The determination of weight loss in grain fragments (L70)

Tropical Development and Research Institute

L70

The determination of weight loss in grain fragments

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SUMMARY

An experiment was designed (a) to examine the weight losses caused by *Sitophilus* feeding on maize cultures which contained different proportions (0%, 5% and 15%) of broken grains and (b) to assess and compare the efficiency of different weight loss assessment methods on the different cultures.

The weight loss assessment methods examined were the Count and Weigh, the Converted Percentage Damage, the Simple and Multiple Thousand Grain Mass (TGM) methods and the Standard Volume Weight (SVW) methods by direct comparison and by reference to a baseline calibration.

Weight losses in cultures containing different proportions of broken grains were *not* significantly different.

Further work is recommended using pests with secondary status.

Regression analyses of real weight loss against estimates of loss produced by the different methods showed generally that each method produced the same regression line with the same reliability regardless of the initial level of broken grains in the cultures.

Apart from the two SVW methods which produce the same regression lines the different methods estimate losses with significantly different regression lines. In order of decreasing gradient from steepest to shallowest, (i.e. from the greatest tendency to overestimate losses to the tendency to underestimate) the methods are: Simple TGM, Multiple TGM, SVW (direct), SVW (calibration), Count and Weigh and Converted Percentage Damage. This sequence is in agreement with that suggested by earlier work and it probably reflects general characteristics of the methods.

Generally the methods are not adversely affected by the presence of broken grains and no evidence is produced by this work to suggest the need for special measures when loss estimates are required for samples containing broken grains. However, caution is advised when using the Count and Weigh method when high proportions (20%) of brokens are present and it is advised that grain used for establishing baseline relationships in the SVW method should contain a similar level of brokens to the grain assessed against the baseline.

The changes that occur in the appropriate conversion factor for the Converted Percentage Damage method during the experiment were observed and an overall conversion factor of 0.25 is suggested.

The multiple TGM method depends for its accuracy on the separation of grains by size. The sieving of maize into three size classes was analysed and found reliable and repeatable. Further work using different cereals and different pest insects is suggested.

To define a broken grain as one with mechanical damage which makes it vulnerable to attack by secondary pests produces difficulties and repeatability in scoring samples is hard to attain. Special techniques will be required in laboratory work to identify different levels of broken grains.

Chemical analyses were consistent with the observations that *Sitophilus* does not feed preferentially on the embryo of maize grains but does avoid feeding on the fibrous seed coat. The observed differences in chemical composition of damaged and undamaged grains could not be used in current loss assessment.

RÉSUMÉ

Une expérience a été mise au point pour (a) examiner les pertes de poids provoquées par *Sitophilus* se nourrissant sur des cultures de maïs contenant différentes proportions (0, 5% et 15%) de grains brisés et (b) évaluer et comparer l'efficacité de différentes méthodes d'évaluation de pertes de poids sur les différentes cultures.

Les méthodes d'évaluation des pertes de poids examinées ont été le Décompte et la Pesée, la Détérioration convertie en pour cent, les méthodes de la Masse de mille grains simple et multiple et les méthodes Standard de Volume et de Poids par comparaison directe et par référence à un calibrage de base.

Les pertes de poids dans des cultures contenant différentes proportions de grains brisés n'étaient *pas* dignificativement différentes.

Un travail plus approfondi est recommandé en utilisant des insectes nuisibles avec un état secondaire.

Des analyses de régression de perte de poids réelle par rapport aux estimations de perte fournies par les différentes méthodes ont montré que chaque méthode a donné la même droite de régression avec la même fiabilité indépendamment du taux initial de grains brisés dans les cultures.

A l'exception des deux méthodes Standard de Volume et de Poids qui donnent les mêmes droites de régression, les différentes méthodes estiment les pertes avec des droites de régression significativement différentes. Dans l'ordre de gradient de décroissant depuis le plus raide jusqu'au plus plat (c'est-à-dire depuis la tendance maximale à surestimer les pertes jusqu'à la tendance à sous-estimer, les méthodes se classent comme suit: méthode de la masse de mille grains simple, méthode de la masse de mille grains multiple, méthode standard de volume et de poids (directe), méthode standard de volume et de poids (calibrage), décompte et pesée. Cet ordre est en accord avec celui suggéré par un travail antérieur et il traduit probablement les caractéristiques générales de méthodes.

En général, les méthodes ne sont pas influencées défavorablement par la présence de grains brisés et aucune preuve n'est apportée par ce travail pour suggérer la nécessité de mesures spéciales lorsque des estimations de pertes sont nécessaires pour des échantillons contenant des grains brisés. Cependant, la prudence est conseillée en utilisant la méthode de Décompte et de pesée lorsque des taux élevés (20%) de brisures sont présents et il est recommandé que le grain utilisé pour l'établissement des relations de base dans la méthode Standard du Volume et du Poids contienne un taux de brisures similarie à celui du grain évalué par rapport au grain de base.

Les modifications qui se produisent dans le facteur de conversion approprié pour la méthode de Détérioration convertie en pour cent pendant l'expérience sont observées et un facteur de conversion global de 0,25 est proposé.

La méthode de la masse de mille grains multiple dépend quant à sa précision de la séparation des grains par taille. Le tamisage du maïs en trois classes de taille est analysé et trouvé fiable et reproductible. Un travail plus approfondi en utilisant différentes céréales et différents insectes nuisibles est proposé.

Définir un grain brisé comme un grain avec une détérioration mécanique qui le rend vulnérable à l'attaque par des insectes nuisibles secondaires présente des difficultés et la reproductibilité dans la cotation des échantillons est difficile à obtenir. Des tenchiques spéciales seront nécessaires dans le travail de laboratoire pour identifier les différents taux de grains brisés.

Des analyses chimiques sont en accord avec les observations selon lesquelles *Sitophilus* ne se nourrit pas préférentiellement sur le germe des grains de maïs, mais évite de se nourrir sur l'enveloppe fibreuse de la graine. Les différences observées dans la composition chimique des grains détériorés et non détériorés n'ont pas pu être utilisées dans la présente évaluation de pertes.

RESUMEN

Se diseñó un experimento para (a) analizar las pérdidas de peso causadas por *Sitophilus* al alimentarse en cultivos de maíz que contienen diferentes proporciones (0, 5% y 15%) de granos fragmentados, y (b) para evaluar y comparar la eficacia de diferentes métodos de evaluación de pérdida de peso en los distintos tipos de cultivos.

Los métodos de evaluación de pérdida de peso analizados fueron el de contaje y peso, el de daños por porcentaje convertido, el de masa de mil granos sencillo y múltiple (TGM) y el de peso volumen standard (SVW), mediante comparación directa y haciendo referencia a la medición de la línea base.

Las pérdidas de peso en cultivos conteniendo diferentes proporciones de granos fragmentados *no* resultaron diferentes en grado importante.

Se recomienda una investigación ulterior usando plagas con estado secundario.

Los análisis regresivos de pérdidas de peso reales en comparación con los cálculos de pérdidas producidas por los diferentes métodos mostraron generalmente que cada método produjo la misma línea de regresión con la misma fiabilidad, sin importar el nivel inicial de granos fragmentados en los cultivos.

Aparte de los dos métodos SVW que producen las mismas líneas de regresión, los méthodos diferentes calculan las pérdidas con líneas de regresión de marcada diferencia. En el orden de gradiente descendente desde lo más alto a lo más bajo (i.e. desde la mayor tendencia a calcular excesivamente las pérdidas hasta la tendencia a calcularlas de manera insuficiente), los métodos son: TGM sencillo, TGM múltiple, SVW (directo), SVW (con calibración), contaje y peso. Esta secuencia está de acuerdo con la que se sugiere en investigaciones anteriores, y probablemente refleja las características generales de los métodos.

En términos generales, los métodos no se ven afectados adversamente por la presencia de granos fragmentados y no se presentan pruebas algunas en estas investigaciones que sugieran la necesidad de tener que adoptar medidas especiales cuando los cálculos de pérdidas son requeridos para muestras que contienen granos fragmentados. No obstante, se aconseja tener precaución cuando se usa el método de contaje y peso en el cual intervienen altas proporciones (20%) de fragmentos, por lo que se recomienda que el grano usado para establecer las relaciones de la línea base en el método SVW, contenga un nivel parecido de fragmentos al que tiene el grano evaluado en comparación con la línea base.

Se observan los cambios que se producen en el factor de conversión apropiado para el método de daños por porcentaje convertido durante el experimento, y se sugiere un factor de conversión global equivalente a 0,25.

El método TGM múltiple depende en su precisión de la separación de los granos por tamaños de granos es analizado y considerado confiable y repetible. Se sugieren investigaciones ulteriores usando cereales e insectos parásitos diferentes.

El definir el grano fragmentado como que está dañado mecánicamente que lo hace vulnerable al ataque de plagas secundarias, crea dificultades y es difícil de obtener repetibilidad en las muestras de marcaje. Serán necesarias en el laboratorio técnicas especiales para definir los diferentes grados de granos fragmentados.

Los análisis químicos están de acuerdo con las observaciones de que el *Sitophilus* no se alimenta preferencialmente en el embrión de los granos de maíz, sino que evita alimentarse en la capa fibrosa de la semilla. Las diferencias observadas en la composición química de granos dañados e intactos, no pudieron ser usadas en la evaluación de pérdidas actual.

The determination of weight loss in grain fragments

INTRODUCTION

It is generally accepted that insects can feed more easily on grains that are already damaged than on entire, intact grains. In one form this idea distinguishes between primary and secondary pests. Although primary pests are held to be capable of attacking and feeding on entire grains it is still accepted that they would be able to feed more easily on broken grains. This might mean that insects would cause greater weight losses in grain containing grain fragments than in batches of entire grains. No weight loss assessment method takes account of broken grains. A particular cause for concern are the methods in which whole grains are scored visually as being either undamaged or damaged by insects, (e.g. the Count and Weight and Converted Damage Percentage methods) and no provision is made for the scoring of broken grains. The observations on whole grains are used to calculate mean grain weights for the different categories of grain and these are then used to estimate weight loss. The underlying principle in these methods is that the damaged grains would have had the same mean grain weight as the undamaged grains if the insect attack had not occurred. This is clearly not the case for a grain which was broken and then attacked by insects. It would be expected that when broken grains were damaged by insects and included for the first time in the 'damaged' category the resulting weight loss estimates would tend to overestimate the real losses.

The questions to be approached by this study were therefore:

1 Does the level of broken grains in a culture affect the weight losses caused by insects?

2 Are weight loss assessment methods equally accurate on cultures containing different proportions of broken grains?

A secondary objective was the examination of the Simple and Multiple Thousand Grain Mass (TGM) methods of weight loss assessment (Proctor and Rowley, 1983).

Choice of materials

Maize was chosen for this experiment because it was felt that broken grains were a more important problem in maize than in smaller-grained cereals. Also earlier laboratory experiments on the accuracy of the formula method of loss assessment had shown that the Standard Volume Weight (SVW) and the Count and Weigh methods were equally accurate on this cereal (Adams, Internal Report, 1977). Adams did not examine the TGM method, but his observations of numbers and weights of grains in samples, collected for use in the Count and Weigh method, were available for analysis.

Maize is also easier to manipulate and examine visually than smaller grains and pesticide-free supplies of maize are cheap and readily available.

Available resources, including time, constrained experiments to only one species of insect. *Sitophilus* was chosen for the experiment because it is known to attack both whole and broken grains. The use of a so-called secondary pest, had it proved to be truly secondary, attacking only broken grains, would have proved very little. If this work is to be pursued it is suggested that the experiment be repeated, using perhaps *Tribolium* or a species believed to have very poor ability to attack intact grains.

Very little work seems to have been done on the feeding of *Sitophilus* adults. Golebiowska (1969) and Steffan (1963), respectively, have estimated that adults consume 1 mg and 0.4 mg–0.49 mg per day. Such figures suggest that during its life *Sitophilus* will consume far more food as an adult than during its development as a larva. It is commonly observed that adult *Sitophilus* will concentrate their feeding on a few damaged grains with many adults often attacking the same grain. There would be advantages in adults feeding in already damaged grains and in avoiding grains in which their own larvae are developing. It was suspected that adult feeding by *Sitophilus* might be an important source of loss and it was hoped that measurement and comparison with losses caused by larval development could be achieved. However, it was impossible to combine this investigation with the other objectives of the project. (*See* below).

