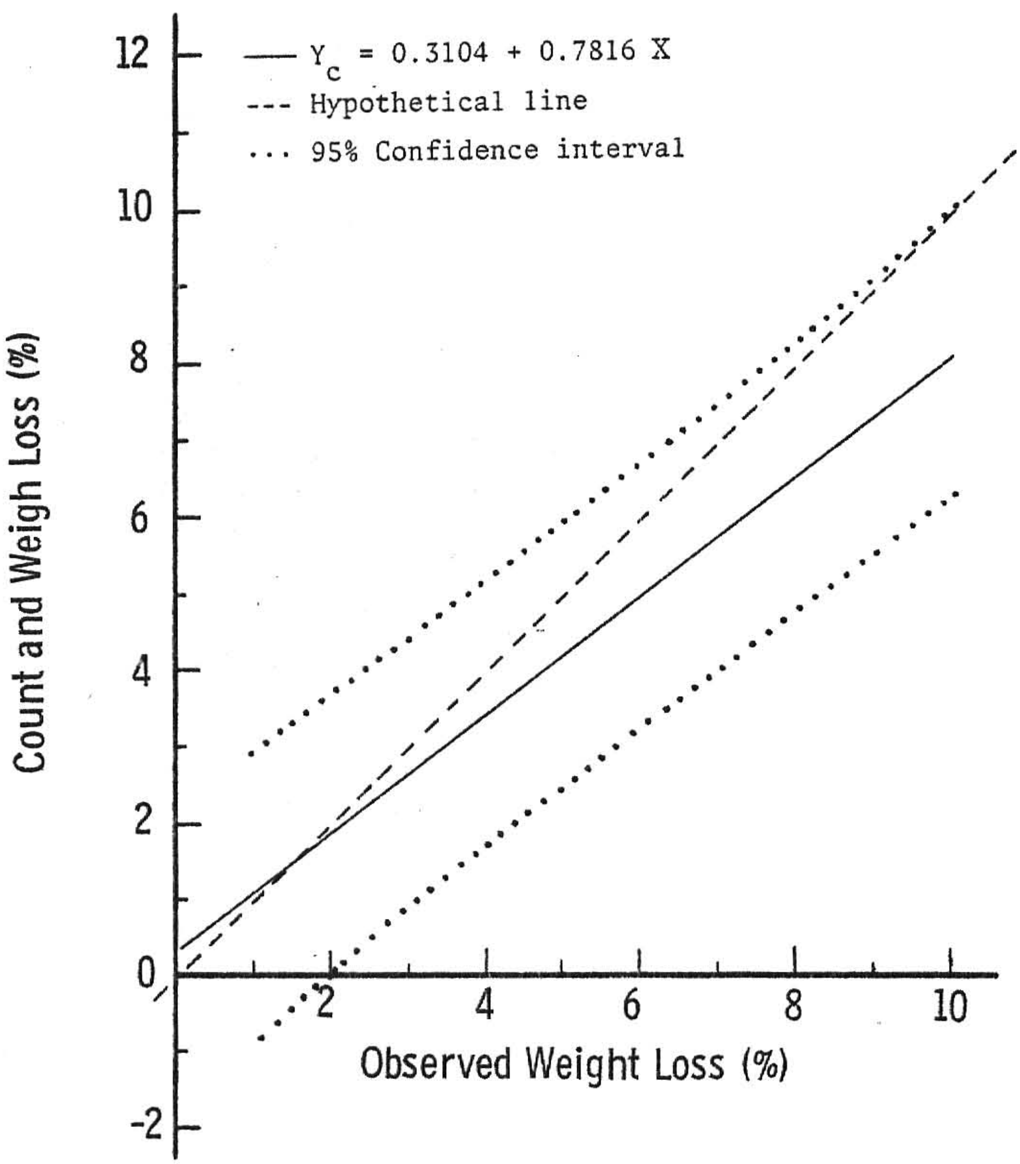
The predicted regression line for wheat (Figure 5) crosses the hypothetical line. The Count and Weigh estimation is less accurate as the observed loss increases, and generally underestimates the Observed Weight Loss. The R^2 value of 0.9130 for wheat is not as near 1.0000 as was the R^2 in sorghum and thus, not as many points will be on or close to the estimated Count and Weigh regression line. The 95% confidence interval is broader than that for sorghum.

Figures 3 through 5 show how well the predicted regression lines compare to the hypothetical line, the dashed line from (0,0) through (10,10), and also show the confidence intervals for the regression lines. However, the figures do not indicate whether the regression lines are significantly different from the desired line and whether the Count and Weigh Method is accurate.

If Y is a good measure of X, then Y should have no higher variance than X. Using a one-tailed F test for Y, the variance in Y is compared to F for X which is $F_{.05}(2,16) = 3.63$ for maize and wheat and $F_{.05}(2,15) = 3.68$ for sorghum. F for Y is calculated by:

$$F_y = \frac{[\text{Variance} \times (\text{d.f.} - 1) - \text{Error}_{ss}]/2}{\text{Error}_{ms}}$$

Figure 5. Relationship between percent weight loss estimated by the Count and Weigh Method and the percent Observed Weight Loss produced in wheat by *Sitophilus zeamais* (Mots.) at 26 ± 2°C and 68 ± 5% r.h. $R^2 = 0.9130$.



Y_c = 0.3104 + 0.7816 X
--- Hypothetical line
... 95% Confidence interval
Count and Weigh Loss (%)
Observed Weight Loss (%)
12
10
8
6
4
2
0
-2
2
4
6
8
10

If F_y is greater than 3.63 (3.68 for sorghum), the estimate of loss by the Count and Weigh Method is significantly different from the Observed Weight Loss and is not considered to be an accurate estimator of loss at the 5% level of significance. Results of the comparison for the Count and Weigh Method are shown in Table 3. The Count and Weigh Method accurately estimates loss within the prescribed limits for sorghum and wheat only.

Table 3. F Test for COUNT AND WEIGH METHOD

Corn	Rice	Sorghum	Wheat
F_y = 18.11	F_y = 11.02	F_y = .48	F_y = 1.74
18.11 > 3.63	11.02 > 3.63	.48 < 3.68	1.74 < 3.63
*	*	accept	accept

*Significant at P = 0.05

Standard Volume/Weight Method

Duncan's multiple range test was used also to analyze the means of loss estimated by the Standard Volume/Weight Method at varying levels of infestation. In maize and wheat (Table 4), the means estimated by the method are comparable to the means of Observed Weight Loss in Table 1.

In comparing the Standard Volume/Weight Method estimated loss means to the Observed Weight Loss means, the method closely estimated losses for maize and sorghum. The method underestiamted

Table 4. Percent Weight Loss Caused by Various Levels of Maize Weevils in Maize, Rice, *Sorghum* and Wheat Estimated by the Standard Volume/Weight Method[1]

Percent Estimated Weight Loss (- values signify loss; + values, gain)

Infestation Rate/100 g	MAIZE	RICE	SORGHUM	WHEAT
0	-0.73^{A}	-0.16^{C}	-0.64^{A}	$+0.54^{A}$
20	-2.77^{B}	$+0.56^{A}$	-3.60^{B}	-0.68^{B}
40	-3.43^{B}	$+0.49^{A}$	-5.83^{C}	-3.08^{C}
60	-2.52^{B}	$+0.22^{B}$	-7.57^{D}	-4.02^{CD}
80	-3.51^{B}	$+0.47^{AB}$	-7.76^{D}	-4.79^{D}
100	-3.55^{B}	$+0.65^{A}$	-8.80^{D}	-6.23^{E}

[1]Duncan's Multiple Range Test. Alpha level = 0.05 (d.f.) = 12 for maize, rice and wheat; (d.f.) = 11 for sorghum.
Means with the same letter in columns are not significantly different.

loss in maize with the largest underestimation being 1.44%. In sorghum, the method overestimated at the lower levels of loss and underestimated slightly at the higher levels of loss. The largest overestimation in sorghum was 1.10%. In wheat, the method consistently underestimated loss by over 2% (2.19 to 2.74%).

Adams and Harman (1977) using this method for maize, found that "The comparison of constant volumes of grain, when corrected for moisture content, gave excellent results for losses within 1% of the observed values". Results reported here are similar with observed differences of 1.44% or less.

Proc GLM was used in regression analysis to compare the Standard Volume/Weight Method to the Observed Weight Loss. The R^2 value for maize (Figure 6) is 0.8879, indicating that 89% of the variance of Y_s is attributable to its linear regression on X, while 11% is the proportion free from X. The regression equation used in Figure 6 was:

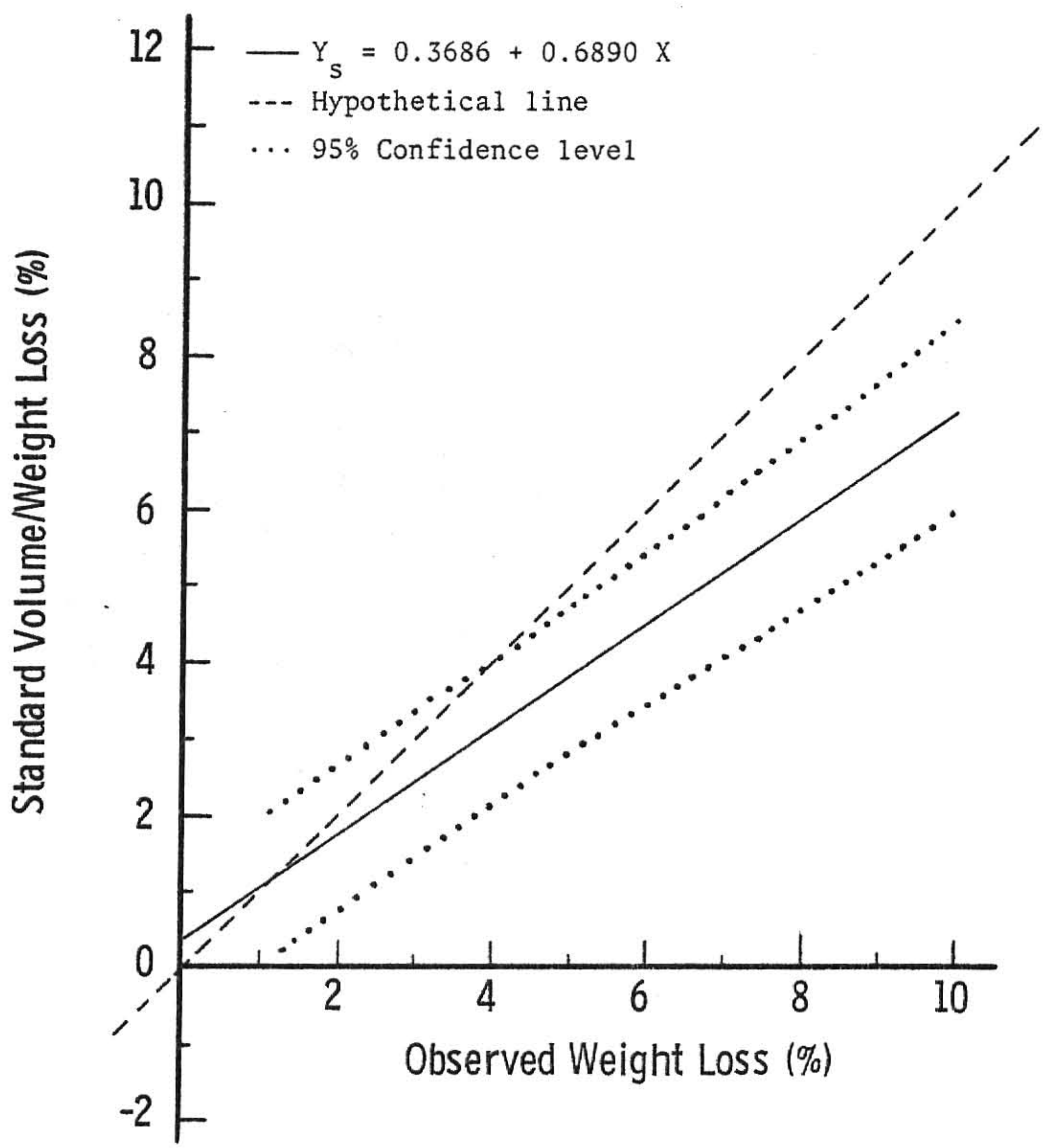
$$Y_s = 0.3686 + 0.6890X$$

Where Y_s = % weight loss estimated by Standard Volume/Weight Method

X = % Observed Weight Loss

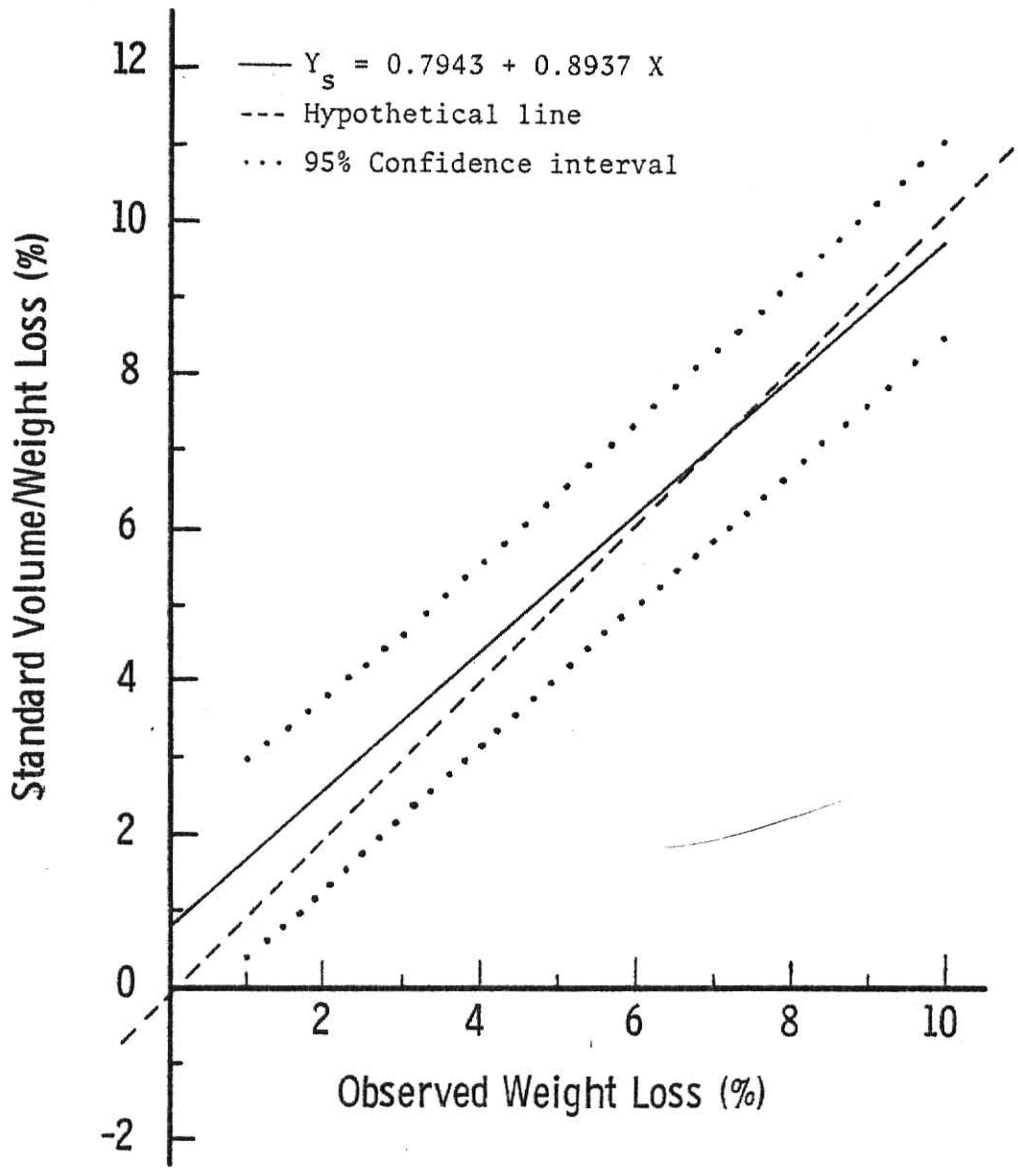
The R^2 value for sorghum is 0.9668 (Figure 7) and for wheat 0.9618 (Figure 8). These R^2 values suggest that the Standard Volume/Weight Method varies less in its estimations for small uniformly sized kernels. Since maize is larger and not so uniform in size, its R^2 value was lower (0.8879).