Choice of method

While cleaning and sorting grain for the experimental cultures it became obvious that broken grain was very hard to define. The only workable and repeatable guideline seemed to be to treat any physical damage as breakage. This guideline is in agreement with the concept of insect attack being facilitated by any damage to the protective outer layer of a grain. The work of White (1982) with *Tribolium* suggests that the nature of the breakage influences survival of the insects but the concept remains part of conventional wisdom.

However, scoring grains with any degree of physical damage as broken produces the unsatisfactory result that small grain fragments and largely whole grains with minor damage are put into the same category. It is also extremely difficult to observe small amounts of damage to grains with any consistency. That the reliable scoring of broken grains would remain a severe difficulty meant that it would be impossible to analyse weight losses in the two classes of grain separately. (The only solution to this problem would be to mark the damaged and undamaged grains in some way that would not change their attractiveness to the insects). It was decided, therefore, to carry out the experiment by setting up cultures containing different proportions of broken grains and to examine the losses in the entire cultures.

Cultures of at least 1 kg each were needed to enable the measurement of bulk density with a standard chondrometer and it was decided that there should be a minimum of five replicate cultures for each treatment. These decisions meant that cultures would have to be analysed for losses and then reconstituted to run on to the next observation time. The alternative strategy of establishing a large number of replicate cultures and removing some at each observation time was rejected because of the enormous quantities of grain required and the amount of work involved in the initial setting up.

Another consideration supporting the reconstitution of cultures to run on was the proposed examination of the TGM method. Since the setting up of cultures of fixed composition precludes representative division of grain the initial TGMs of the different replicates would be different. The use of different cultures to provide sequential estimates of TGM would clearly not lead to an accurate trial of the method.

METHODS AND MATERIALS

Cultures of 1 kg of maize were established in rock jars with five replicates of each of three levels of broken grains: 0%, 5% and 15%. The cultures were allowed to equilibrate in a Constant Temperature and Humidity (CTH) room at 70% relative humidity (RH) and 28°C for two months before the experiment began. Twenty adult

Sitophilus zeamais were added to each culture. Two sets of controls containing 0% and 20% brokens but no insects were also established to check against weight losses caused by grain respiration or other unknown sources of loss. The cultures were arranged in the CTH room in a random pattern (five treatments and five blocks) to eliminate the effects of position in the room.

Procedure

Every fortnight the cultures were weighed and then sieved over a 5 mm screen to remove dust and insects. The dust was weighed and the insects were counted. Moisture content of the grain was estimated using a Burrows Moisture Computer (a capacitance meter). The standard volume weight was obtained from three replicate weighings and using a standard bulk density chondrometer. Three subsamples of approximately 130 g each were then taken from each culture by a Burrows sampler (green tower, multiple selection cone). Each subsample was sieved over 9 mm and 8 mm screens into three size classes and the grains in each size class scored as broken, whole or damaged. The grains in each category were counted and weighed.

Four 1 kg batches of grain were conditioned to different moisture contents (10.4%, 11.4%, 13.4% and 15.4%) and used to check the calibration of the moisture meter and to establish a baseline graph of dry weight per standard volume against moisture content for the SVW method of loss assessment. The grain used for this baseline contained about 15% broken grains. It is recognised that for a complete examination of the SVW method it would have been useful to have drawn up different baselines with different levels of broken grains, although the results of this experiment seem to suggest that the one baseline was satisfactory for all the different levels of brokens.

After fourteen weeks, i.e. seven observations, the experiment was stopped because the grain was very seriously damaged and unlikely to be accepted under any known grading standard and only likely to be eaten by the most hungry, i.e. beyond the point where the measurement of weight losses makes any practical sense.

An additional small-scale experiment was carried out with just two levels of broken grains (20% and 0%) using eight replicates on only 125 g of grain and 20 adult insects per culture. The cultures were simply sieved and weighed at irregular intervals to check the levels and rates of weight loss caused by this higher density of insects.

RESULTS

The observations made provided the following information:

Dry weight loss
Weight of dust produced
Number of adult insects present
Weight loss estimates by the Count and Weigh method
- Simple TGM method
- Multiple TGM method
- SVW method (by direct comparison)
- SVW method (by calibration, i.e. by comparison with a baseline graph)

Conversion factor estimates
Proportions of grains in different size classes.

Weight losses in the controls at the end of the experiment were all less than 0.8% and were ignored in all calculations. No significant differences were found in the weight losses in cultures in different positions in the CTH room, nor between those examined on different days in the analysis schedule.

The mean percentage weight loss of the five replicates plotted against time showed an exponential increase in losses with time (*see* Figures 1 and 2). The logarithm (base 10) of the mean percentage loss plotted against time is a straight line. Since at time zero weight loss is by definition zero it was possible to analyse the results by regression through the origin. To achieve this it was necessary to plot the logarithm of percentage weight loss plus one against time (*see* Figure 3). The gradients of the lines from the three experimental levels of broken grains were not significantly different. The same analytical procedure was followed with the observations of the small-scale experiment with the same conclusion (*see* Figure 4).

The accuracy of the different weight loss assessment methods was examined by linear regression of the real weight loss against the estimates of weight loss produced by the different methods. (A line with a gradient of one and a correlation coefficient of one would indicate that the method gave a perfect assessment of losses). The regression lines produced by each method on the different levels of broken grains were compared but only one significant difference was observed. This implies that the methods gave similar assessments of loss regardless of the intial level of broken grains in the cultures (*see* Figures 5–9). The exception referred to concerns the Count and Weigh method which produced the same regression line for real loss against estimated loss for the cultures containing zero and 5% brokens but a different (steeper) line for cultures containing 15% brokens (*see* Figure 9). This may be explained by the caution in the introduction, in which it is suggested that when initially broken grains are attacked by insects, and then used in the calculation of the mean weight of attacked grains, they will significantly reduce this mean and an inflated estimate of loss will be produced

The correlation coefficients of the regressions were also compared for each loss assessment method at the different levels of brokens. No significant differences were found except for the SVW (calibration) method which produced the same regression line for real loss against estimated loss for all cultures; the correlation coefficient is larger (stronger correlation) for the cultures with higher levels of broken grains. This might be explained by the fact that the grain used to calculate the baseline contained a proportion of broken grains similar to the highest levels used in the experiments.

The two SVW methods produced regression lines of real weight loss against estimated loss with the same gradient. The other methods produced lines significantly different from each other at each level of broken grains (*see* Figures 10–12). The correlation coefficients of the regression lines of all assessment methods were not significantly different in the cultures containing 0% and 5% brokens.

At 15% broken grains the correlation coefficients for the Count and Weigh method and the Simple TGM method were smaller (weaker correlation) than for the other methods. The observation that the different loss assessment methods produced estimates of loss that related in the same ways to real weight loss irrespective of the initial levels of broken grains allowed the combination of the results from all the cultures for each method. The results of these combinations are shown in Figures 13–19. This is merely another way of presenting data and yields no more information nor does it change the conclusions.

The efficiency of the Converted Damage Percentage method was examined by two procedures. First, the average conversion factor was calculated for each level of brokens in the experiment at each sampling occasion. Second, linear regression analysis was carried out on the real weight loss against the observed percentage damaged grains throughout the experiment. The first procedure demonstrated how the conversion factor is a variable which increases during the experiment probably because of the increasing damage done to individual grains (*see* Figure 19). Although there was a general increase in the value of the conversion factor there was a significant drop after six weeks, connected probably with the synchronous emergence of adult insects. This phenomenon was observed in the data from Adams' laboratory work on both wheat and maize, where it occured with each emergence of adults. The second procedure produced significant straight line relationships between percentage damaged grains and percentage loss where the gradient of the line was the conversion factor (*see* Figures 20 and 21). The line relationship in question was that of percentage damaged grains AGAINST percentage loss, not the inverse since what was being examined was the reliability of percentage damaged grains as a predictor of loss, not the descriptive correlation of the two variables. (For the inverse descriptive relationships *see* Figures 22 and 23). The lines for the three experiments are probably not different. An analysis of variance of the gradients suggested significant differences, but the multiple comparison of gradients produced the most irritating of results; a=b and b=c but a≠c. Such an equivocal result can best be interpreted as it being improbable that real differences exist and that the question can only be resolved by further work. The common gradient for the three experiments would be 0.253, which is significantly larger than the conversion factors for maize (0.125 or 0.222) suggested in the Harris and Lindblad manual (1978).

There were significant correlations between real weight loss and observed value of conversion factors (K) (*see* Figures 24 and 25). This is another presentation of the suggestion that conversion factors increase as damage to individual grains increases. (When all observations are increasing in value with time, correlations between any pair of observations should be interpreted with caution.) This finding contradicted the idea that insects attacking grain cause a relatively uniform weight loss per attacked grain. Clearly it is important that the grain samples used to calculate conversion factors should resemble the grain that will be examined in the losses study in which the conversion factor will be used. In particular the amount of damage in the damaged grains should resemble damage likely to be found in the field.

OBSERVATIONS ON THE MULTIPLE TGM METHOD

The sieving of grains into different size classes is both a potential strength and a potential weakness of the Multiple TGM method. The method was developed to overcome a weakness of the Simple TGM method which occurs when samples for sequential estimates of TGM are not representative. In such a case changes in overall TGM reflect the proportions of grains of different sizes in the samples which may obscure changes in TGM caused by insect feeding. (Where the proportions of grains in each size class are identical in sequential samples then the Simple and Multiple TGM methods are identical). The sieving of grain into different size classes and the use of a baseline TGM for each size class can overcome the problem of non-representative sampling if two conditions are fulfilled. The first is that sieving itself is a reliable and repeatable operation where, in the absence of other disturbing influences, the proportions of grains in the different size classes remain the same or, at least, within expected limits. Expected limits in this case would be those predicted by the chi-squared distribution of the numbers of grains in each size class, i.e. random variation around known proportions. The second condition is that neither insect feeding nor any other disturbing influence changes the way that the grains separate into different size classes during sieving. It is easy to imagine the situation in which insect feeding might reduce the size of grains, causing them to pass into a smaller size class and disturb the estimates of TGM for the different size classes.

To examine these potential problems the numbers of grains that appeared in each size class during the examination of each culture were analysed in two ways throughout the experiment. First, using chi-squared tests of the proportions of grains in each size class of each of the three replicate samples of each observation time. Since the grain was sieved into three size classes the analysis was of 3x3 contingency tables. Of the 105 analyses (15 cultures observed on 7 occasions) only five produced chi-squared values significant at p=0.05. Thus it is only rarely that variations in the proportions of grains in different size classes in replicate samples from cultures exceeded that expected.

For the second analysis the numbers of grains in the replicate samples were combined and compared with the combined figures for the seven observation times. Of the fifteen 3x7 contingency tables only three produced chi-squared values significant at p=0.05. Thus, although insect feeding was continuous between observations, it is again rare for proportions of grains in the different size classes to change beyond that expected by random variations. Although these results seem to vindicate the Multiple TGM method, it must be remembered that the feeding of *Sitophilus* on maize is probably the combination of pest and grain least likely to cause the disruptive changes in grain sizes that would create inaccuracies in the method. A more severe test of the method (e.g. a surface-feeding pest on a smaller-grained cereal) should be carried out as soon as possible.

CHEMICAL ANALYSES

Chemical analyses of grain samples were carried out on samples of grain from controls and experimental cultures at the beginning and end of the experiment. The analyses were of moisture, protein, fat and fibre contents. No significant differences were found between these components in whole and broken grains, either at the beginning or at the end of the experiment. No significant changes took place in these components in either whole or broken grains in the controls during the experiment.

At the end of the experiment there was still no significant difference between the fat content of insect-damaged grains and those apparently undamaged. This was the case whether results were analysed for each experimental level of brokens separately or when the results of all different levels were combined. Since most of the fat in a seed is in the embryo, this result suggests that *Sitophilus* was not feeding preferentially on the embryos of the maize grains. *Sitophilus* is commonly observed not to attack grain embryos and this behaviour is part of the general understanding of the biology of this pest. The protein content of insect-damaged grains was found to be significantly higher than that of undamaged grains (10.8% and 10.1% respectively). This difference only emerged when all experimental results were combined: multiple range tests of the means from cultures containing different levels of broken grains could detect no significant differences. This result was probably caused by the addition of protein to the damaged grains by frass, cast skins and insect bodies which remained in the grains during chemical analysis. Such events would mask any effects of selective breeding by the insects.

The fibre content of damaged grains was found to be significantly higher than that for undamaged grains when all results were combined (4.1% and 3.6% respectively). Multiple range tests of the mean fibre content for cultures containing different levels of broken grains showed considerable overlapping of groups of means which prevented the identification of significant differences. The overall result was consistent with the suggestion that *Sitophilus* feeds selectively, avoiding the fibrous parts of the grain.

The differences observed in chemical composition were not highly informative. The levels of significance were not great although there were effectively 15 replicates and the absolute differences between means were not large. Chemical analyses like these have no part to play in loss assessment.

DISCUSSION AND CONCLUSION

The results suggest that *Sitophilus* causes the same weight losses in laboratory cultures of maize regardless of the level of broken grains present. It is suggested that further investigations should be undertaken to establish whether similar results are likely with different pest species.

Generally the loss assessment methods produced equally accurate estimates of weight loss regardless of the level of broken grains present. Exceptions have been mentioned and explained previously. It would seem clear that care must be taken when using the Count and Weigh method on samples of grain that contain large proportions of grain fragments. The additional source of inaccuracy that this introduces to this method is not sufficient of itself to suggest rejection of the method. Indeed the inflation of loss estimates produced by this method in the presence of grains that are first broken and then attacked by insects may offset the method's inherent tendency to underestimate weight losses. This minor exception does not change the general conclusion that methods examined produce accurate and reliable estimates of weight loss with this cereal in laboratory cultures. This conclusion is in agreement with Adams' laboratory work on maize. Special measures need not generally be taken when using these methods on grain containing levels of brokens covered in this experiment.

Problems

The production of dust by *Sitophilus* on maize was a major problem during this work. The dust adhered to grains and filled grains that had been hollowed out by adult feeding. Despite the initial sieving, dust continued to fall off the grain during all subsequent operations. This may account for the apparent overestimates of weight loss produced by the two TGM methods. The estimate of dry weight loss was made on the weight of grain minus the initial sievings of dust (no account was made for the weight of insects subsequently removed), whereas the estimates of TGM were made at the end of the analysis procedure. The estimate of dry weight loss would therefore be an underestimate where significant amounts of dust were removed by the later operations.

The estimation of the proportion of broken grains by visual scoring remained a problem throughout the experiment. Successive estimates of broken grains showed a convergence to a similar level in all cultures. It seems unlikely that this was a true effect but rather the result of the observer fulfilling expectations of an amount of brokens in each subsample. In future work where it is considered important to assess the levels of broken grains it will be necessary to mark grains as suggested in the introduction, or distinguish brokens by size as well as damage. It might, for example, be necessary to break grains individually to ensure that they are recognisable.

During the experiment the time taken to examine each culture increased from under one hour to over one and a half hours and such an increase had not been allowed for. It became barely possible to examine all the cultures in one week. Although the observations of cultures was detailed and thorough by the standards of loss assessment activities in the field, there were still other observations that might have been made and other useful information that might have been gathered during this experiment.