Figure 6. Relationship between percent weight loss estimated by the Standard Volume/Weight Method and the percent Observed Weight Loss produced in maize by _Sitophilus zeamais_ (Mots.) at 26 ± 2°C and 68 ± 5% r.h. R^2 = 0.8879.



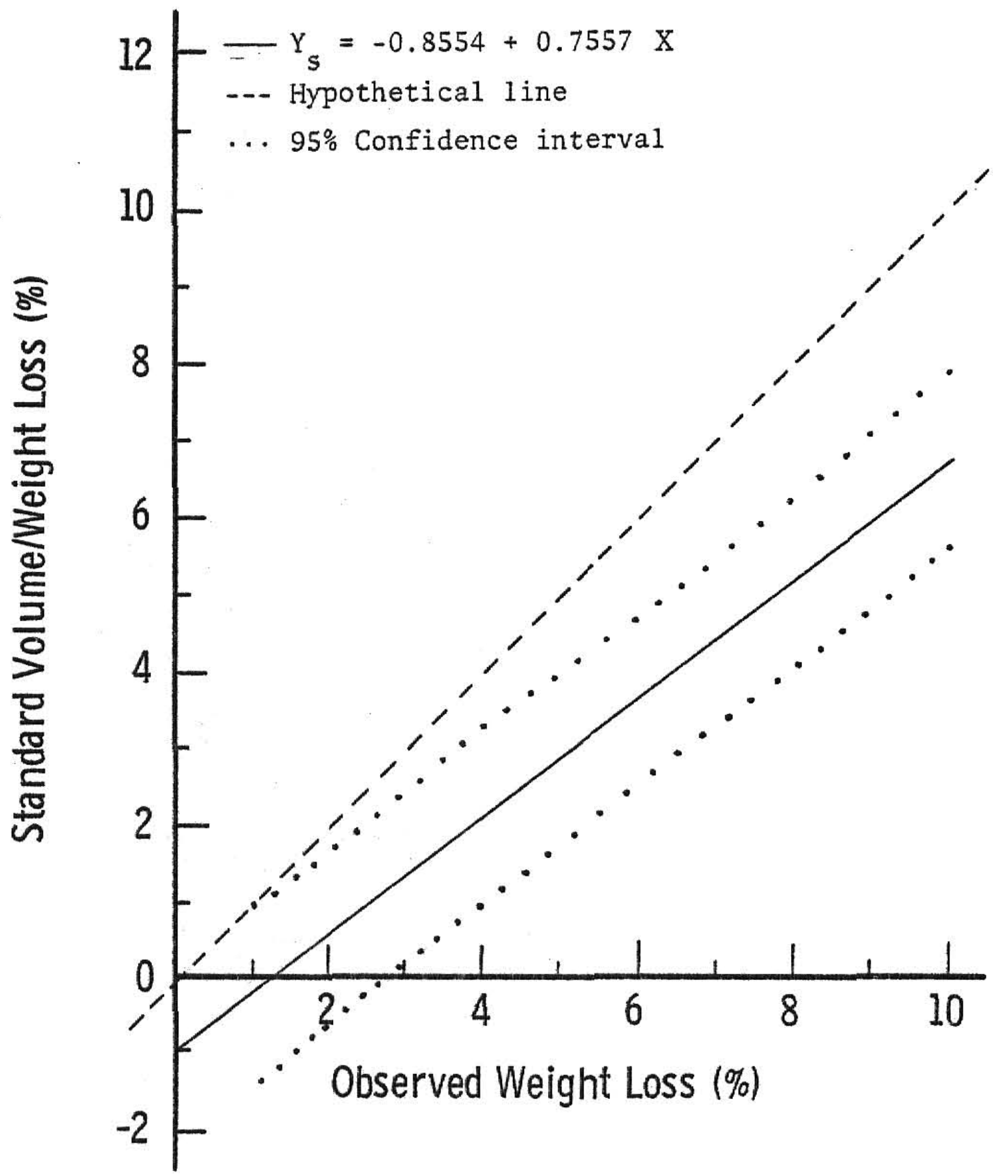
12
10
8
6
4
2
0
-2
2
4
6
8
10
Standard Volume/Weight Loss (%)
Observed Weight Loss (%)
— Y_s = 0.3686 + 0.6890 X
--- Hypothetical line
··· 95% Confidence level

Figure 7. Relationship between percent weight loss estimated by the Standard Volume/Weigh Method and the percent Observed Weight Loss produced in sorghum by Sitophilus zeamais (Mots.) at 26 ± 2°C and 68 ± 5% r.h. $R^2 = 0.9668$.



— Y_s = 0.7943 + 0.8937 X
--- Hypothetical line
··· 95% Confidence interval
Standard Volume/Weight Loss (%)
Observed Weight Loss (%)
12
10
8
6
4
2
0
-2
2
4
6
8
10

Figure 8. Relationship between percent weight loss estimated by the Standard Volume/Weight Method and the percent Observed Weight Loss produced in wheat by Sitophilus zeamais (Mots.) at 26 ± 2°C and 68 ± 5% r.h. $R^2 = 0.9618$.



Y_s = -0.8554 + 0.7557 X
--- Hypothetical line
... 95% Confidence interval
Standard Volume/Weight Loss (%)
Observed Weight Loss (%)
12
10
8
6
4
2
0
-2
2
4
6
8
10

However, Figures 6-8 indicate that the Standard Volume/ Weight Method underestimated the Observed Weight Loss in maize and also wheat. In sorghum the estimated losses were very close to the observed weight losses, being overestimated slightly at low levels of loss and slightly underestimated at higher levels.

Using a one-tailed F test for Y, the variance in Y is compared to the variance in X. F for X is $F_{.05}(2,16) = 3.63$ for all four grains. F_y is calculated using the equation on page 26. The results of this comparison are shown in Table 5.

Table 5. F test for STANDARD VOLUME/WEIGHT METHOD

Corn	Rice	Sorghum	Wheat
$F_y = 3.18$	$F_y = 5.65$	$F_y = 1.33$	$F_y = 9.24$
$3.18 < 3.63$	$5.65 > 3.63$	$1.33 < 3.63$	$9.24 > 3.63$
accept	*	accept	*

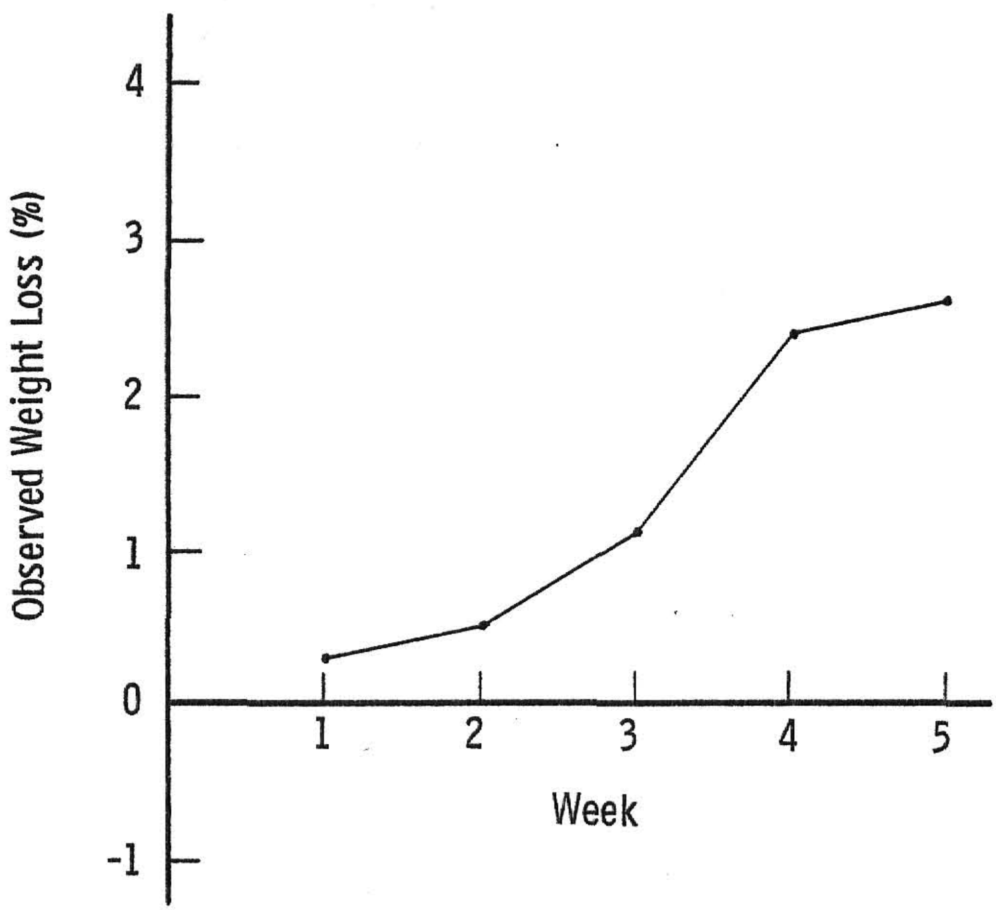
*Significant at P = 0.05

F_y for maize and sorghum is less than 3.63, indicating that the Standard Volume/Weight Method estimates loss at the 5% level of significance for maize and sorghum (most accurately for sorghum).

Weekly Weight Loss In Wheat

Figure 9 shows the observed weight loss over a 5 wk period. There was a progressive increase in the rate of weight loss during

Figure 9. Change in percent Observed Weight Loss in wheat caused by development of *Sitophilus zeamais* (Mots.) at 26 ± 2°C and 68 ± 5% r.h., measured weekly over a 5 wk period.


Observed Weight Loss (%)
4
3
2
1
0
-1
1
2
3
4
5
Week

the first 4 weeks but a slight decrease in the 5th week. Many of the insects probably were pupating during the 5th wk, causing the reduced rate of weight loss. The experiment was terminated at 5 weeks.

The observed weight loss means and those estimated by the Count and Weigh and Standard Volume/Weight Methods are shown in Table 6. Duncan's multiple range test was used to analyze the means of loss, both observed and estimated. The means of Observed Weight Loss show a progressive increase in loss with the letters beside them indicating significant differences.

The Count and Weigh Method is shown to estimate loss only in the last week of the experiment. This was because the method relies on visual damage in the grain and insects did not emerge from the wheat until the 5th wk. For kernels with internal insects, the Count and Weigh Method is inaccurate in predicting weight loss. The mean for week 5 for the Count and Weight Method is underestimated by 2.26%.

Means of weight loss estimated by the Standard Volume/Weight Method show a weight gain in the first two weeks, while there was no observed weight gain for those weeks. The method also underestimated the losses in weeks 3-5, with the largest underestimation 1.27% in week 4.