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Figure 1

Large-scale experiment

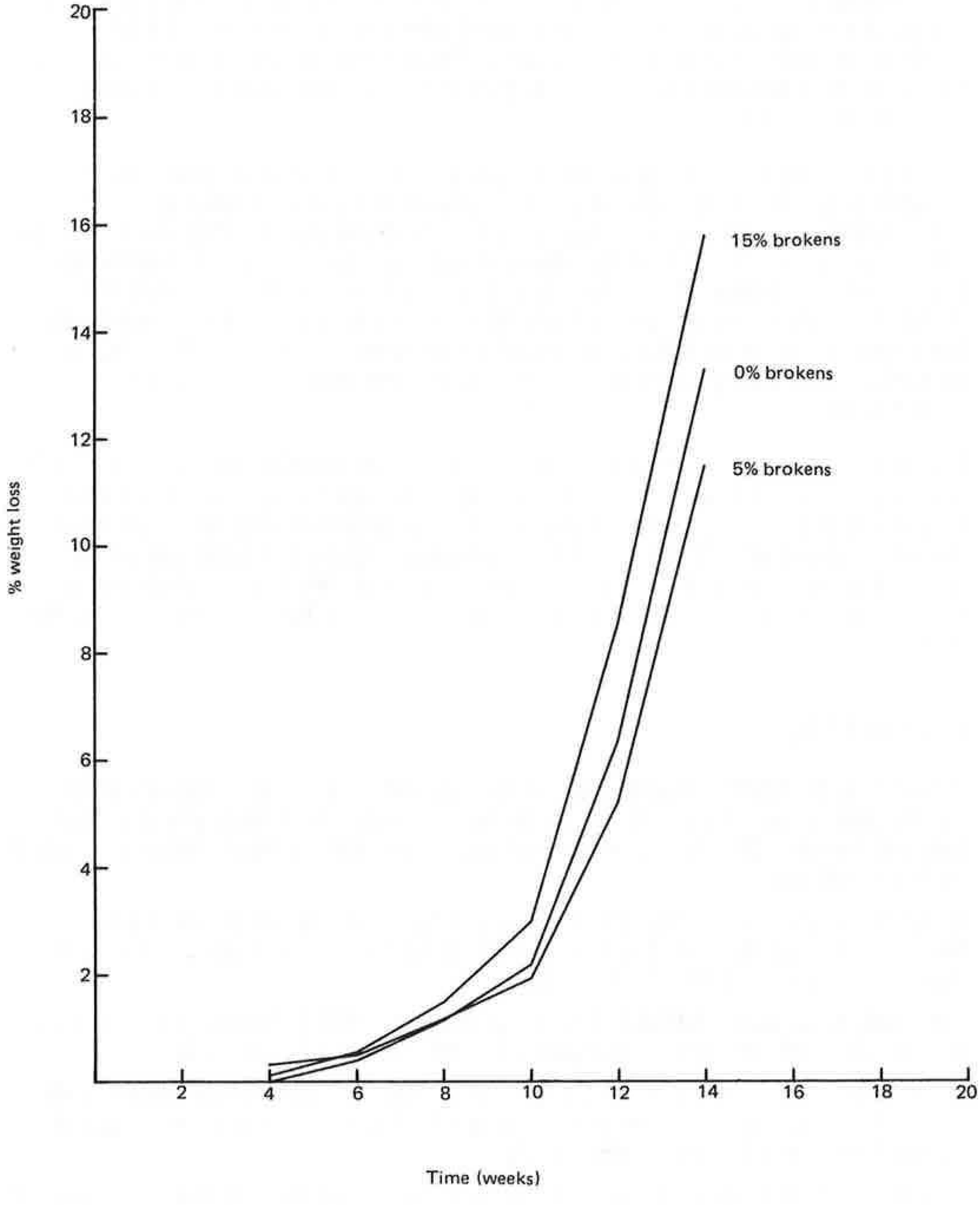


Figure 2

Small-scale experiment

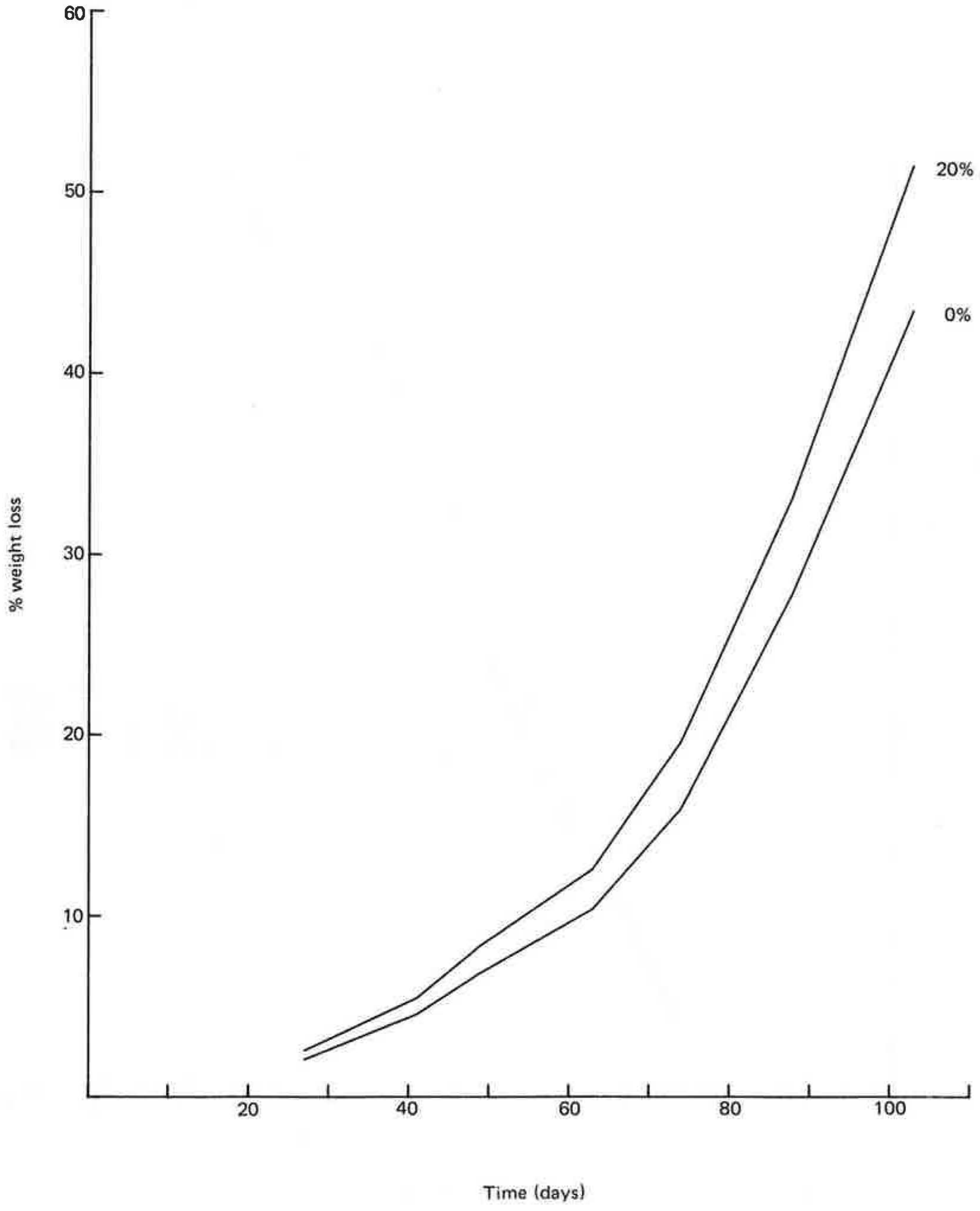


Figure 3

Large-scale experiment

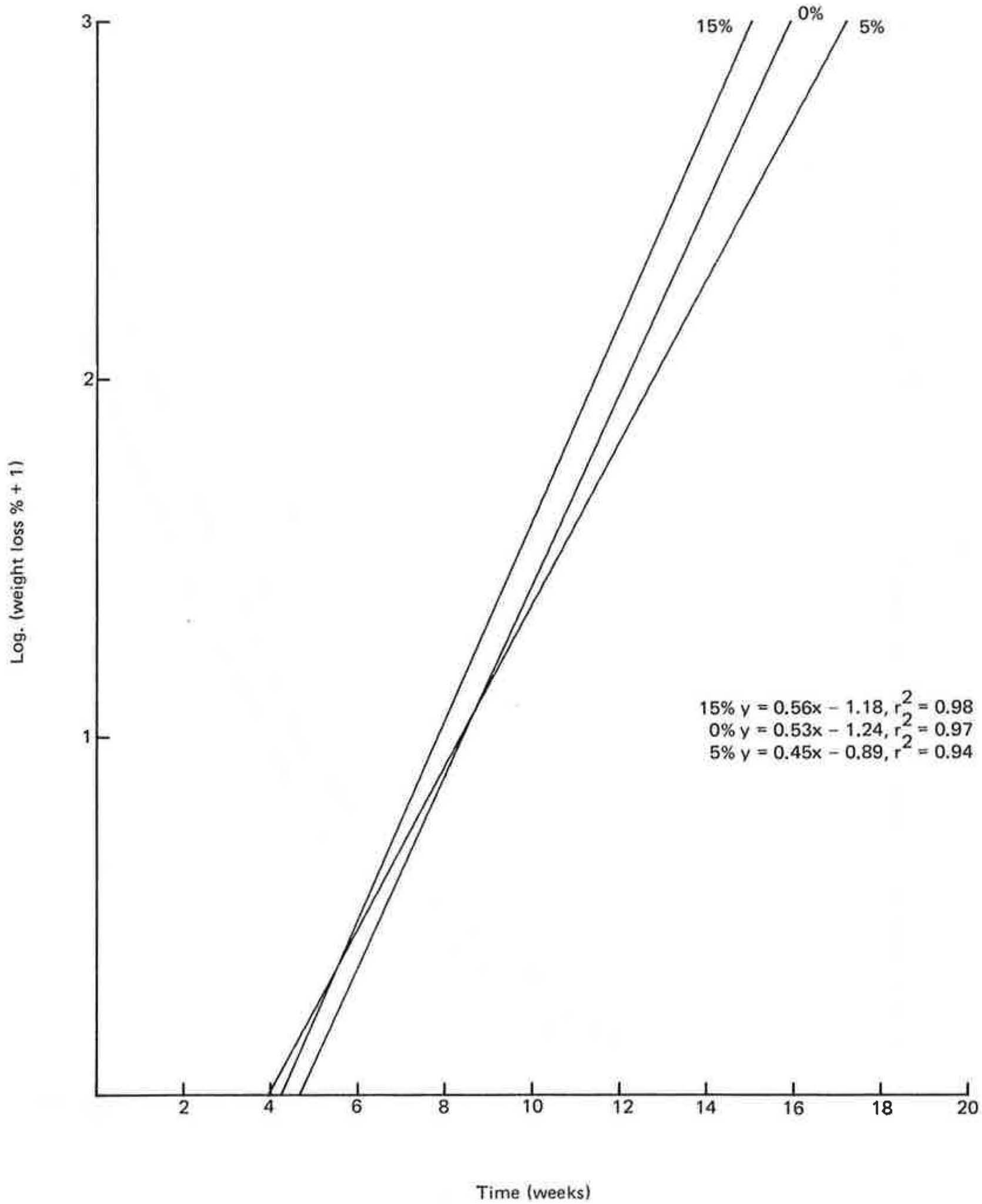