Proc GLM was used for a regression analysis comparing the Count and Weigh Method and the Standard Volume/Weight Method to the Observed Weight Loss. The R^2 value was 0.3153 for the Count and Weigh Method indicating that 32% of the variance of Y_c is

Table 6. Comparison of Weekly Observed and Estimated Weight Loss Means Caused by Maize Weevils in Wheat[1]

Percent Weight Loss (- values signify loss; + values, gain)

	Observed Weight Loss	Count and Weigh Method	Standard Volume/Weight Method
Control	$+0.30^{A}$	0.00^{A}	$+0.54^{B}$
Week 1	-0.30^{B}	0.00^{A}	$+1.08^{A}$
2	-0.50^{B}	0.00^{A}	$+1.16^{A}$
3	-1.07^{C}	0.00^{A}	-0.34^{C}
4	-2.43^{D}	0.00^{A}	-1.16^{D}
5	-2.63^{D}	-0.37^{B}	-1.48^{D}

[1]Duncan's Multiple Range Test. Alpha level = 0.05 (d.f.) = 12 for Observed Weight Loss and Count and Weigh Method (d.f.) = 11 for Standard Volume/Weight Method
Means with the same letter in columns are not significantly different.

attributable to its linear regression on X, while 68% is the proportion free form X (Figure 10). The regression equation used was:

$$Y_c = -0.0372 + 0.0889X$$

where Y_c = % weight loss estimated by Count and Weigh Method

X = % Observed Weight Loss

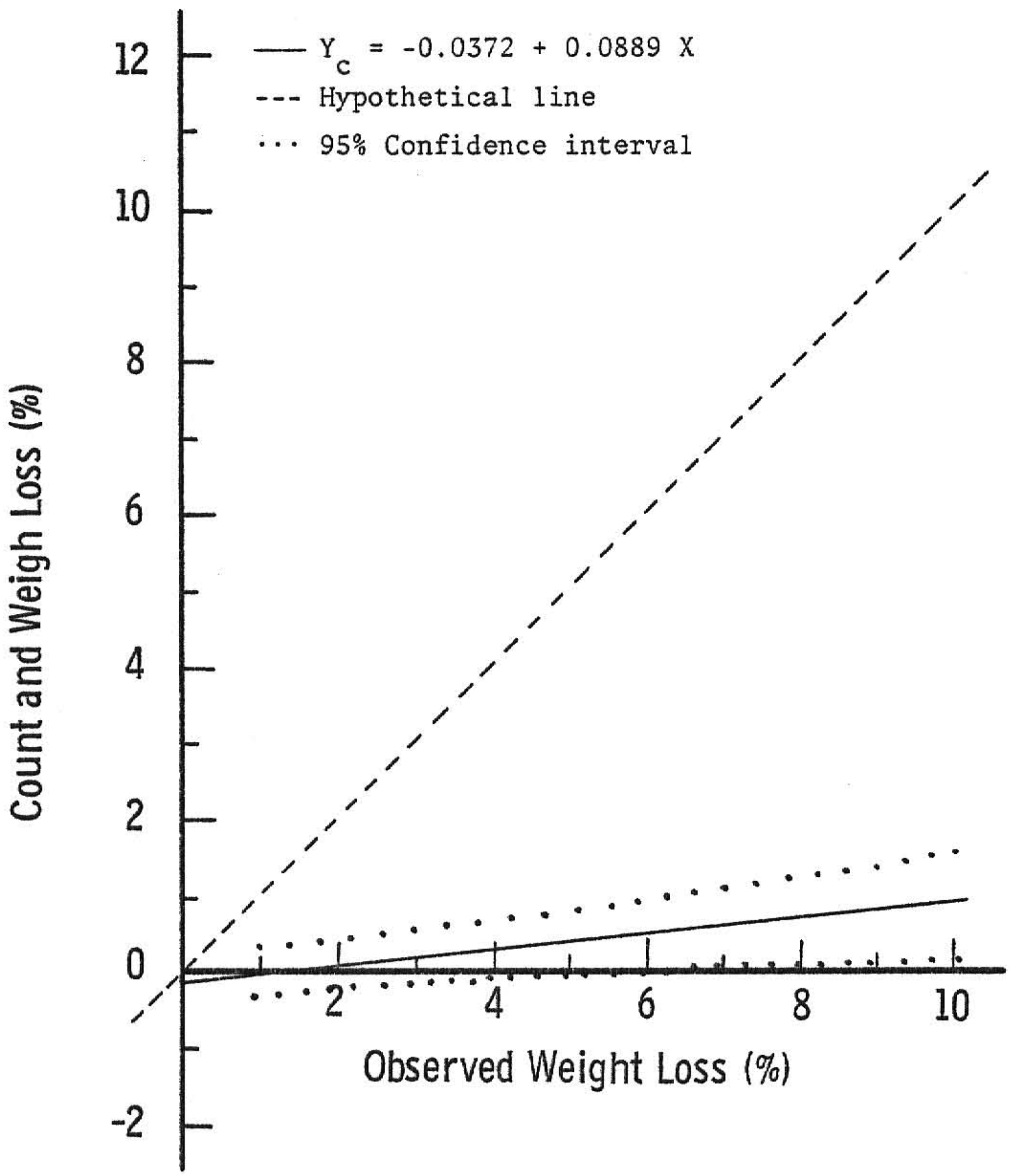
A R^2 value of 0.3153 indicated that many points estimated by the Count and Weigh Method in this case would not fall on or close to the estimated regression line.

The Standard Volume/Weight Method has a R^2 value of 0.8126, (Figure 11), indicating the method's point estimations will tend to fall on or close to the estimated regression line more often then for the Count and Weigh Method.

If Y is a good measure of X, then Y should have no higher variance than X. Using a one-tailed F test for Y, the variance in Y is compared to F for X which if $F_{.05}(2,16) = 3.63$ for wheat. F for Y is calculated as indicated on page 26.

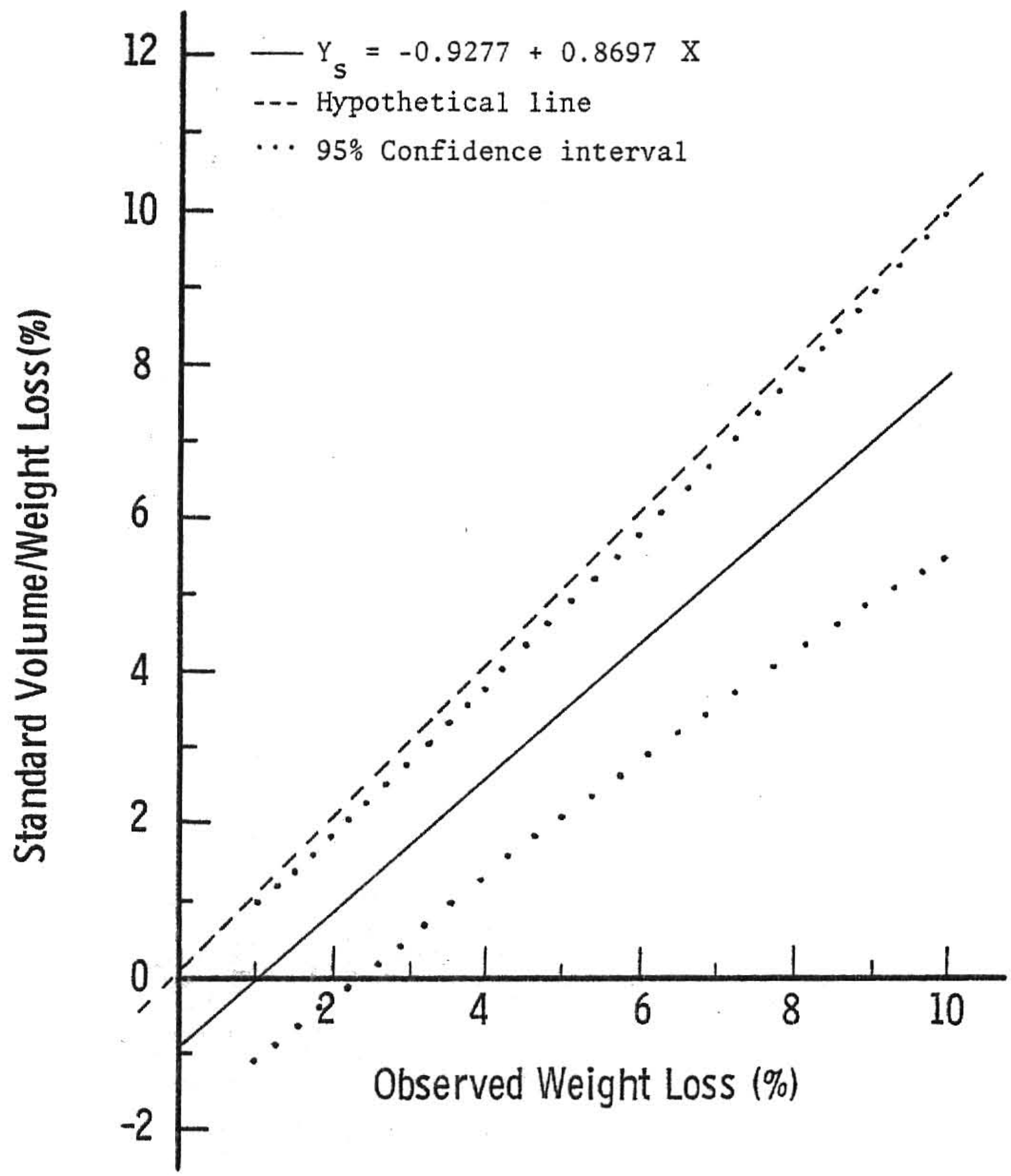
If F_y is greater than 3.63, the estimates of loss by the Count and Weigh Method and the Standard Volume/Weight Method are significantly different from the Observed Weight Loss and are not considered to be accurate estimators of loss at the 5% level of significance. Tables 7 shows the results of the F tests. Neither the Count and Weigh Method nor the Standard Volume/ Weight Method was an accurate estimator of loss in the weekly wieght loss experiment.

Figure 10. Relationship between percent weight loss estimated by the Count and Weigh Method and the percent Observed Weight Loss caused at 5 weekly intervals in wheat by <u>Sitophilus zeamais</u> (Mots.) at 26 ± 2°C and 68 ± 5% r.h. $R^2 = 0.3153$.



12
10
8
6
4
2
0
-2
Count and Weigh Loss (%)
— Y_c = -0.0372 + 0.0889 X
--- Hypothetical line
··· 95% Confidence interval
2
4
6
8
10
Observed Weight Loss (%)

Figure 11. Relationship between percent weight loss estimated by the Standard Volume/Weight Method and the percent Observed Weight Loss caused at 5 weekly intervals in wheat by Sitophilus zeamais (Mots.) at 26 $\pm$ 2^{o}C and 68 $\pm$ 5% r.h. $R^2 = 0.8126$.



12
10
8
6
4
2
0
-2
—— Ys = -0.9277 + 0.8697 X
--- Hypothetical line
··· 95% Confidence interval
Standard Volume/Weight Loss(%)
2
4
6
8
10
Observed Weight Loss (%)

Table 7. F Test for Weekly Weight Loss in Wheat Comparisons

Count and Weigh Method	Standard Volume/Weight Method
$F_y = 526.0$	$F_y = 27.51$
$526.0 > 3.63$	$27.51 > 3.63$
*	*

*Significant at $P = 0.05$

It would be useful to determine the accuracy of these methods over a longer period of time.

CONCLUSION

Under laboratory conditions and in the range of approximately 0 to 10% weight loss:

1. The Count and Weigh Method estimated the observed weight loss caused by maize weevils after one generation in sorghum and wheat at the 0.05 level.
2. The Standard Volume/Weight Method estimated the observed weight loss caused by maize weevils after one generation in maize and sorghum at the 0.05 level.
3. Neither the Count and Weigh Method nor the Standard Volume/Weight Method estimated the observed weight loss caused by maize weevils during the first generation development in wheat when observed at 5 weekly intervals.

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APPENDIX

APPENDIX A

DUST AS A PREDICTOR OF LOSS

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DUST AS A PREDICTOR OF LOSS

When this research was initiated, provision was made to weigh and record the dust sieving from each sample. When insects started to emerge, the jars were sieved at least every other day to remove insects and dust. The dust was weighed and recorded for each grain to determine the total amount of dust sieved out of each jar. These totals were then compared to the observed weight losses to determine if a relationship existed. U.S. Standard sieves were used: 10 meshes/in. for corn, rice and sorghum and 12 meshes/in. for wheat. A Sartorius scale accurate to 0.1 g was used to weigh the dust.

Using Duncan's multiple range test, the means of observed percent weight loss (Table 1) and the means of grams of dust (Table A-1) sieved out at the varying levels of infestation (three replicates at each level) were analyzed. A very good relationship exists between the weights of dust produced and observed weight loss.

In Table A-1, the letters next to the means indicate if they are significantly different. Since the means in Table 1 are in percent and those in Table A-1 are in grams, a comparison can not be made among the actual number values of the means. However, there is a general trend for increase in weight of dust as observed weight loss increases. In wheat and sorghum, this trend is best defined.

Proc GLM was used for a regression analysis comparing the

Table A-1. Grams of Dust Removed From Samples of Maize, Rice, Sorghum and Wheat Infested With Various Levels of Maize Weevils[1]

Grams of Dust Removed (- signifies a loss of grams of dust)

Infestation Rate/100 g		MAIZE	RICE	SORGHUM	WHEAT
	0	0.00^{A}	0.00^{A}	0.00^{A}	0.00^{A}
	20	-5.90^{B}	-0.97^{B}	-7.15^{B}	-9.57^{B}
	40	-7.67^{BC}	-0.97^{B}	-9.77^{B}	-14.30^{C}
	60	-6.43^{BC}	-1.33^{BC}	-13.40^{C}	-16.40^{CD}
	80	-7.70^{BC}	-1.13^{BC}	-14.30^{CD}	-18.87^{D}
	100	-8.67^{C}	-1.40^{C}	-16.90^{D}	-22.63^{E}

[1]Duncan's Multiple Range Test. Alpha level = 0.05 (d.f.) = 12 for all grains.
Means with the same letter in columns are not significantly different.

Dust totals to the Observed Weight Loss. In Figure A-1 for corn the R^2 value is 0.8526, meaning that 85% of the variance of Y_d is attributable to its linear regression on X, while 15% is the proportion free from X. The regression equation used in Figure A-1 was:

$$Y_d = 0.0489 + 1.7371\ X$$

where Y_d = grams of dust estimated lost

X = % observed weight loss

Sorghum in Figure A-2 has a R^2 value of 0.9520 and wheat in Figure A-3 has a R^2 value of 0.9886. Both of these values are very high and with that for corn indicates the various points representing dust sieved out in grams are close to the calculated regression line. However, the regression lines lie above the hypothetical line and indicate dust as overpredicting loss. Even if the predictions were accurate, such predictions would only be reliable in situations where a small amount of grain was stored in a container where all the dust was adequately contained and able to be sieved out and weighed. Large bulk or bag storage, where dust could filter out of the storage unit, would make it impossible to collect all the dust in order to accurately predict the amount of loss.

The amount of dust sieved out also was recorded in the Weekly Weight Loss Experiment. The results from Duncan's multiple range test (Table A-2) show that there was generally an increasing amount of dust over the 5 weeks which corresponded to increased Observed Weight Loss.

Figure A-1. Relationship between dust (grams) produced by *Sitophilus zeamais* (Mots.) and percent Observed Weight Loss in maize over 5 weeks at 26 ± 2°C and 68 ± 5% r.h. R^2 = 0.8526.

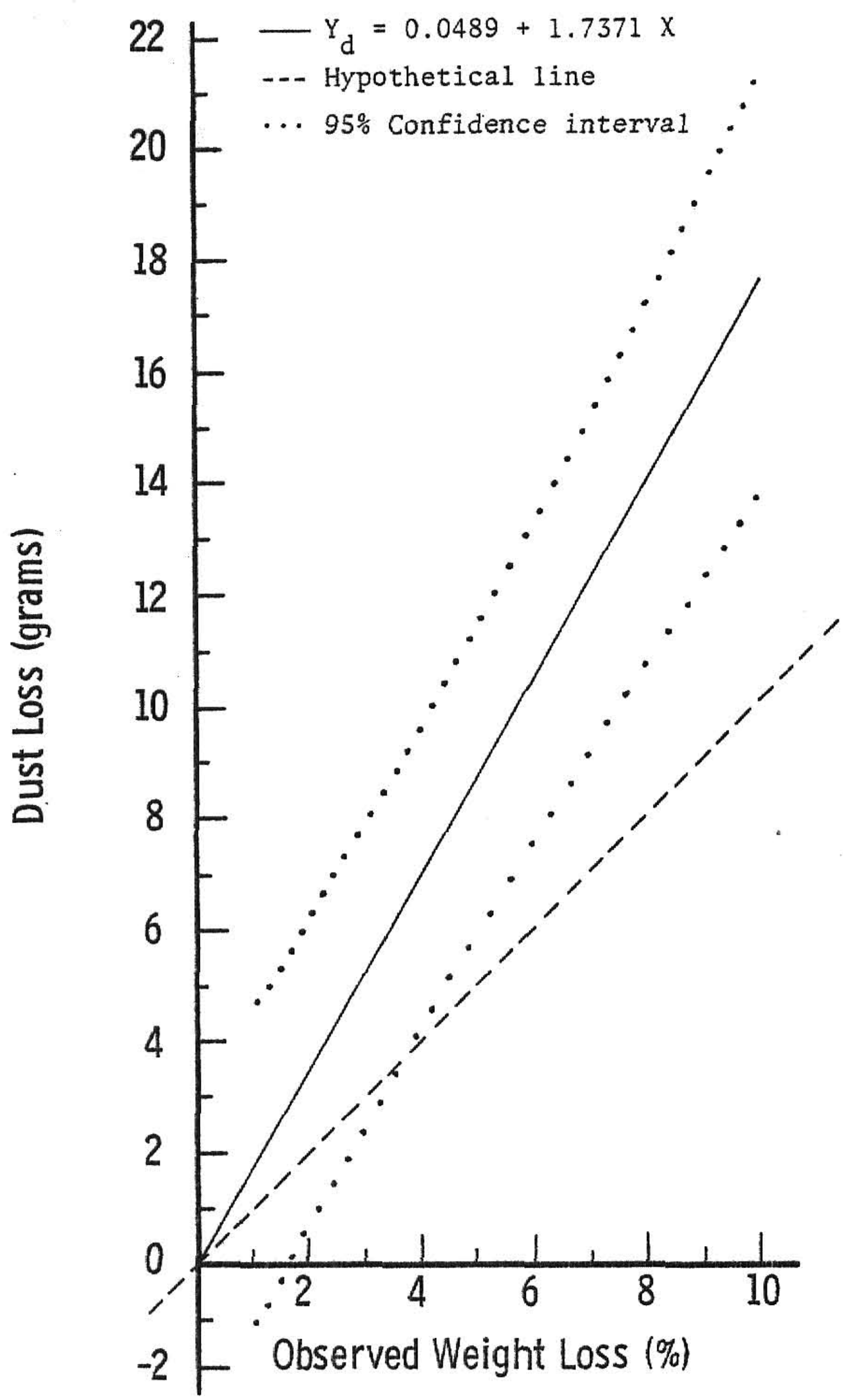
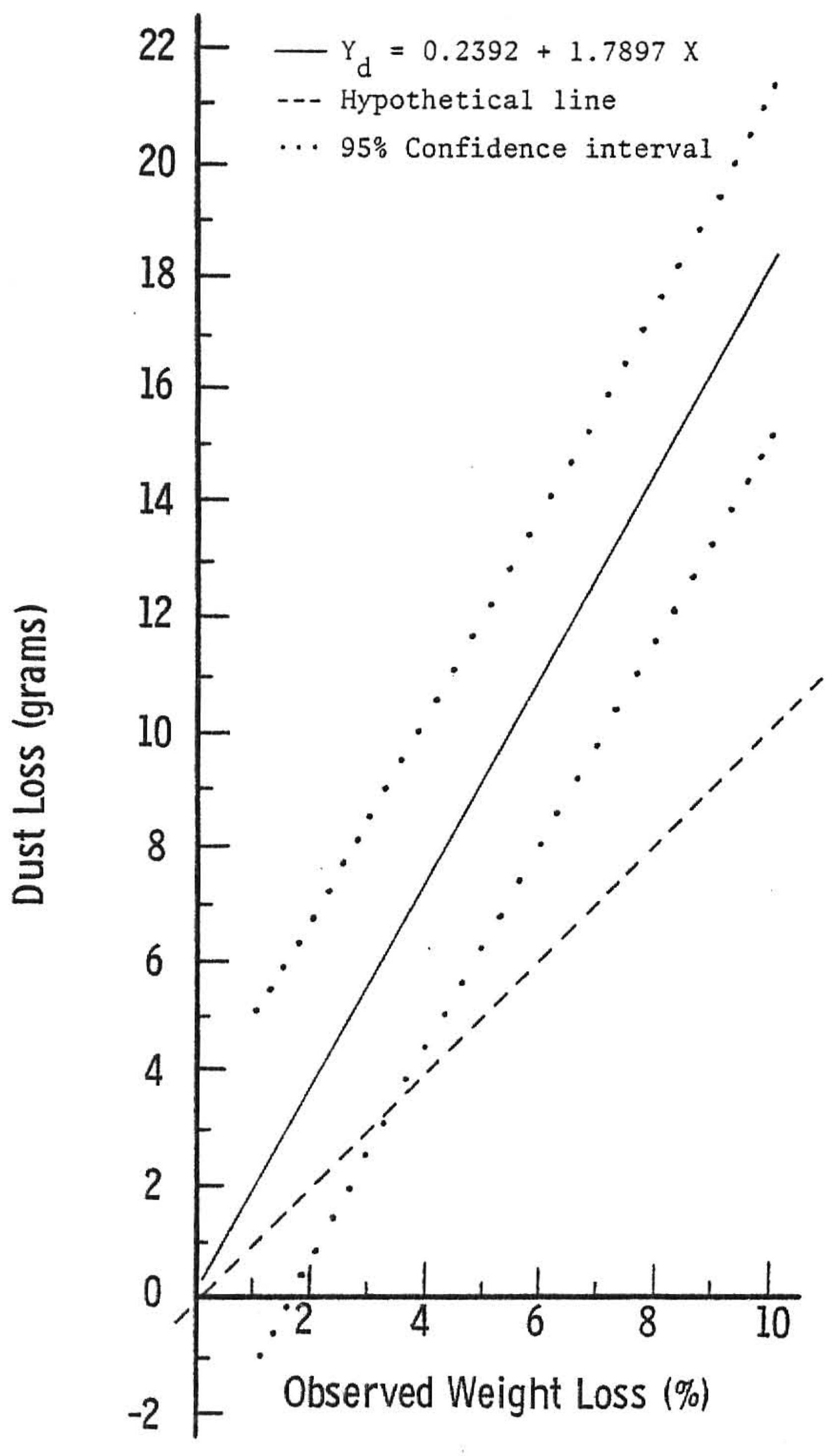
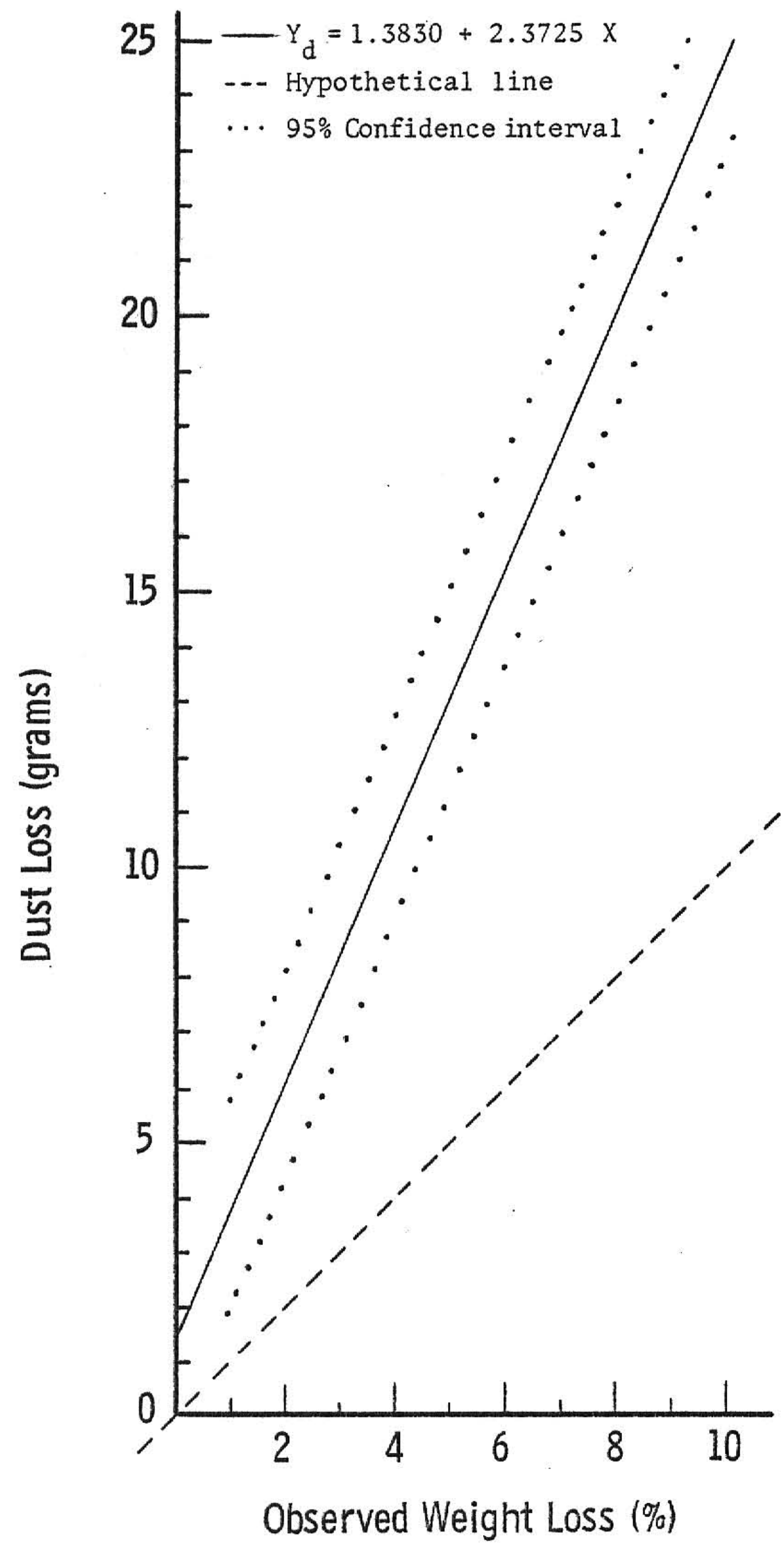

Y_d = 0.0489 + 1.7371 X
--- Hypothetical line
··· 95% Confidence interval
Dust Loss (grams)
22
20
18
16
14
12
10
8
6
4
2
0
-2
2
4
6
8
10
Observed Weight Loss (%)

Figure A-2. Relationship between dust (grams) produced by Sitophilus zeamais (Mots.) and percent Observed Weight Loss in sorghum over 5 weeks at 26 ± 2°C and 68 ± 5% r.h. $R^2 = 0.9520$.



— Y_d = 0.2392 + 1.7897 X
--- Hypothetical line
··· 95% Confidence interval
Dust Loss (grams)
Observed Weight Loss (%)
22
20
18
16
14
12
10
8
6
4
2
0
-2
2
4
6
8
10

Figure A-3. Relationship between dust (grams) produced by *Sitophilus zeamais* (Mots.) and percent Observed Weight Loss in wheat over 5 weeks at 26 ± 2°C and 68 ± 5% r.h. R^2 = 0.9886.



—— $Y_d = 1.3830 + 2.3725\ X$
--- Hypothetical line
··· 95% Confidence interval
25
20
15
10
5
0
2
4
6
8
10
Dust Loss (grams)
Observed Weight Loss (%)

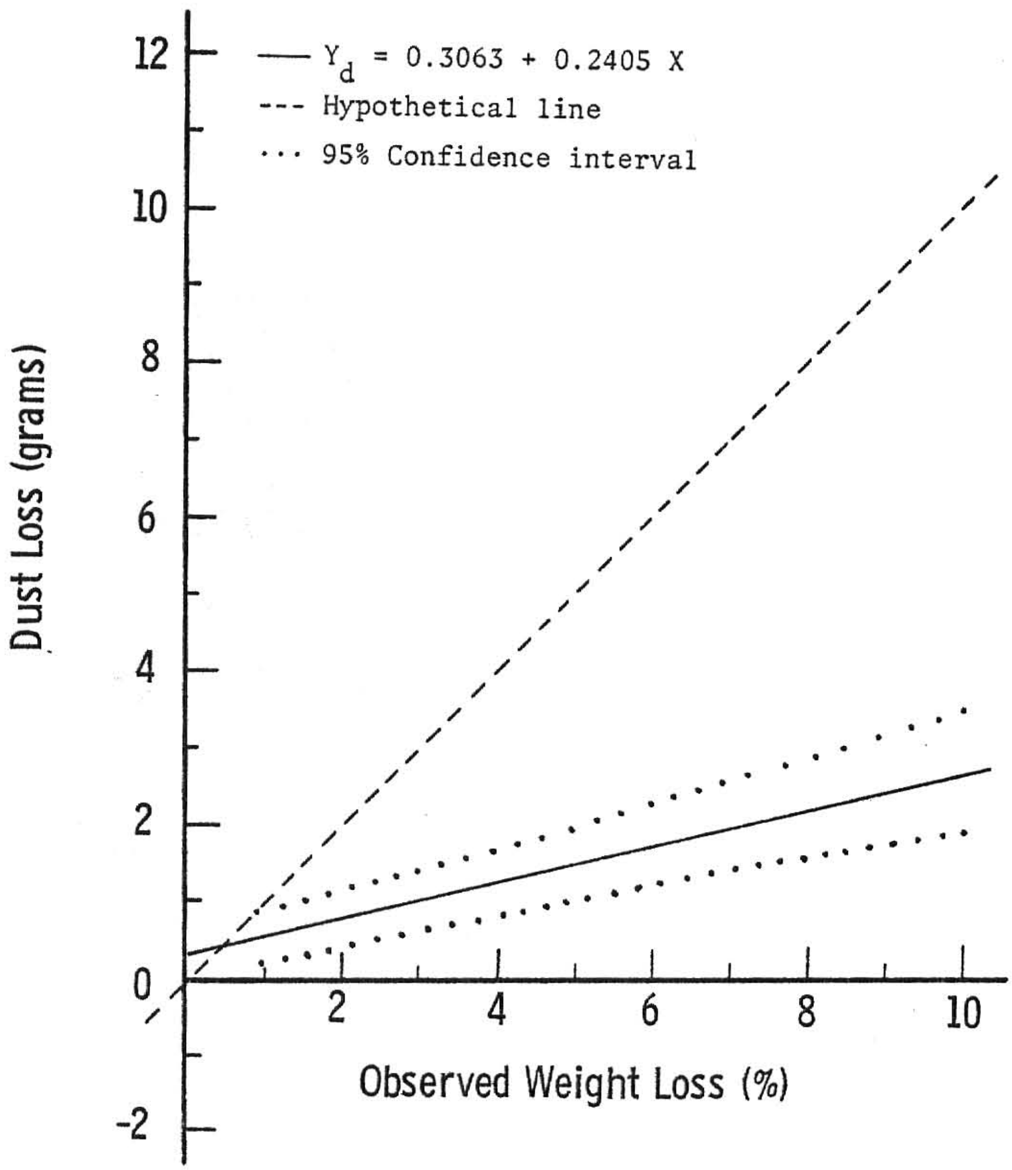
Table A-2. Grams of Dust Produced in Wheat by 40 Maize Weevils/100 g Over a 5 Week Period