Figure 4

Small-scale experiment

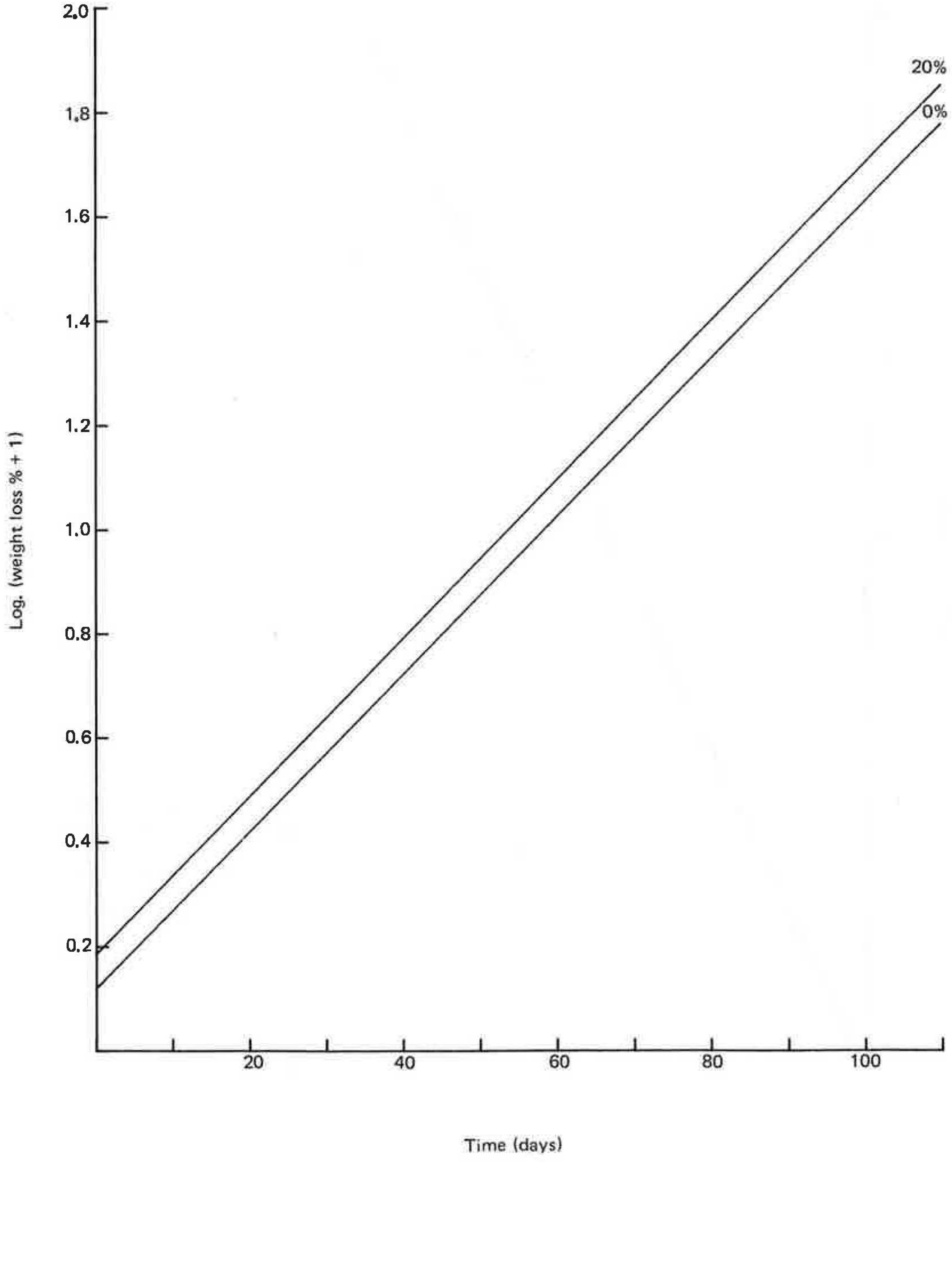


Figure 5

Simple TGM method

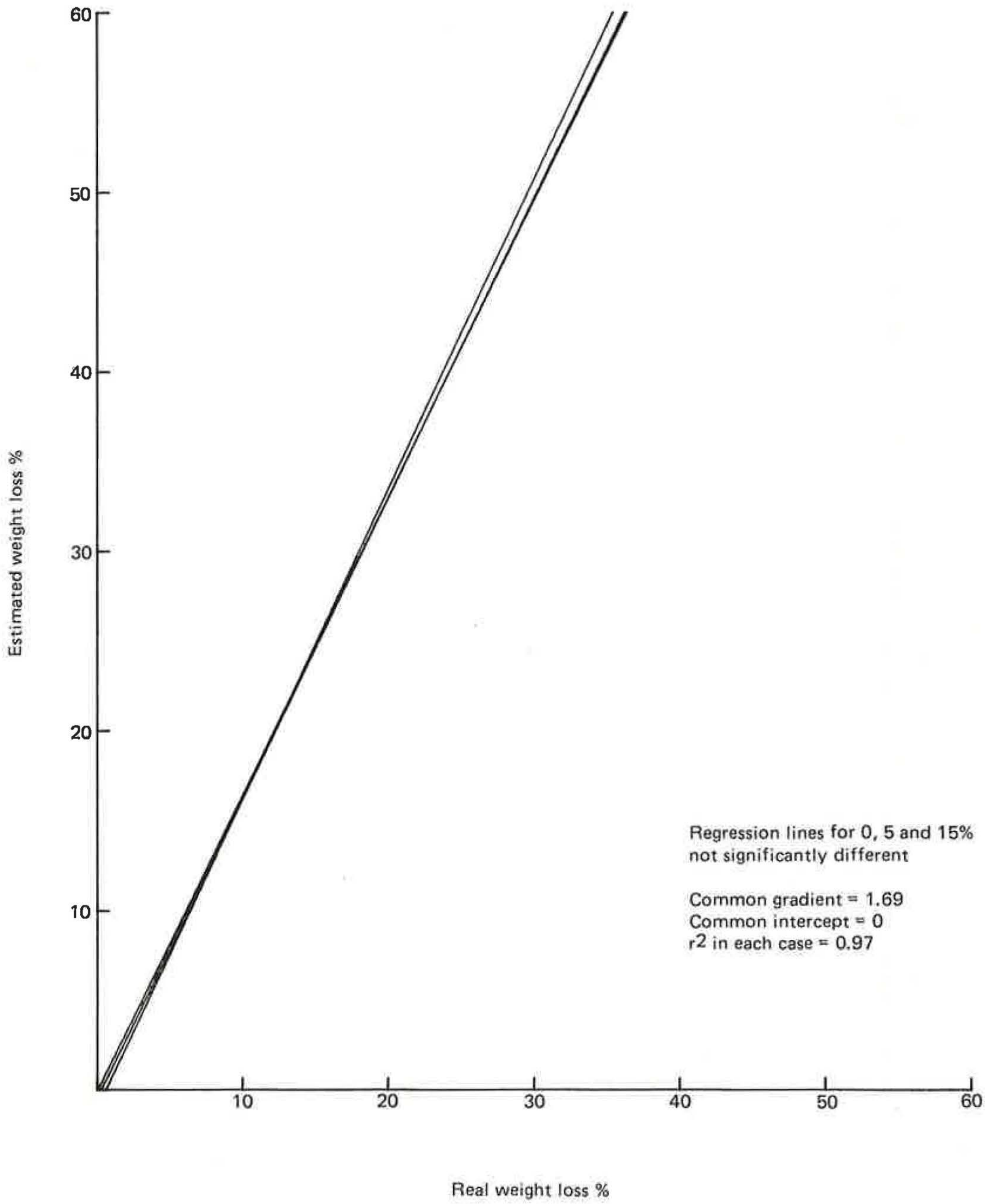


Figure 6

Multiple TGM method

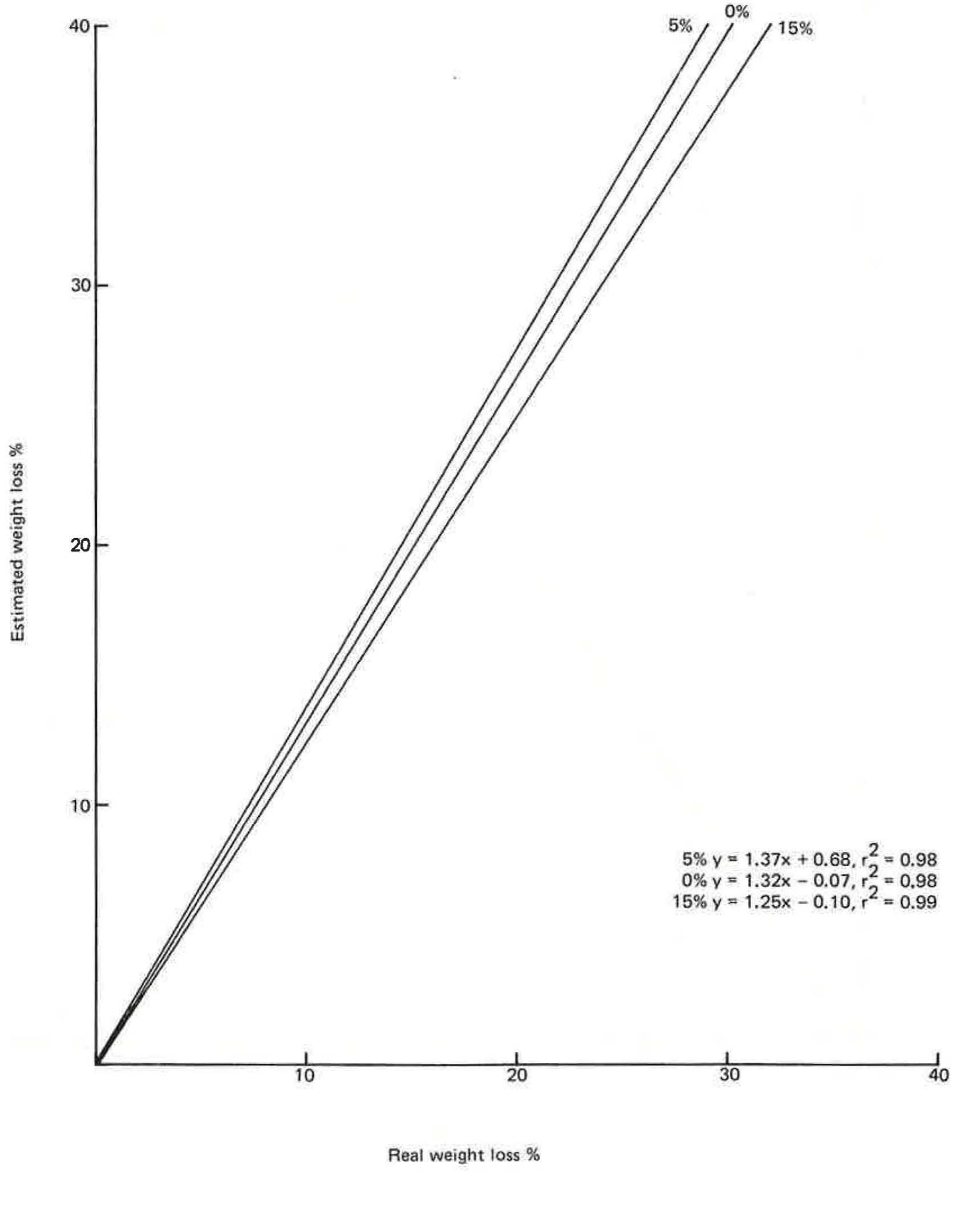


Figure 7

SVW method

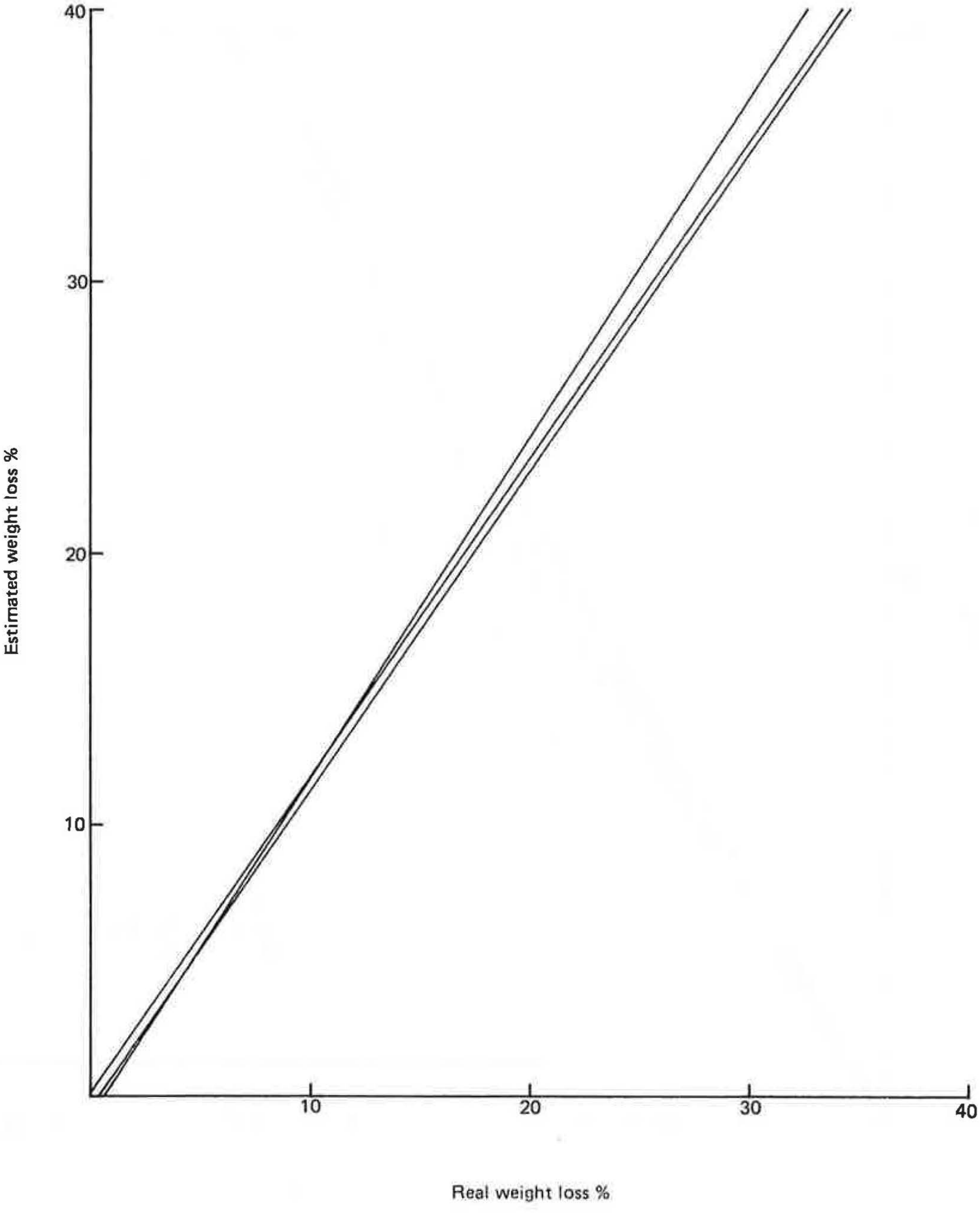