	DUST (grams)
Control	0.00^{A}
Week 1	-0.47^{B}
2	-0.50^{B}
3	-0.77^{C}
4	-0.77^{C}
5	-0.93^{C}

[1] Duncan's Multiple Range Test. Alpha level = 0.05 (d.f.) = 12
Means with the same letter are not significantly different

Proc GLM was used to carry out a regression analysis comparing the Dust totals to the Observed Weight Loss (Fig. A-4). The R^2 value was 0.7046. The regression line for Dust lies below the hypothetical line and underestimated loss. Possibly when the insects emerge and expel dust from the inside of the kernel, the dust estimation would rise to meet or exceed the hypothetical line.

Figure A-4. Relationship between dust (grams) produced by *Sitophilus zeamais* (Mots.) and percent Observed Weight Loss measured in wheat weekly over 5 wk period at 26 ± 2°C and 68 ± 5% r.h. $R^2 = 0.7046$.



12
10
8
6
4
2
0
-2
Dust Loss (grams)
2
4
6
8
10
Observed Weight Loss (%)
— Y_d = 0.3063 + 0.2405 X
--- Hypothetical line
··· 95% Confidence interval

APPENDIX B

SIEVING OF DUST

APPENDIX B

SIEVING OF DUST

The grain was sieved using U.S. Standard sieves 10 meshes/in. for corn, rice and sorghum and 12 meshes/in. for wheat. The grain was shaken back and forth by hand until the insects were out of the grain. There was no particular time period involved. The sievings were weighed in the bottom pan of the U.S. Standard sieve on a tared Sartorius scale accurate to 0.1 g.

APPENDIX C

COUNT AND WEIGH METHOD

APPENDIX C

COUNT AND WEIGH METHOD (*Adams and Schulten, 1978*)

There are many situations in which a loss estimate is required but where there is only minimal equipment available and the baseline could not be determined before the storage period. In addition, it is *sometimes impossible* to determine a baseline for the standard volume/weight method because too many grains have been damaged.

This is essentially a method that takes a sample, separates it into undamaged and damaged portions, counts and weighs each, and calculates the percentage weight loss. It assumes that the undamaged portion is totally undamaged.

Used for unshelled and mold-damaged grains, it provides a useful means of estimating loss at moderate infestation levels with a minimum of apparatus.

Equipment

1. Balance with a range of 0.5 g to 1.5 kg accurate to 0.1 g.
2. Tally counter.
3. Plastic bags and a liquid fumigant such as CCl_4 to enable retention of samples.

Procedure

The grains are separated into undamaged and damaged categories, the latter being separated according to cause. Grains in each category are counted and weighed. The resultant data may be substituted in the formula below:

$$\% \text{ weight loss} = \frac{(UNd) - (DNu)}{U(Nd + Nu)} \times 100$$

where U = weight of undamaged grains,

Nu = number of undamaged grains

D = weight of damaged grains,

Nd = number of damaged grains.

Sample Size

Experience with this method is still limited. A sample size is recommended of 100-1,000 grains. Besides its simplicity, the method has the advantage that damage by different species of insects, such as *Sitophilus*, *Sitotroga*, *Ephestia* spp., and *Rhizopertha*, can be measured. The method may also be used to determine damage caused by termites, rodents, and birds.

Sources of Error

Hidden infestation results in an underestimation of loss because grains that have lost weight are included in the undamaged portion. When the grain is heavily damaged, it may become so broken as to lead to counting errors.

At low levels of infestation with the insects selecting larger or otherwise nonrandom grains, the method is not dependable. At very high levels of infestation, kernels may be so destroyed as to be not measurable. For example, in maize ears at low infestation, often only the grains at the top of the ear are damaged because they are incompletely protected by the husks. These grains are often the smallest of the ear. The only recommendation to reduce this error is to take large samples.

Since insects will sometimes select and infest larger kernels, any procedure that compares the individual weights of kernels may result in a negative weight loss finding. The selection of internally infested kernels and their inclusion and weighing as undamaged can also result in negative loss findings unless care is taken to recognize and account for these samples.

A preference of insects for moist grains may confuse the relation between weight loss and damaged grains as well. To reduce a possible error arising from this behavior, the grains could be dried to the same moisture content.

APPENDIX D

STANDARD VOLUME/WEIGHT METHOD

APPENDIX D

STANDARD VOLUME/WEIGHT METHOD EXPLANATION (Adams and Schulten, 1978)

Method for Baseline Determination

A sample of approximately 5 kg is either taken from every farmer's store if they are being treated as individual case studies or, if there are distinct grain varieties under study, a representative sample of at least 5 kg is taken for each variety, assuming that they are fairly homogeneous. If any of the varieties is not uniform (does not have a standard weight-to-volume variation with changes in moisture due to intravarietal variations of the local grain(s)), then either each lot of stored grain must be treated individually or expert advice must be sought.

This large sample is sieved in the laboratory. The bulk sample is subdivided into five replicate subsamples. The moisture content which might be expected in the field over the storage season is determined either from locally available data or by approximation (a normal range that fulfills most purposes is 8-18%, depending on climatic conditions). The weight/volume relationship is taken over the range as follows: the range is broken down into five equal steps, e.g., if it is 10-18%, this will be 10, 12, 14, 16, 18. If small, perhaps 1%, steps such as from 8-12%, this will be 8, 9, 10, 11, 12%. One subsample will have a moisture content near to one of these figures and the moisture contents of the other subsamples will have to be changed either by drying or wetting, as follows, to cover the range.

Drying down to a moisture content.

This should be done with the grain in a shallow layer either in a warm, dry place with a current of air passing over it but protected from insect attack or, preferably, in a ventilated oven in shallow trays at a temperature not exceeding 35°C. Its moisture content should be checked at regular intervals by allowing a sample to cool and measuring its approximate water content. When it has reached the required moisture content, it should be placed in a sealed container to cool and the moisture content should be measured accurately. As a rough guide, a small sample of known weight can be placed on a dish in the oven and its loss in weight checked.

Wetting up to a moisture content.

This requires addition of a calculated weight of water to the grain to bring it up to a required moisture content. The weight of water required is given by the formula:

$$\text{Weight of water to be added (g)} = \text{weight of grain} \times \frac{\text{Required \% moisture content} - \text{initial \% moisture content}}{100 - \text{required \% moisture content}}$$

For example, if we have a subsample of 1,000 g of grain at 12% moisture content and require it to be at 16% moisture content, the calculation is:

$$\text{Weight of water} = 1000\,\frac{16-12}{100-16} = 1000\,\frac{4}{84} = 47.6\ \text{g}$$

This can be weighed out or, since 1 g of water occupies

1 ml, it can be measured out as a volume. Water is added to the grain in a sealed container with sufficient headspace for mixing, and mixed well. It is left for two weeks to condition, but vigorously shaken daily. For moisture contents over 16%, the container should be kept at 5^{o}-$10^{o}C$ in a refrigerator to discourage mold growth. At the end of the conditioning period, an accurate moisture content is determined for each subsample.

There are now five subsamples of grain at different moisture content for each variety. For each subsample the weight that occupies the volume measure (test weight container) should be determined by filling the container according to the instructions provided with the apparatus and then pouring out the contents and weighing it to the nearest 0.1 g. This should be done three times for each subsample and a mean result obtained.

There will now be five mean weights for each variety at five accurately measured moisture contents. Each of these weights should then be converted to dry weight as follows:

$$\text{Dry weight} = \text{weight of grain} \times \frac{100 - \%\ \text{moisture content}}{100}$$

For example, if the volume of grain in the test weight container weighed 800 g and had a moisture content of 15%, then its dry weight is:

$$\text{Dry weight} = 800 \times \frac{100 - 15}{100} = 800 \times \frac{85}{100} = 680\ \text{g}.$$

This is done for all subsamples so as to obtain a set of dry weights for each moisture content. A graph is now drawn of the dry weight against the moisture content, for example:

% m.c.	10.2	12	13.9	16	17.8
Dry wt.	700	680	650	620	600

From this a reference line can be plotted of dry weights as determined by measuring the actual moisture content and test weight at the time a test is made. This graph is then used throughout the rest of the sampling period to represent the dry weight of sample at any moisture content as if it had not been damaged in store.

A curve must be made for each variety or area-cultural situation (see Figrue D-1).

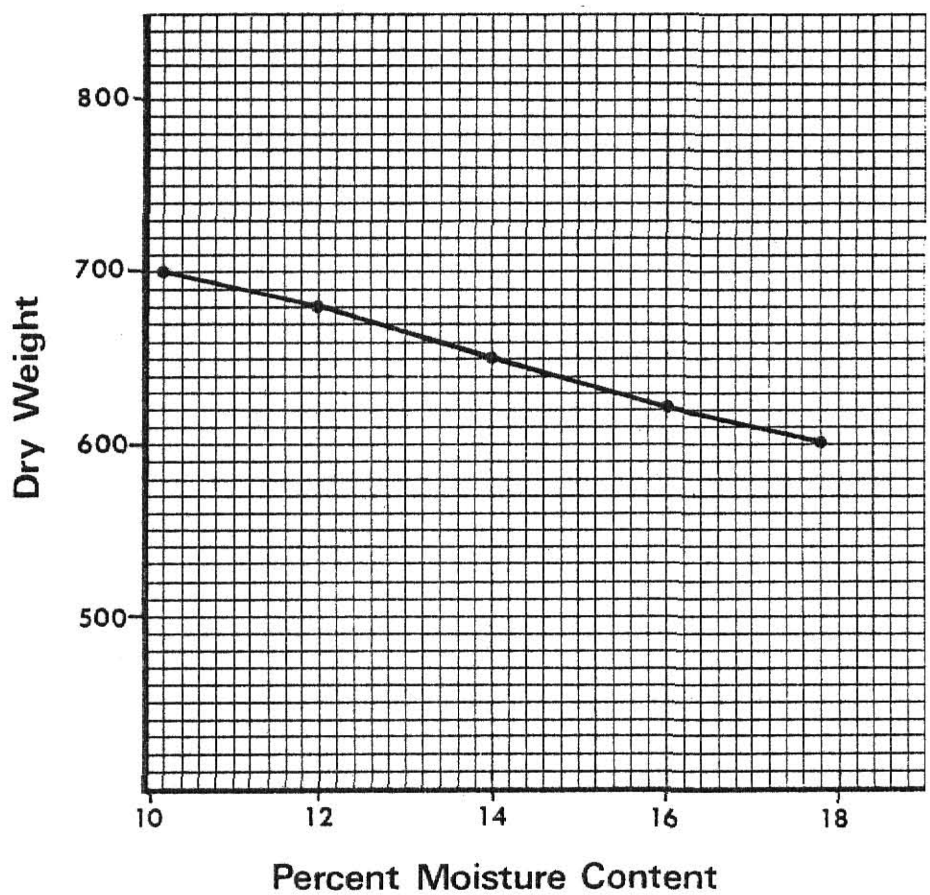
Loss Measurement Procedures

After preliminary laboratory work for the baseline figure, the measurements can be made in the field or laboratory.

Equipment

1. Test weight apparatus for obtaining a standardized volume of grain.
2. Balance, such as a triple beam balance, capable of measuring 1.0-1.5 kg accurate to 0.1 g.
3. A moisture meter capable of measuring to 0.1% and calibrated for the type of grain being measured.
4. A suitable size of grain sieve for the removal of insects, dust, and any other material that would

Figure D-1. Standard baseline curve for dry weight of a fixed volume of grain as moisture content changes (example).


800
700
600
500
Dry Weight
10
12
14
16
18
Percent Moisture Content

normally be removed prior to further processing.

5. Plastic sample bags and a liquid fumigant such as CCl_4, to retain samples for examination at a later date.

Procedure

A well-mixed sample, taken from the store, is first sieved by a locally appropriate method and the weight of sievings are counted as a loss if they are not used locally or calculated back to the weight/volume if they are used.

The moisture content is measured.

The weight occupying the volume container is measured. This is repeated three times and a mean taken. This weight is converted to dry weight using the moisture content and formula for dry weight (see derivation of Figure D-1).

The graph is used to find the dry weight of a sample at the same moisture content taken at the time of storage. For example, if the moisture content of the farmer's sample was 12%, then referring to the example, Fig. D-1, the dry weight would be 680.

The weight loss in the farmer's sample is then calculated as follows:

$$\% \text{ of weight loss} = \frac{\text{dry wt. from graph} - \text{dry wt. in sample}}{\text{dry wt. from graph}} \times 100$$

For example, if our farmer's sample at a moisture content of 12% had a dry weight of 600 g, then as the dry weight on the graph for 12% moisture is 680 g, the loss would be:

$$\% \text{ dry weight loss} = \frac{680 - 600 \text{ X } 100}{680} = \frac{80 \text{ X } 100}{680} = 11.8\%$$

This is the dry weight loss, which by definition excludes moisture content changes.

Sources of Error

The standardized method of obtaining the volume attempts to eliminate variations in packing, but with grain samples containing very high levels of damage, some of the grains may become crushed and lead to inaccuracies especially with small grains that may be sieved or winnowed out or crushed so that their insect- or microorganism-caused emptiness is not detected. In this case they may have to be picked out and losses otherwise estimated. Conversion factors change in the course of the storage period from high to low, due to increased severity of damage to the already-damaged grains.

The admixture of an insecticidal dust to shelled grain increases friction between grains and will reduce packing and hence the weight per unit volume will be less. Therefore, the weights for treated grain must not be compared with weights obtained for untreated grain.

For paddy, the effect of moisture content on the dry weight occupying a given volume is negligible, so within a range of 5% moisture there is no requirement for a predictive graph.

Rice (as distinct from paddy) would best be measured by out-turn of the mill.

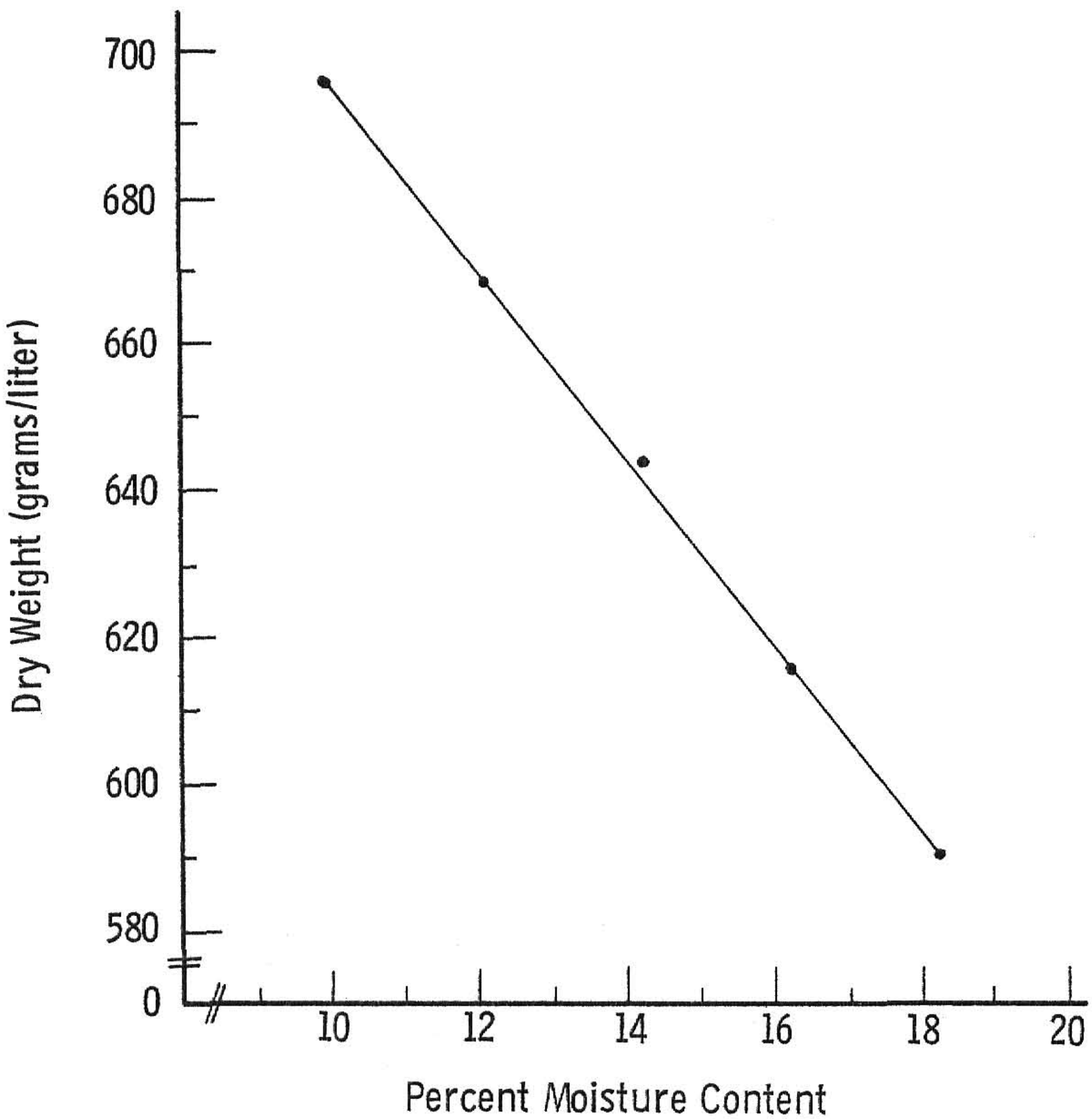
Lumps of, or otherwise webbed-together, grain can add weight.

However, if the lumps are picked or sieved out by local custom, they should also be picked out and the kernel loss estimated.

Since little is known about methods for determining losses in insect-damaged millet which, in effect, are hollowed shells, and since no procedures have been satisfactorily described for picking out and weighing of insect-infested millet, this grain presents a real problem not yet resolved by this current method.

Figure D-2. Standard Baseline curve for the experiment for dry weight of a liter of maize.

Moisture Content (%)	Observed Dry Weight (grams/liter)	Sample Regression Predicted Value (grams/liter)
10.05	695	695.9
12.15	669	668.8
14.25	644	641.7
16.24	615	616.1
18.23	590	590.4



700
680
660
640
620
600
580
0
Dry Weight (grams/liter)
10
12
14
16
18
20
Percent Moisture Content

Figure D-3. Standard baseline curve for the experiment for dry weight of a liter of rice.

Moisture Content (%)	Observed Dry Weight (grams/liter)	Sample Regression Predicted Value (grams/liter)
10.36	540	539.6
12.38	531	531.2
14.39	523	522.9
16.46	513	514.3
18.46	507	506.0

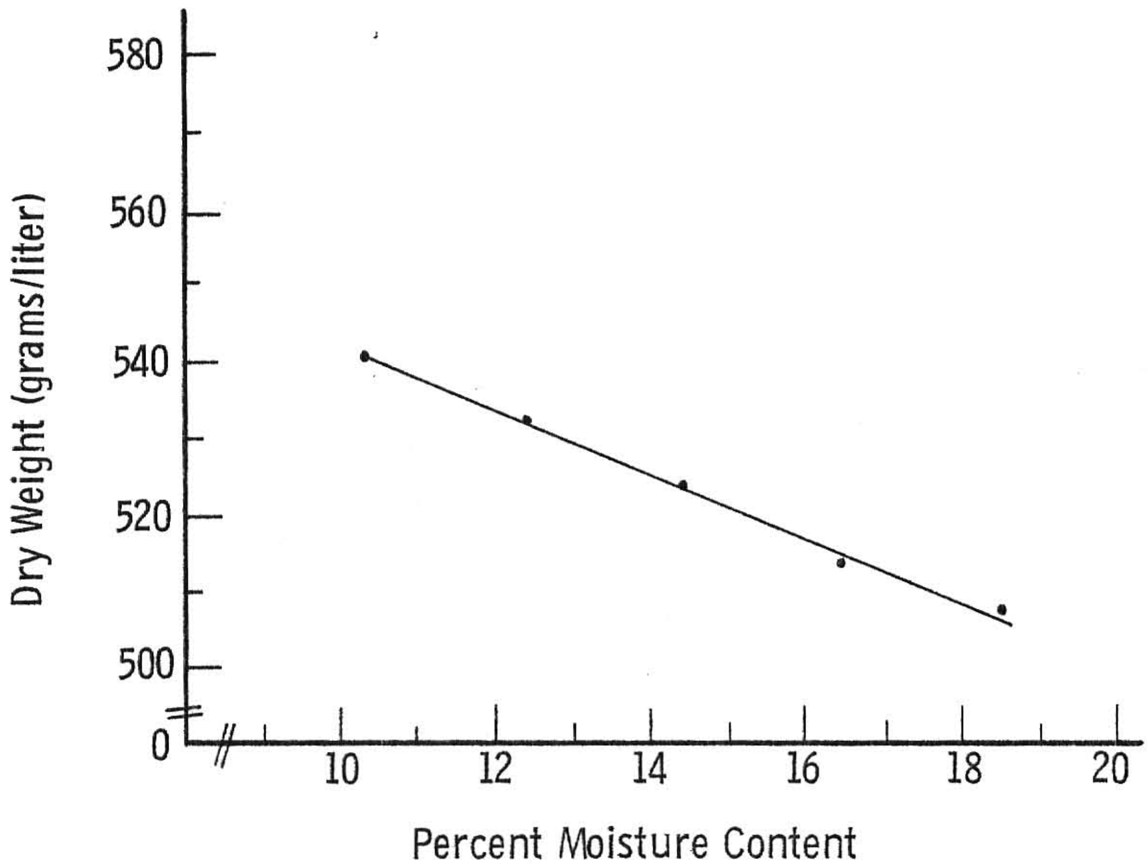

580
560
540
520
500
0
Dry Weight (grams/liter)
10
12
14
16
18
20
Percent Moisture Content

Figure D-4. Standard baseline curve for the experiment for dry weight of a liter of sorghum.

Moisture Content (%)	Observed Dry Weight (grams/liter)	Sample Regression Predicted Value (grams/liter)
10.51	699	701.0
12.44	685	683.1
14.33	667	665.6
16.29	647	647.5
18.74	624	624.8

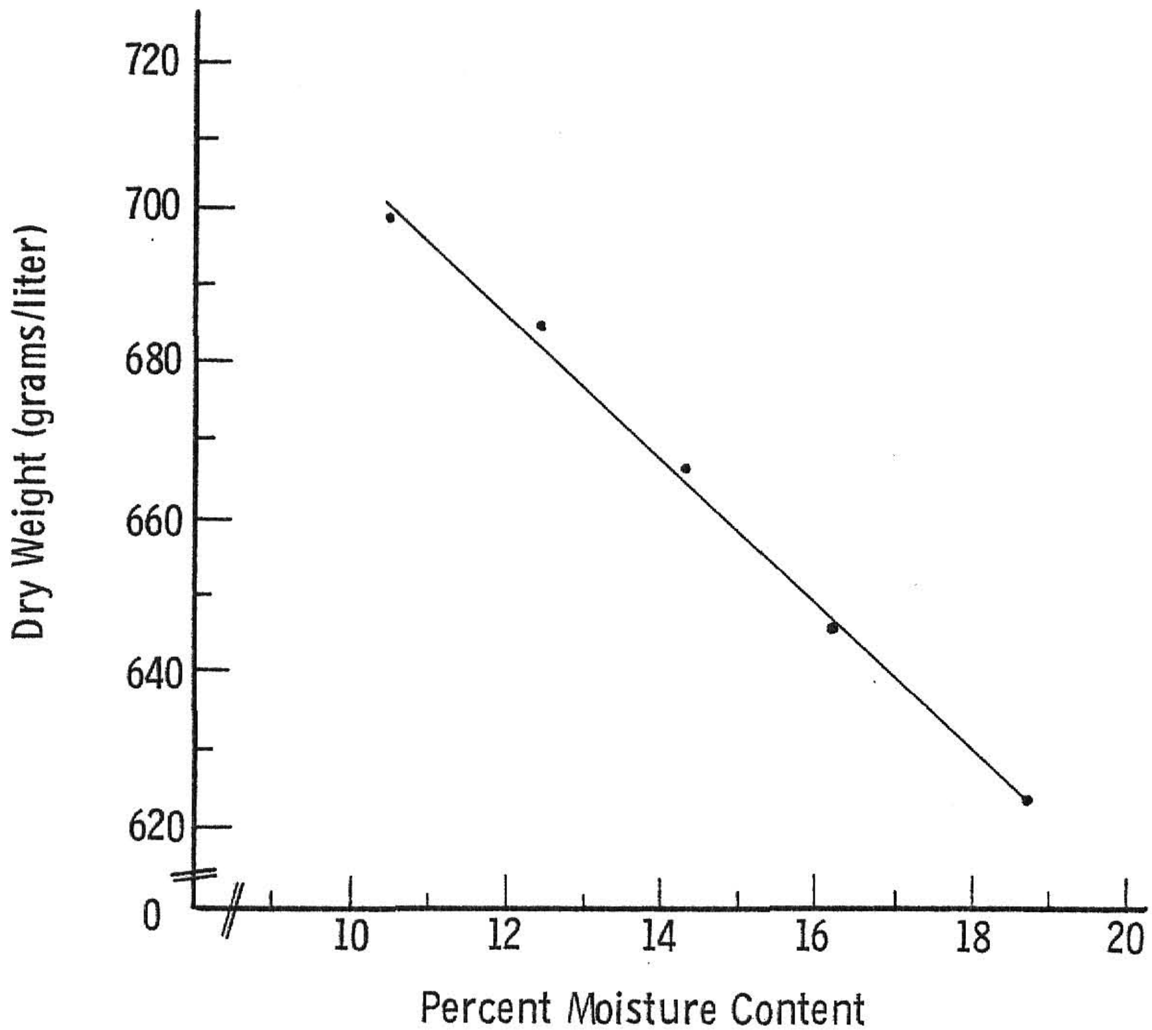
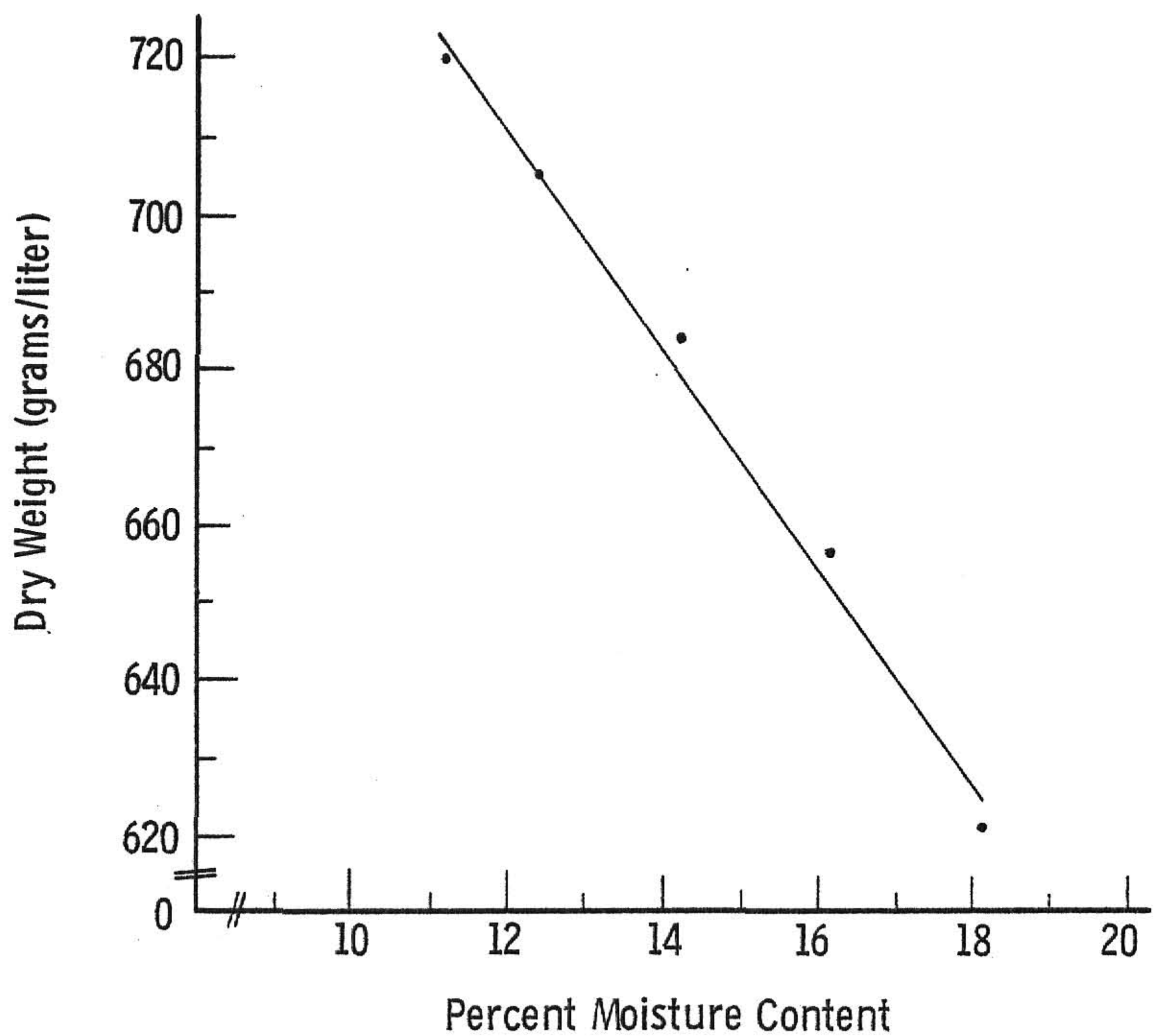