Figure 8

SVW calibration method

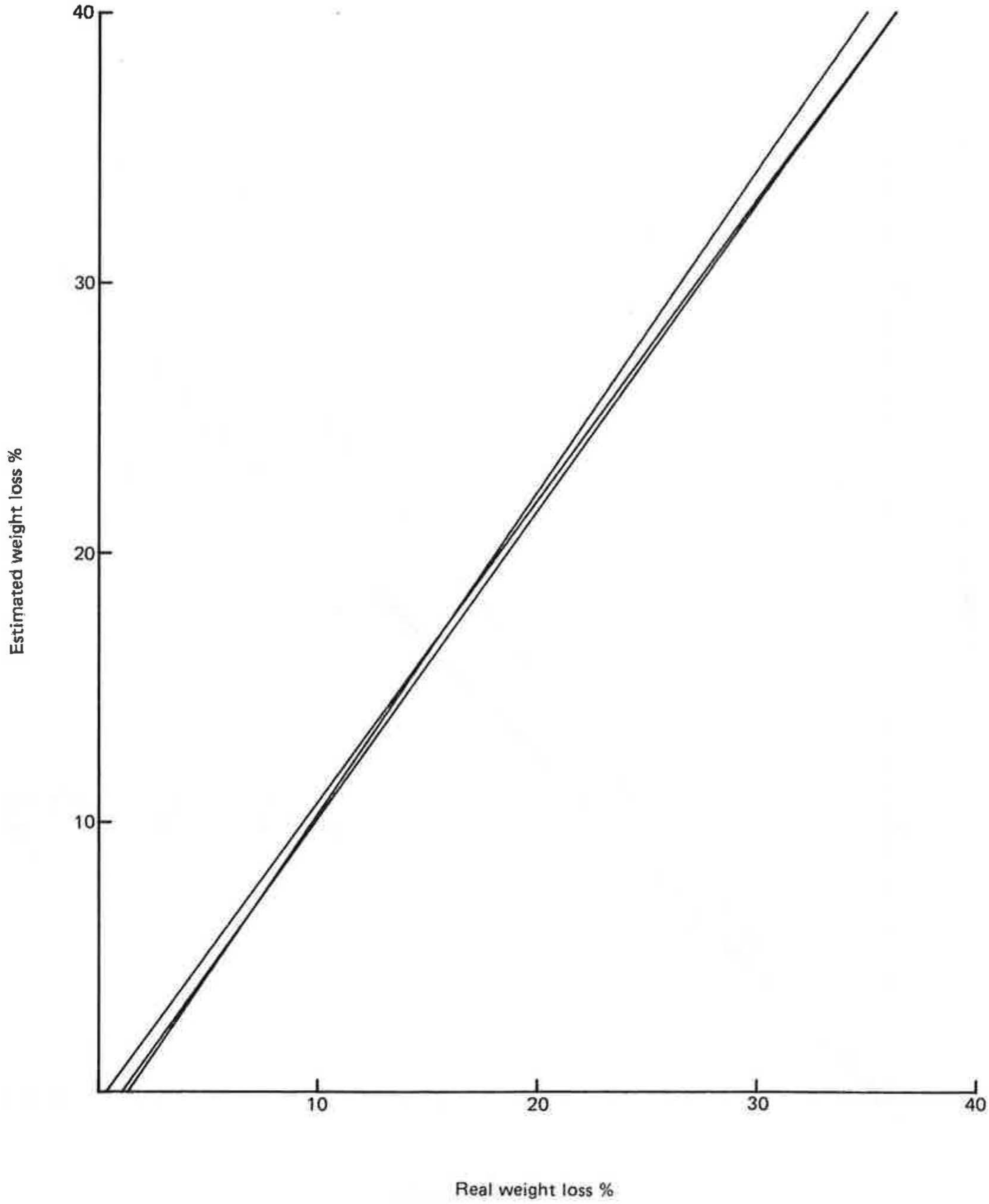


Figure 9

Count and Weigh method

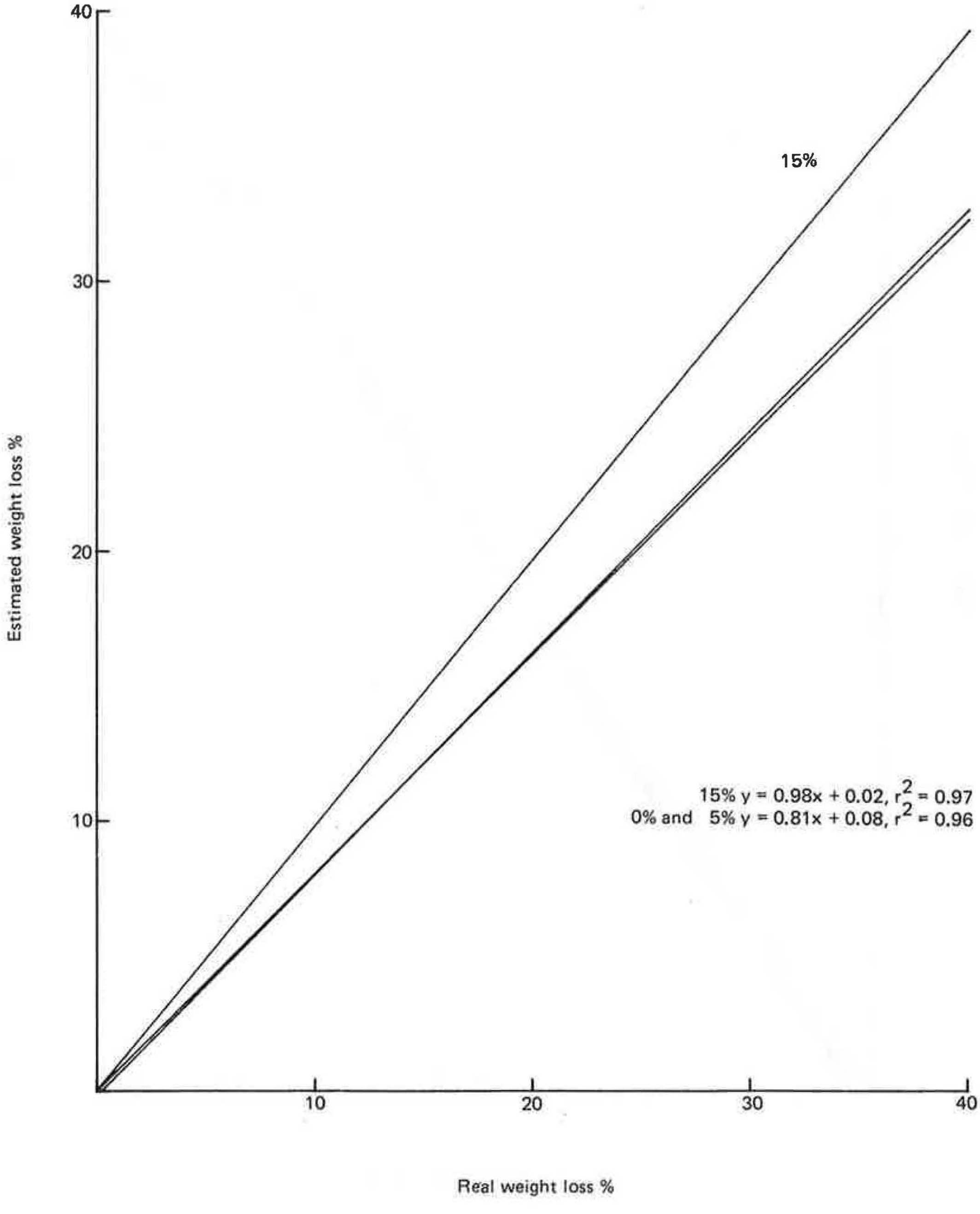


Figure 10

15% brokens

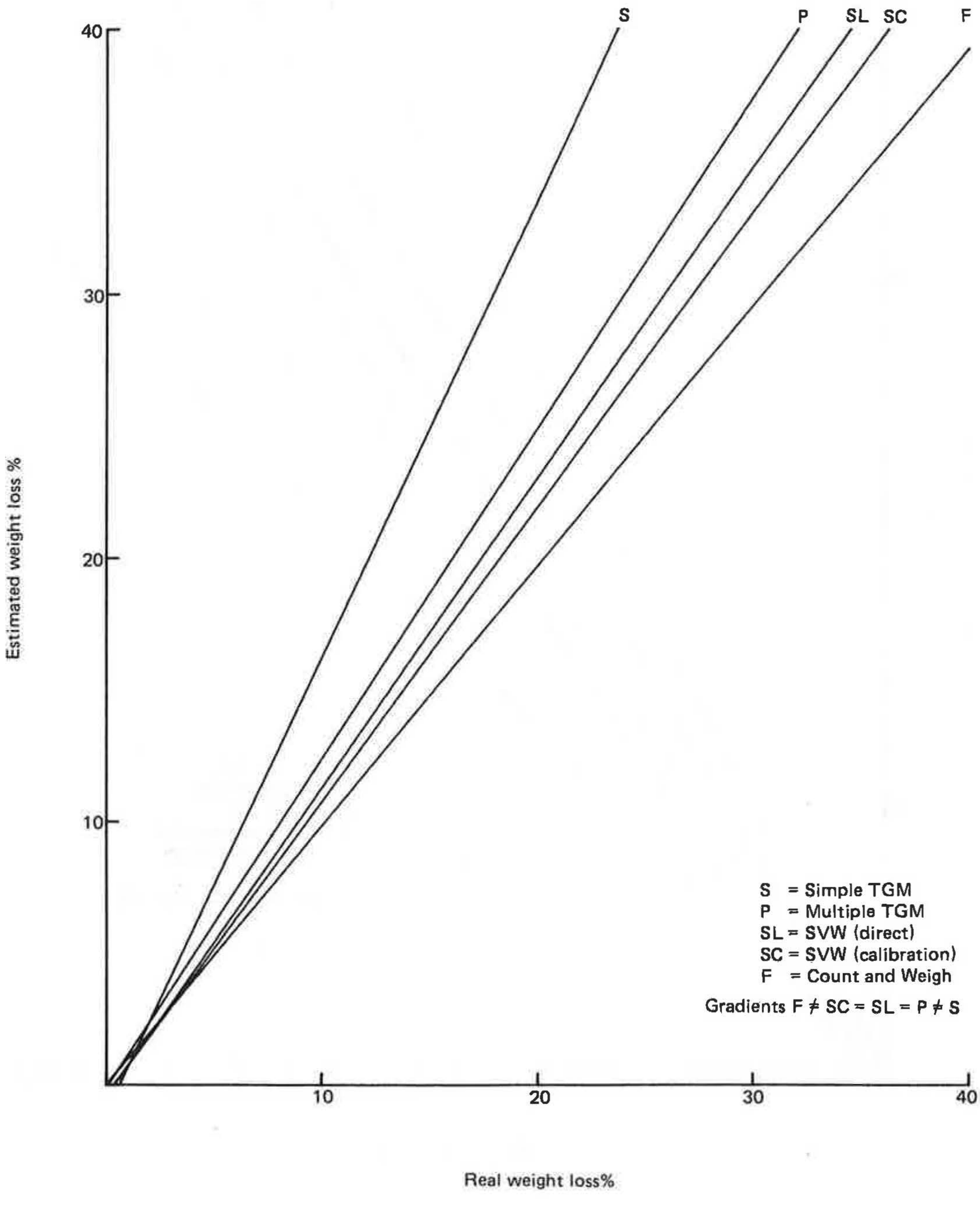


Figure 11

5% brokens

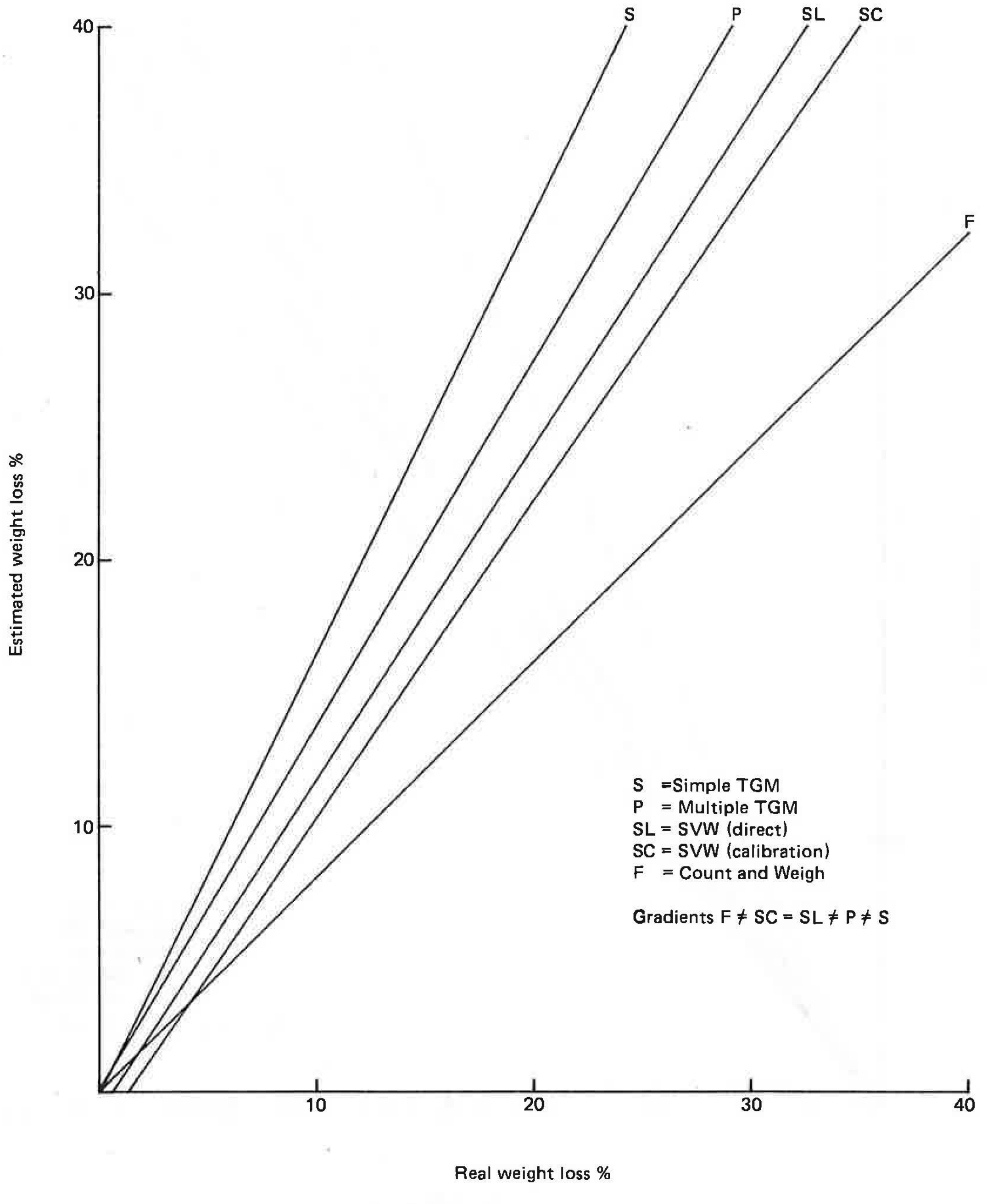