Dry Weight (grams/liter)
720
700
680
660
640
620
0
10
12
14
16
18
20
Percent Moisture Content

Figure D-5. Standard baseline curve for the experiment for dry weight of a liter of wheat.

Moisture Content (%)	Observed Dry Weight (grams/liter)	Sample Regression Predicted Value (grams/liter)
11.15	720	723.2
12.41	705	705.3
14.21	684	679.8
16.16	656	652.2
18.11	620	624.5


Dry Weight (grams/liter)
720
700
680
660
640
620
0
10
12
14
16
18
20
Percent Moisture Content

APPENDIX E

RAW DATA

Table E-1. Raw Data for MAIZE

Infestation Rate Insects per 100 g	Wet Weight of Maize-End of Storage (grams)	Final Moisture Content (Wet Basis) (%)	Dry Weight of Maize-End of Storage (grams)	Total Weight Loss (grams)	Observed Weight Loss (%)	Dry Test Weight (grams/liter)	Predicted Dry Test Weight (grams/liter)
20	1149.8	12.4	1007.2	-40.0	-3.9	644	666
	1143.3	12.7	998.1	-49.5	-4.7	639	662
	1159.2	12.3	1016.6	-31.0	-3.0	656	666
40	1131.5	12.9	985.5	-62.1	-5.9	631	659
	1135.4	13.0	987.8	-59.8	-5.7	632	658
	1158.7	12.3	1016.2	-31.4	-3.0	653	667
60	1154.2	12.6	1008.8	-38.8	-3.7	647	663
	1151.3	12.2	1010.8	-36.8	-3.5	649	668
	1160.8	12.2	1019.2	-28.4	-2.7	653	668
80	1141.8	12.4	1000.2	-47.4	-4.5	641	666
	1153.0	12.2	1012.3	-35.3	-3.4	649	668
	1141.9	12.5	999.2	-48.4	-4.6	638	664
100	1141.1	12.5	998.5	-49.1	-4.7	639	664
	1153.3	12.3	1011.4	-36.2	-3.5	651	666
	1142.7	12.4	1001.0	-46.6	-4.4	636	665
Control	1190.6	12.1	1046.5	- 1.1	-0.1	666	669
	1188.4	12.2	1043.4	- 4.2	-0.4	663	668
	1187.9	12.3	1041.8	- 5.8	-0.6	661	666

Original moisture content going into store = 12.7% (Wet Basis)
1200 g = 1047.6 g dry weight
Final moisture content coming out of store - 12.2% (Wet Basis)
1189.0 g = 1043.9 g dry weight
- signifies a weight loss

Table E-2. Raw Data for Maize

Infestation Rate Insects per 100 g	Observed Weight Loss (%)	Mean	Count and Weight Loss (%)	Mean	Standard Volume/ Weight Loss (%)	Mean	Weight of Dust Sieved Out (g)	Mean
20	-3.9		-7.9		-3.2		- 6.7	
	-4.7	-3.87	-6.7	-6.43	-3.4	-2.77	- 5.3	-5.90
	-3.0		-4.7		-1.6		- 5.7	
40	-5.9		-4.7		-4.3		- 9.0	
	-5.7	-4.87	-5.5	-5.57	-3.9	-3.43	- 9.0	-7.67
	-3.0		-6.5		-2.1		- 5.0	
60	-3.7		-6.8		-2.4		- 7.0	
	-3.5	-3.30	-6.6	-6.83	-2.9	-2.52	- 6.5	-6.43
	-2.7		-7.1		-2.3		- 5.8	
80	-4.5		-7.7		-3.7		- 7.7	
	-3.4	-4.20	-6.2	-7.23	-2.9	-3.51	- 7.6	-7.70
	-4.6		-7.8		-4.0		- 7.8	
100	-4.7		-9.8		-3.8		-10.0	
	-3.5	-4.20	-6.6	-8.13	-2.4	-3.55	- 6.3	-8.67
	-4.4		-8.0		-4.5		- 9.7	
Control	-0.1		0.0		-0.5		0.0	
	-0.4	-0.37	0.0	0.00	-0.8	-0.73	0.0	0.00
	-0.6		0.0		-0.9		0.0	

- signifies a weight loss

Table E-3. Raw Data for RICE

Infestation Rate Insects per 100 g	Wet Weight of Rice- End of Storage (grams)	Final Moisture Content (Wet Basis) (%)	Dry Weight of Rice- End of Storage (grams)	Total Weight Loss (grams)	Observed Weight Loss (%)	Dry Test Weight (grams/liter)	Predicted Dry Test Weight (grams/liter)
20	1189.8	12.1	1045.8	+3.0	+0.3	536	532
	1188.9	12.1	1045.0	+2.2	+0.2	536	532
	1191.3	12.1	1047.2	+4.4	+0.4	534	532
40	1191.5	12.0	1048.5	+5.7	+0.5	535	533
	1191.7	12.1	1047.5	+4.7	+0.5	534	532
	1190.8	12.2	1045.5	+2.7	+0.3	536	532
60	1193.1	12.2	1047.5	+4.7	+0.5	533	532
	1186.6	12.0	1044.2	+1.4	+0.1	534	533
	1189.0	12.0	1046.3	+3.5	+0.3	534	533
80	1188.5	12.0	1045.9	+3.1	+0.3	535	533
	1188.0	12.1	1044.3	+1.5	+0.1	535	532
	1188.1	12.1	1044.3	+1.5	+0.1	535	532
100	1186.8	12.2	1042.0	-0.8	-0.1	536	532
	1187.2	12.5	1038.8	-4.0	-0.4	534	531
	1179.9	12.2	1036.0	-6.8	-0.7	535	532
Control	1194.8	12.8	1041.9	-0.9	-0.1	528	529
	1195.4	12.7	1043.6	+0.8	+0.1	529	530
	1194.4	13.1	1037.9	-4.9	-0.5	528	528

Original moisture content going into store = 13.1% (Wet Basis)
1200 g = 1042.8 g dry weight
Final moisture content coming out of store = 12.9% (Wet Basis)
1194.9 g = 1040.8 g dry weight
+ signifies a weight gain
- signifies a weight loss

Table E-4. Raw Data for Rice

Infestation Rate Insects per 100 g	Observed Weight	Mean	Count and Weight Loss (%)	Mean	Standard Volume/ Weight Loss (%)	Mean	Weight of Dust Sieved Out (g)	Mean
20	+0.3		-1.2		+0.7		-1.1	
	+0.2	+0.30	-1.3	-0.90	+0.7	+0.56	-0.7	-0.97
	+0.4		-0.2		+0.3		-1.1	
	+0.5		-0.2		+0.4		-1.0	
40	+0.5	+0.43	-0.5	-0.23	+0.3	+0.49	-1.2	-0.97
	+0.3		0.0		+0.8		- .7	
	+0.5		-0.2		+0.2		-1.3	
60	+0.1	+0.30	-0.5	-0.33	+0.2	+0.22	-1.5	-1.33
	+0.3		-0.3		+0.2		-1.2	
	+0.3		-0.4		+0.4		-1.1	
80	+0.1	+0.17	-0.1	-0.27	+0.5	+0.47	-1.1	-1.13
	+0.1		-0.3		+0.5		-1.2	
100	-0.1		-0.3		+0.8		-1.7	
	-0.4	-0.40	-0.4	-0.40	+0.6	+0.65	-1.0	-1.40
	-0.7		-0.5		+0.6		-1.5	
Control	-0.1		0.0		-0.3		0.0	
	+0.1	-0.17	0.0	0.00	-0.2	-0.16	0.0	0.0
	-0.5		0.0		0.0		0.0	

+ signifies a weight gain
- signifies a weight loss

Table E-5. Raw Data for SORGHUM

Infestation Rate Insects per 100 g	Wet Weight of Sorghum-End of Storage (grams)	Final Moisture Content (Wet Basis) (%)	Dry Weight of Sorghum-End of Storage (grams)	Total Weight Loss (grams)	Observed Weight Loss (%)	Dry Test Weight (grams/liter)	Predicted Dry Test Weight (grams/liter)
20	1167.0	13.0	1015.3	- 28.7	-2.7	655	678
	1170.5	12.9	1019.5	- 24.5	-2.3	653	679
	1160.3	13.1	1008.3	- 35.7	-3.4	646	677
40	1142.5	13.4	989.4	- 54.6	-5.2	635	674
	1133.5	13.5	980.5	- 63.5	-6.1	634	673
	1132.4	13.5	979.5	- 64.5	-6.2	634	673
60	1121.3	13.6	968.8	- 75.2	-7.2	620	672
	1109.6	13.9	955.4	- 88.6	-8.5	612	670
	1130.9	13.7	976.0	- 68.0	-6.5	629	671
80	1111.8	14.0	956.1	- 87.9	-8.4	619	669
	1126.4	13.7	972.1	- 71.9	-6.9	623	671
	1115.0	14.0	958.9	- 85.1	-8.2	611	669
100	1109.1	14.0	953.8	- 90.2	-8.6	617	669
	1093.8	14.3	937.4	-106.6	-10.2	599	666
	1110.0	14.0	954.6	- 89.4	-8.6	611	669
Control	1198.0	12.9	1043.5	- 0.5	-0.1	674	679
	1196.2	13.1	1039.5	- 4.5	-0.4	673	677
	1197.0	13.1	1040.2	- 3.8	-0.4	673	677

Original moisture content going into store = 13.0% (Wet Basis)
1200 g = 1044 g dry weight
Final moisture content coming out of store = 13.0% (Wet Basis)
1197.1 g = 1041.5 g dry weight
- *signifies a weight loss*

Table E-6. Raw Data for SORGHUM

Infestation Rate Insects per 100 g	Observed Weight Loss (%)	Mean	Count and Weight Loss (%)	Mean	Standard Volume/ Weight Loss (%)	Mean	Weight of Dust Sieved Out (g)	Mean
20	-2.7		-2.0		-3.4		- 9.8	
	-2.3	-2.80	-3.0	-2.50	-3.8	-3.93	- 4.5	- 6.67
	-3.4		--		-4.6		- 5.7	
40	-5.2		-5.6		-5.8		- 8.7	
	-6.1	-5.83	-5.7	-6.00	-5.8	-5.83	-10.1	- 9.77
	-6.2		-6.7		-5.8		-10.5	
60	-7.2		-7.2		-7.8		-13.1	
	-8.5	-7.40	-7.8	-6.83	-8.6	-7.57	-15.1	-13.40
	-6.5		-5.5		-6.3		-12.0	
80	-8.4		-8.6		-7.4		-15.0	
	-6.9	-7.83	-8.3	-8.13	-7.2	-7.76	-12.9	-14.30
	-8.2		-7.5		-8.6		-15.0	
100	-8.6		-8.5		-7.7		-16.2	
	-10.2	-9.13	-9.7	-9.20	-10.0	-8.80	-18.2	-16.90
	-8.6		-9.4		-8.6		-16.3	
Control	-0.1		0.0		-0.7		0.0	
	-0.4	-0.30	0.0	0.00	-0.6	-0.64	0.0	0.00
	-0.4		0.0		-0.6		0.0	

- signifies a weight loss

Table E-7. Raw Data for WHEAT

Infestation Rate Insects per 100 g	Weight of Wheat-End of Storage (grams)	Final Moisture Content (Wet Basis) (%)	Dry Weight of Wheat-End of Storage (grams)	Total Weight Loss (grams)	Observed Weight Loss (%)	Dry Test Weight (grams/liter)	Predicted Dry Test Weight (grams/liter)
20	1157.0	13.2	1004.3	-31.3	-3.0	688	694
	1157.4	13.1	1005.8	-29.8	-2.9	693	696
	1159.2	13.1	1007.3	-28.3	-2.7	690	696
40	1136.5	13.4	984.2	-51.4	-5.0	676	691
	1124.7	13.4	974.0	-61.6	-5.9	668	691
	1124.2	13.4	973.6	-62.0	-6.0	666	691
60	1107.4	13.6	956.8	-78.8	-7.6	655	688
	1117.6	13.6	965.6	-70.0	-6.8	658	688
	1139.7	13.4	987.0	-48.6	-4.7	672	691
80	1112.2	13.7	959.8	-75.8	-7.3	657	687
	1111.5	13.7	959.2	-76.4	-7.4	657	687
	1107.1	13.8	954.3	-81.3	-7.9	647	686
100	1099.5	13.8	947.8	-87.8	-8.5	645	686
	1089.5	14.0	937.0	-98.6	-9.5	635	683
	1098.2	13.8	946.6	-89.0	-8.6	646	686
Control	1192.3	12.9	1038.5	+ 2.9	+0.3	702	698
	1192.6	13.0	1037.6	+ 2.0	+0.2	701	697
	1193.3	12.9	1039.4	+ 3.8	+0.4	702	698

Original moisture content going into store - 13.7% (Wet Basis)
1200 g = 1035.6 g dry weight
Final moisture content coming out of store - 12.9% (Wet Basis)
1192.7 g = 1038.8 dry weight
\+ signifies a weight gain
\- signifies a weight loss

Table E-8. Raw Data for WHEAT

Infestation Rate Insects per 100 g	Observed Weight Loss (%)	Mean	Count and Weigh Loss (%)	Mean	Standard Volume/ Weight Loss (%)	Mean	Weight of Dust Sieved Out (g)	Mean
20	-3.0		-3.0		-0.9		-9.3	
	-2.9	-2.87	-2.6	-3.03	-0.4	-0.68	-9.5	- 9.57
	-2.7		-3.5		-0.8		-9.9	
40	-5.0		-3.8		-2.2		-12.0	
	-5.9	-5.63	-4.1	-4.40	-3.4	-3.08	-15.8	-14.30
	6.0		-5.3		-3.7		-15.1	
60	-7.6		-6.9		-4.9		-19.2	
	-6.8	-6.37	-6.1	-5.40	-4.4	-4.02	-17.3	-16.0
	-4.7		-3.2		-2.8		-12.7	
80	-7.3		-4.9		-4.4		-17.9	
	-7.4	-7.53	-6.4	-5.37	-4.4	-4.79	-19.1	-18.87
	-7.9		-4.8		-5.6		-19.6	
100	-8.5		-8.3		-5.9		-21.7	
	-9.5	-8.87	-7.5	-7.7	-7.0	-6.23	-24.2	-22.63
	-8.6		-7.8		-5.8		-22.0	
Control	+0.3		0.0		+0.5		0.0	
	+0.2	+0.30	0.0	0.00	+0.6	+0.54	0.0	0.00
	+0.4		0.0		+0.5		0.0	

\+ signifies a weight gain
\- signifies a weight loss

Table E-9. Raw Data for Weekly Experiment in WHEAT

Week	Wet Weight of Wheat-End of Storage (grams)	Final Moisture Content (Wet Basis) (%)	Dry Weight of Wheat-End of Storage (grams)	Total Weight Loss (grams)	Observed Weight Loss (%)	Dry Test Weight (grams/liter)	Predicted Dry Test Weight (grams/liter)
1	1193.4	13.5	1032.3	- 3.3	-0.3	698	690
	1193.2	13.5	1032.1	- 3.5	-0.3	697	690
	1193.9	13.5	1032.7	- 2.9	-0.3	697	690
2	1194.0	13.7	1030.4	- 5.2	-0.5	695	687
	1194.0	13.7	1030.4	- 5.2	-0.5	695	687
	1194.1	13.7	1030.5	- 5.1	-0.5	695	687
3	1189.3	13.8	1025.2	-10.4	-1.0	684	686
	1189.9	13.9	1024.5	-11.1	-1.1	682	684
	1189.7	13.9	1024.3	-11.3	-1.1	681	684
4	1179.7	14.2	1012.2	-23.4	-2.3	673	680
	1179.7	14.3	1011.0	-24.6	-2.4	671	679
	1178.3	14.4	1008.6	-27.0	-2.6	668	677
5	1180.7	14.2	1013.0	-22.6	-2.2	674	680
	1174.8	14.3	1006.8	-28.8	-2.8	665	679
	1175.6	14.5	1005.1	-30.5	-2.9	665	676

Original moisture content going into store = 13.7% (Wet Basis)
1200 g = 1035.6 g dry weight
Infestation rate - 40 insects per 100 g
- signifies a weight loss

Table E-10. Raw Data for Weekly Experiment in WHEAT

Week	Observed Weight Loss (%)	Mean	Count and Weigh Loss (%)	Mean	Standard Volume/ Weight Loss (%)	Mean	Weight of Dust Sieved Out (g)	Mean
1	-0.3		0.0		+1.2		-0.6	
	-0.3	-0.30	0.0	0.00	+1.0	+1.08	-0.4	-0.47
	-0.3		0.0		+1.0		-0.4	
2	-0.5		0.0		+1.2		-0.4	
	-0.5	-0.50	0.0	0.00	+1.2	+1.16	-0.6	-0.50
	-0.5		0.0		+1.2		-0.5	
3	-1.0		0.0		-0.2		-0.9	
	-1.1	-1.07	0.0	0.00	-0.3	-0.34	-0.6	-0.77
	-1.1		0.0		-0.5		-0.8	
4	-2.3		0.0		-1.0		-0.7	
	-2.4	-2.43	0.0	0.00	-1.1	-1.16	-0.9	-0.77
	-2.6		0.0		-1.3		-0.7	
5	-2.2		0.0		-0.9		-0.9	
	-2.8	-2.63	-0.5	-0.37	-2.0	-1.48	-1.0	-0.93
	-2.9		-0.6		-1.6		-0.9	
Control	+0.3		0.0		+0.5		0.0	
	+0.2	+0.30	0.0	0.00	+0.6	+0.54	0.0	0.00
	+0.4		0.0		+0.5		0.0	

Infestation rate = 40 insects per 100 g
+ signifies weight gain
- signifies weight loss

APPENDIX F

GENERAL LINEAR MODELS PROCEDURE INFORMATION

Table F-1. General Linear Models Procedure Information for MAIZE, refers to Figure 3.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
2.4151	-1.9410	6.7711
3.7498	-0.4512	7.9508
5.0845	0.9617	9.2074
6.4193	2.2932	10.5453
7.7540	3.5436	11.9644
9.0887	4.7176	13.4599
10.4235	5.8232	15.0238
11.7582	6.8699	16.6465
13.0929	7.8676	18.3183
14.4277	8.8250	20.0304

Intercept = 1.0803
Slope = 1.3347

Table F-2. General Linear Models Procedure Information for SORGHUM, refers to Figure 4.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
0.8900	-0.6593	2.4393
1.9010	0.3838	3.4181
2.9119	1.4196	4.4042
3.9228	2.4479	5.3978
4.9338	3.4682	6.3993
5.9447	4.4806	7.4088
6.9557	5.4849	8.4264
7.9666	6.4813	9.4519
8.9775	7.4700	10.4851
9.9885	8.4513	11.5256

Intercept = -0.1209
Slope = 1.0109

Table F-3. General Linear Models Procedure Information for WHEAT, refers to Figure 5.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
1.0920	-0.7226	2.9066
1.8736	0.0923	3.6549
2.6553	0.8986	4.4120
3.4369	1.6957	5.1780
4.2185	2.4836	5.9535
5.0001	3.2620	6.7383
5.7818	4.0311	7.5325
6.5634	4.7910	8.3358
7.3450	5.5421	9.1480
8.1267	6.2848	9.9685

Intercept = 0.3104
Slope = 0.7816

Table F-4. General Linear Models Procedure Information for MAIZE, refers to Figure 6.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
1.0576	0.0860	2.0292
1.7466	0.8096	2.6836
2.4355	1.5160	3.3551
3.1245	2.2042	4.0448
3.8135	2.8744	4.7526
4.5024	3.5275	5.4774
5.1914	4.1653	6.2175
5.8804	4.7901	6.9707
6.5693	5.4039	7.7348
7.2583	6.0087	8.5079

Intercept = 0.3686
Slope = 0.6890

Table F-5. General Linear Models Procedure Information for SORGHUM, refers to Figure 7.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
1.6880	0.4246	2.9515
2.5817	1.3432	3.8202
3.4754	2.2561	4.6947
4.3691	3.1628	5.5754
5.2628	4.0632	6.4623
6.1565	4.9573	7.3557
7.0502	5.8449	8.2555
7.9439	6.7261	9.1616
8.8376	7.6013	10.0739
9.7313	8.4706	10.9920

Intercept = 0.7943
Slope = 0.8937

Table F-6. General Linear Models Procedure Information for WHEAT, refers to Figure 8.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
-0,0998	-1.2328	1.0333
0.6559	-0.4563	1.7682
1.4116	0.3147	2.5085
2.1673	1.0801	3.2545
2.9230	1.8397	4.0063
3.6786	2.5933	4.7639
4.4343	3.3412	5.5275
5.1900	4.0833	6.2967
5.9457	4.8199	7.0714
6.7014	5.5513	7.8514

Intercept = 0.8554
Slope = 0.7557

Table F-7. General Linear Models Procedure Information for WHEAT, refers to Figure 10.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
0.0517	-0.2803	0.3837
0.1407	-0.1970	0.4784
0.2296	-0.1275	0.5867
0.3186	-0.0695	0.7067
0.4075	-0.0207	0.8357
0.4965	0.0213	0.9716
0.5854	0.0583	1.1125
0.6744	0.0916	1.2571
0.7633	0.1222	1.4044
0.8523	0.1508	1.5537

Intercept = 0.0372
Slope = 0.0889

Table F-8. General Linear Models Procedure Information for WHEAT, refers to Figure 11.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
-0.0580	-1.1160	1.0000
0.8117	-0.2645	1.8878
1.6813	0.5435	2.8192
2.5510	1.3143	3.7877
3.4207	2.0561	4.7852
4.2903	2.7761	5.8045
5.1600	3.4803	6.8397
6.0297	4.1727	7.8866
6.8993	4.8566	8.9421
7.7690	5.5339	10.0041

Intercept = -0.9277
Slope = 0.8697

Table F-9. General Linear Models Procedure Information for MAIZE, refers to Figure A-1.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
1.7859	-1.0808	4.6527
3.5230	0.7583	6.2877
5.2601	2.5468	7.9734
6.9972	4.2818	9.7126
8.7343	5.9634	11.5052
10.4714	7.5947	13.3480
12.2085	9.1810	15.2359
13.9456	10.7286	17.1625
15.6826	12.2438	19.1215
17.4197	13.7326	21.1069

Intercept = 0.0489
Slope = 1.7371

Table F-10. General Linear Models Procedure Information for SORGHUM, refers to Figure A-2.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
2.0289	-1.0340	5.0918
3.8186	0.8163	6.8210
5.6084	2.6525	8.5643
7.3981	4.4738	10.3224
9.1879	6.2799	12.0958
10.9777	8.0704	13.8848
12.7673	9.8454	15.6893
14.5571	11.6050	17.5092
16.3468	13.3498	19.3439
18.1366	15.0804	21.1928

Intercept = 0.2392
Slope = 1.7897

Table F-11. General Linear Models Procedure Information for WHEAT, refers to Figure A-3.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
3.7555	1.8412	5.6698
6.1280	4.2489	8.0072
8.5005	6.6473	10.3537
10.8730	9.0362	12.7099
13.2455	10.4153	15.0758
15.6180	13.7844	17.4517
17.9906	16.1437	19.8374
20.3631	18.4933	22.2328
22.7356	20.8336	24.6376
25.1081	23.1650	27.0512

Intercept = 1.3830
Slope = 2.3725

Table F-12. General Linear Models Procedure Information for WHEAT, refers to Figure A-4.

Predicted Value	Lower 95% CL Individual	Upper 95% CL Individual
0.5468	0.1524	0.9413
0.7874	0.3861	1.1886
1.0279	0.6037	1.4522
1.2685	0.8074	1.7296
1.5090	1.0002	2.0178
1.7495	1.1850	2.3141
1.9901	1.3638	2.6164
2.2306	1.5383	2.9230
2.4712	1.7095	3.2328
2.7117	1.8783	3.5451

Intercept = 0.3063
Slope = 0.2405

APPENDIX G

OBSERVED WEIGHT LOSS (%) IN WEEKLY WEIGHT LOSS EXPERIMENT IN WHEAT

Table G-1. Observed Weight Loss (%) in weekly weight loss experiment in WHEAT, refers to Figure 9.

Week	Observed Weight Loss (%)
1	0.3
2	0.5
3	1.1
4	2.4
5	2.6

AN INVESTIGATION OF THE ACCURACY OF TWO POSTHARVEST GRAIN LOSS ASSESSMENT METHODS

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The accuracies of two postharvest grain loss assessment methods were investigated. Weevils, from a Mexican strain of Sitophilus zeamais (Mots.), were used to provide 6 levels of infestation in 4 types of grain: yellow dent maize, rough rice, red sorghum and hard red winter wheat. The weevils were unable to oviposit in the rough rice and no useful data was obtained.

The Count and Weigh Method and the Standard Volume/Weight Method were used to estimate weight losses caused by one generation of insects. Observed (actual) weight losses (up to 9.1%) were measured accurately by weighing, measuring the moisture content, and converting to dry matter weight loss. The estimates and observed weight losses were compared using Duncan's multiple range test, a general linear models procedure from SAS, and a one-tailed F test.

The Count and Weigh Method estimated weight loss higher than was observed in maize. The estimated loss was very close to the observed weight loss in sorghum, but in wheat it was slightly less than that for observed weight loss. Using the one-tailed F test, the Count and Weigh Method accurately estimated loss at the 5% level of significance for sorghum and wheat only.

The Standard Volume/Weight Method underestimated loss in maize. In sorghum the method overestimated at the lower levels of loss and underestimated slightly at the higher levels of loss. In wheat the method consistently underestimated weight loss. The one-tailed F test indicated the Standard Volume/Weight

Method accurately estimated weight loss at the 5% level of significance for maize and sorghum.

In another experiment using only wheat, maize weevils were allowed to oviposit for 5 days, and once a week for 5 weeks 3 different jars of wheat were removed from store. The observed weight losses were calculated and losses estimated using the Count and Weigh Method and the Standard Volume/Weight Method. Neither method accurately estimated the observed weight loss during the first generation of infestation.