Figure 12

0% brokens

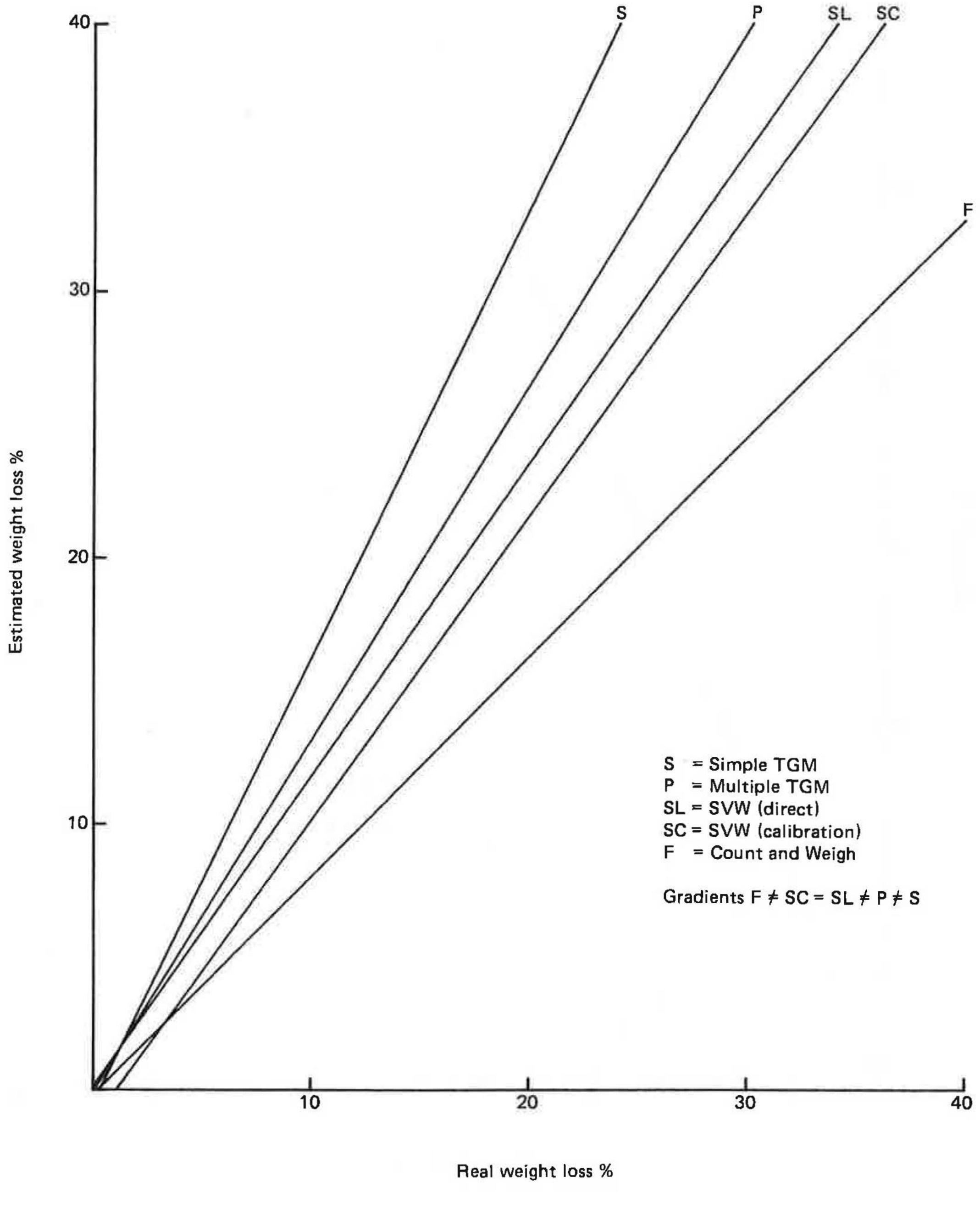


Figure 13

Simple TGM method

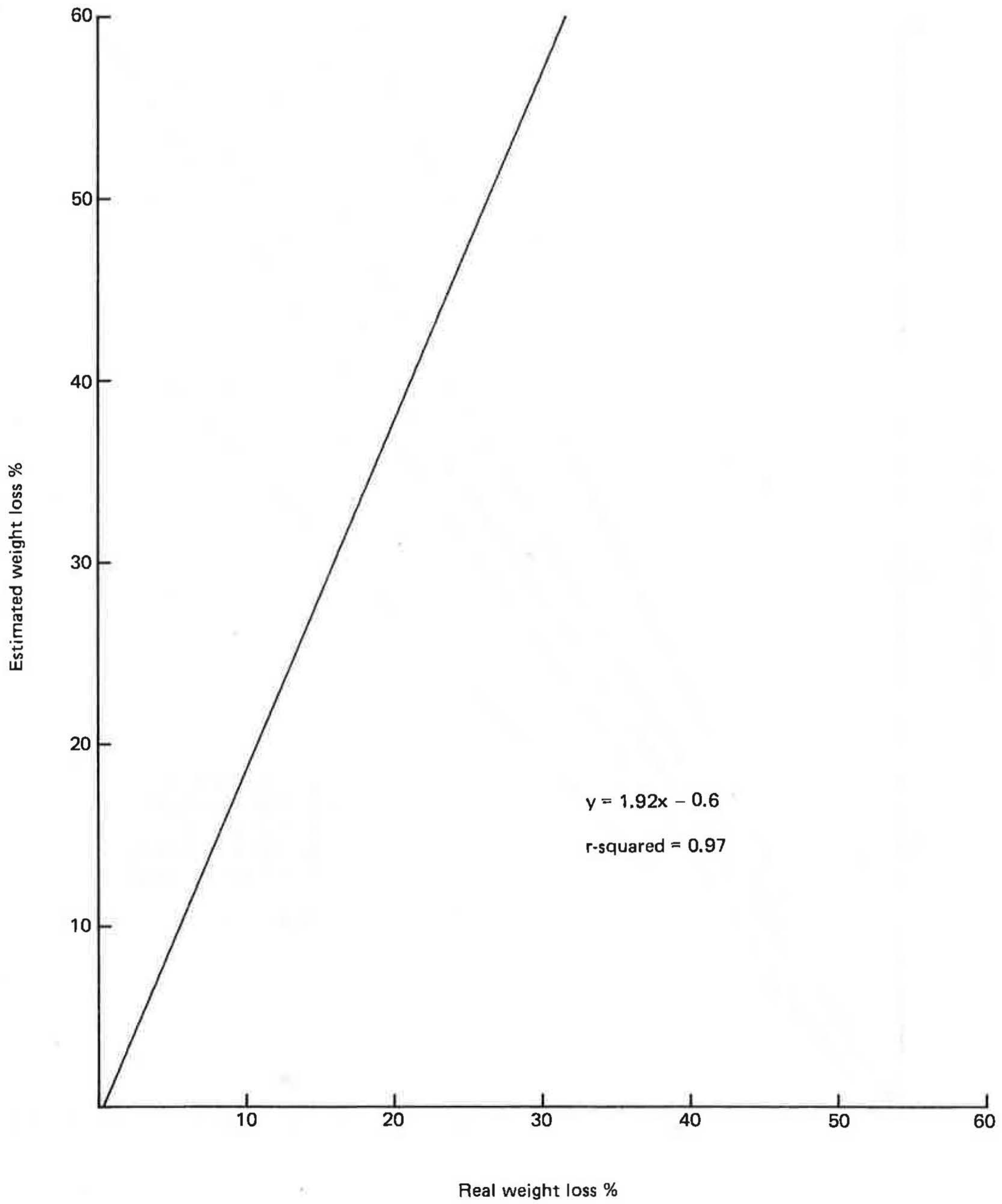


Figure 14

Multiple TGM method

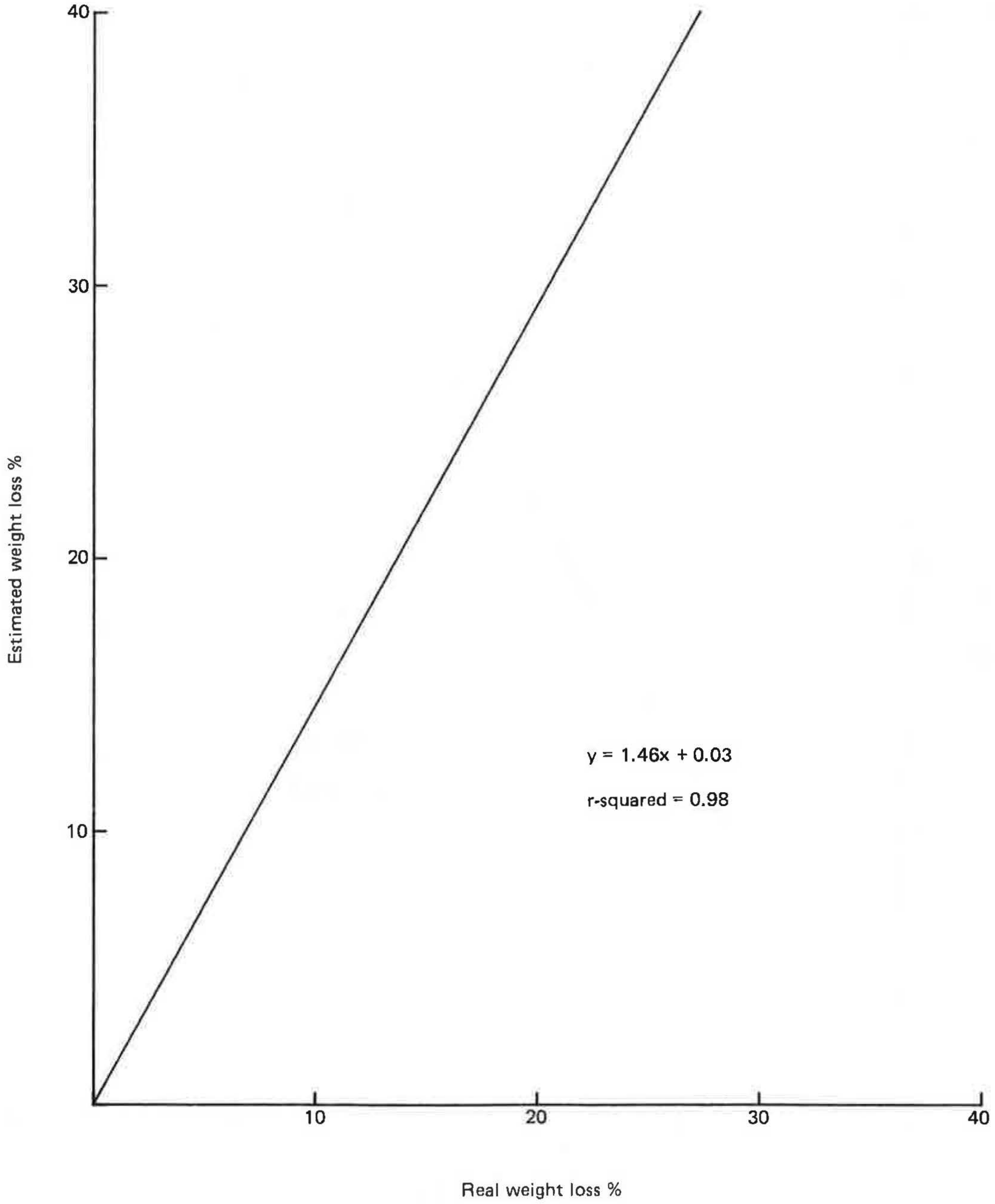


Figure 15

SVW (direct) method

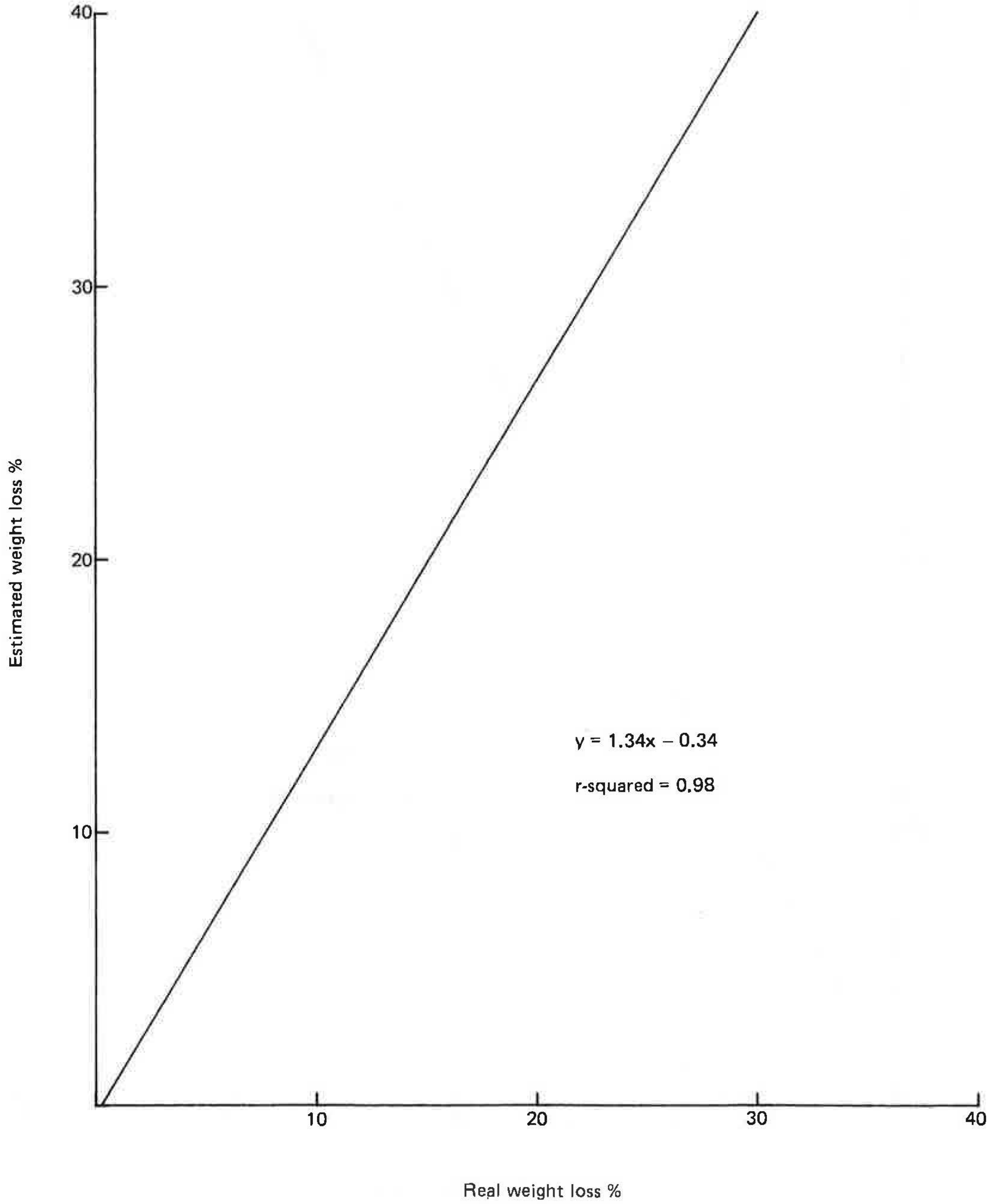


Figure 16

SVW (calibration) method

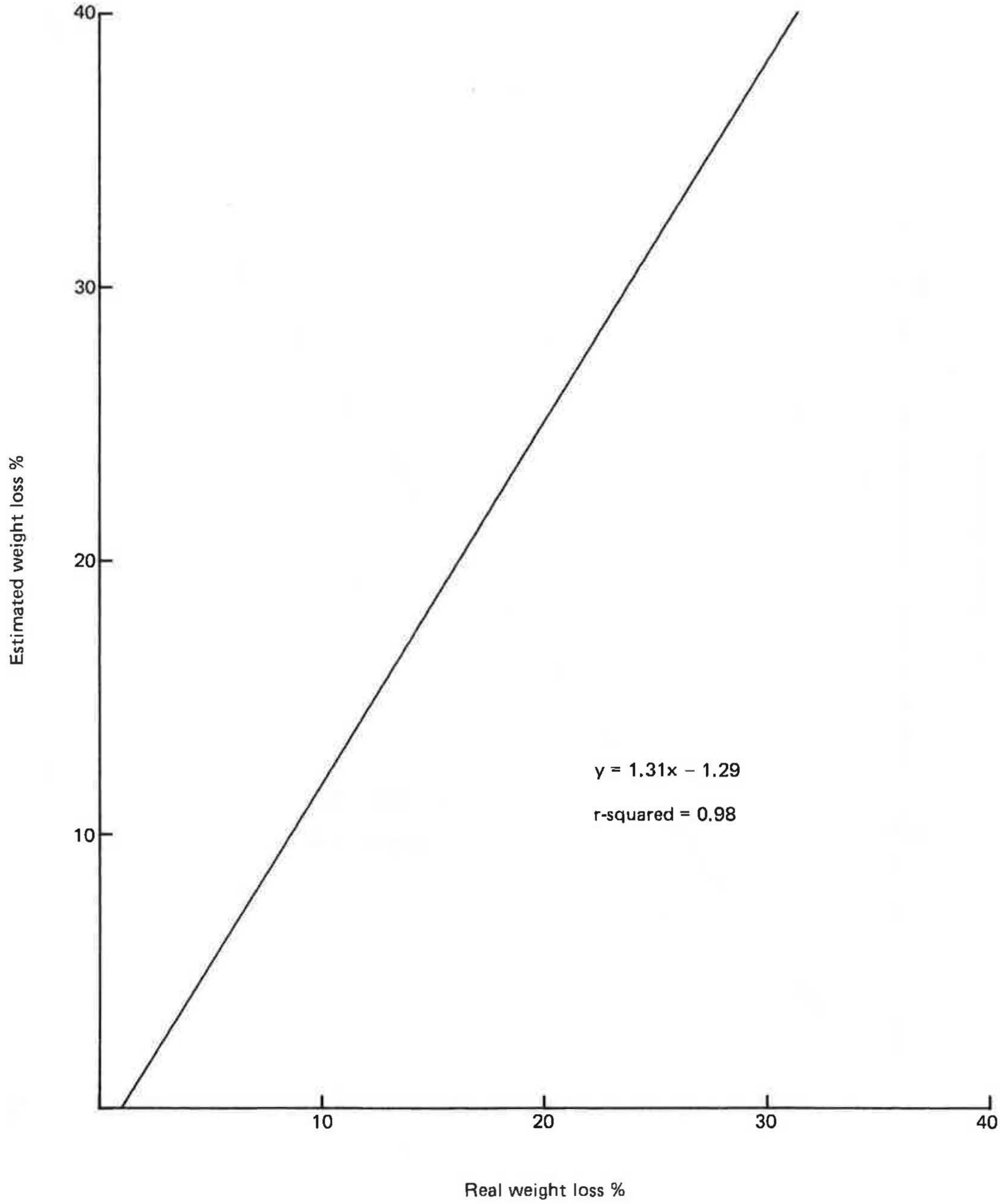


Figure 17

Count and Weigh method

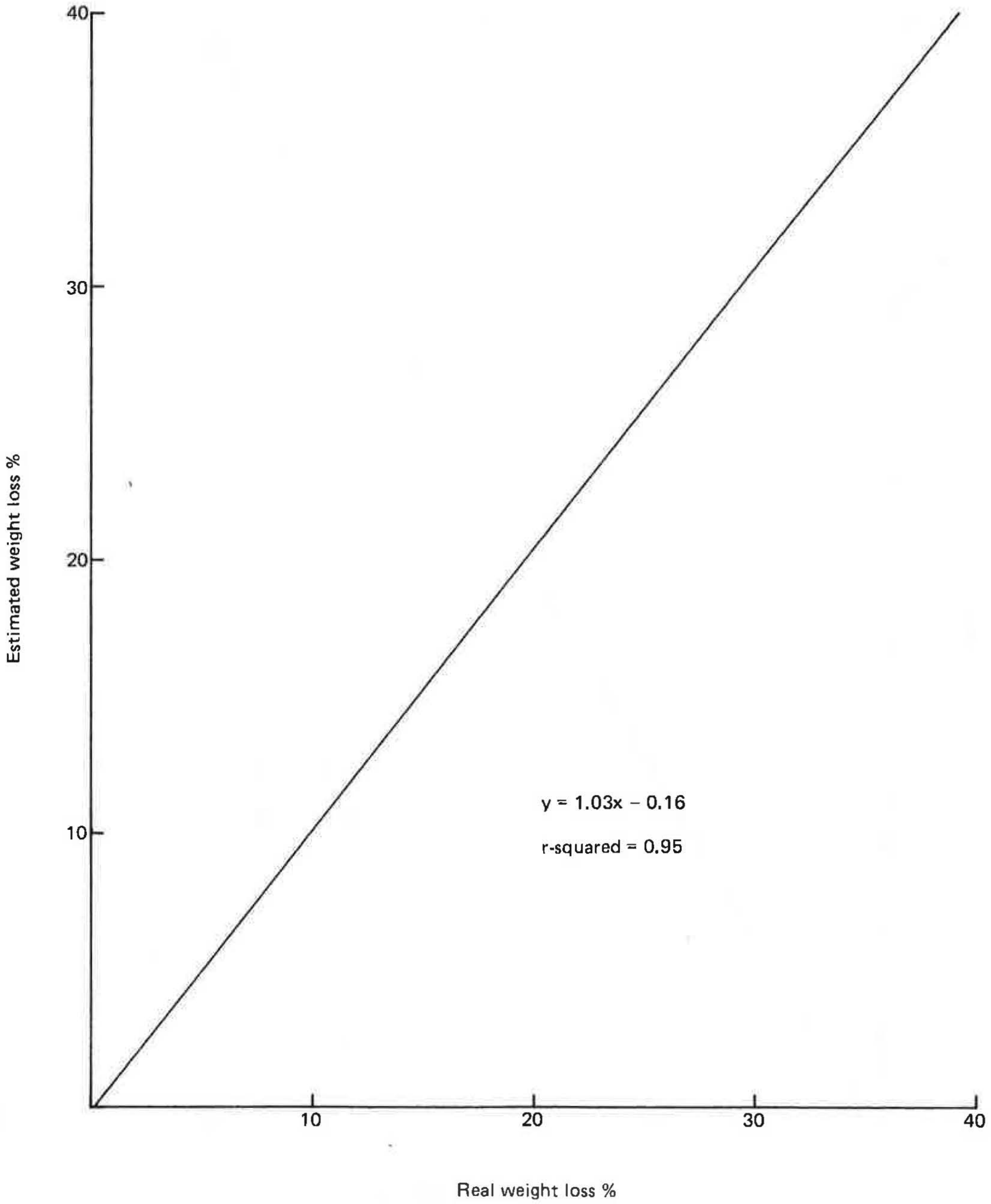


Figure 18

All methods compared

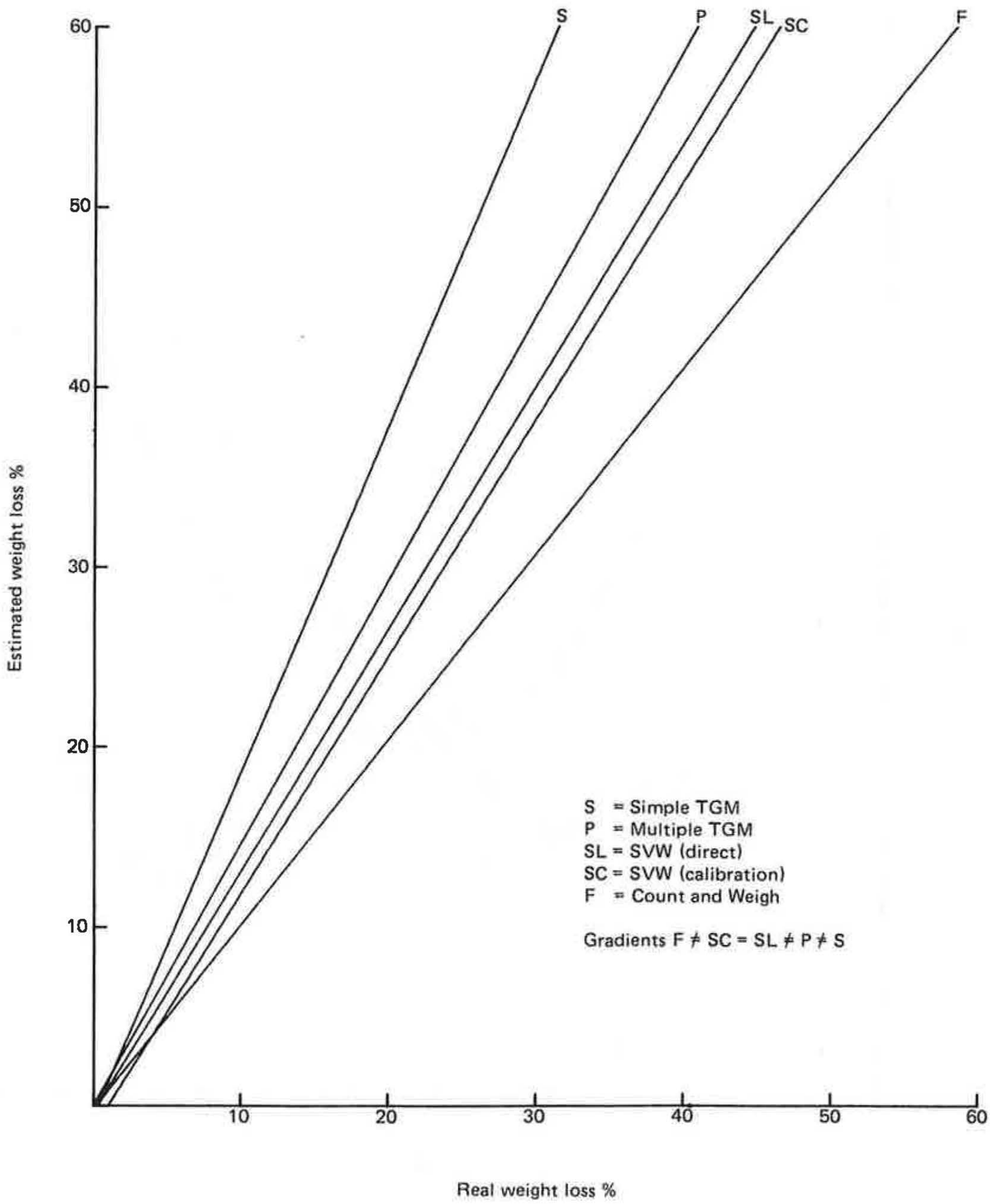


Figure 19

Converted Damage Percentage method

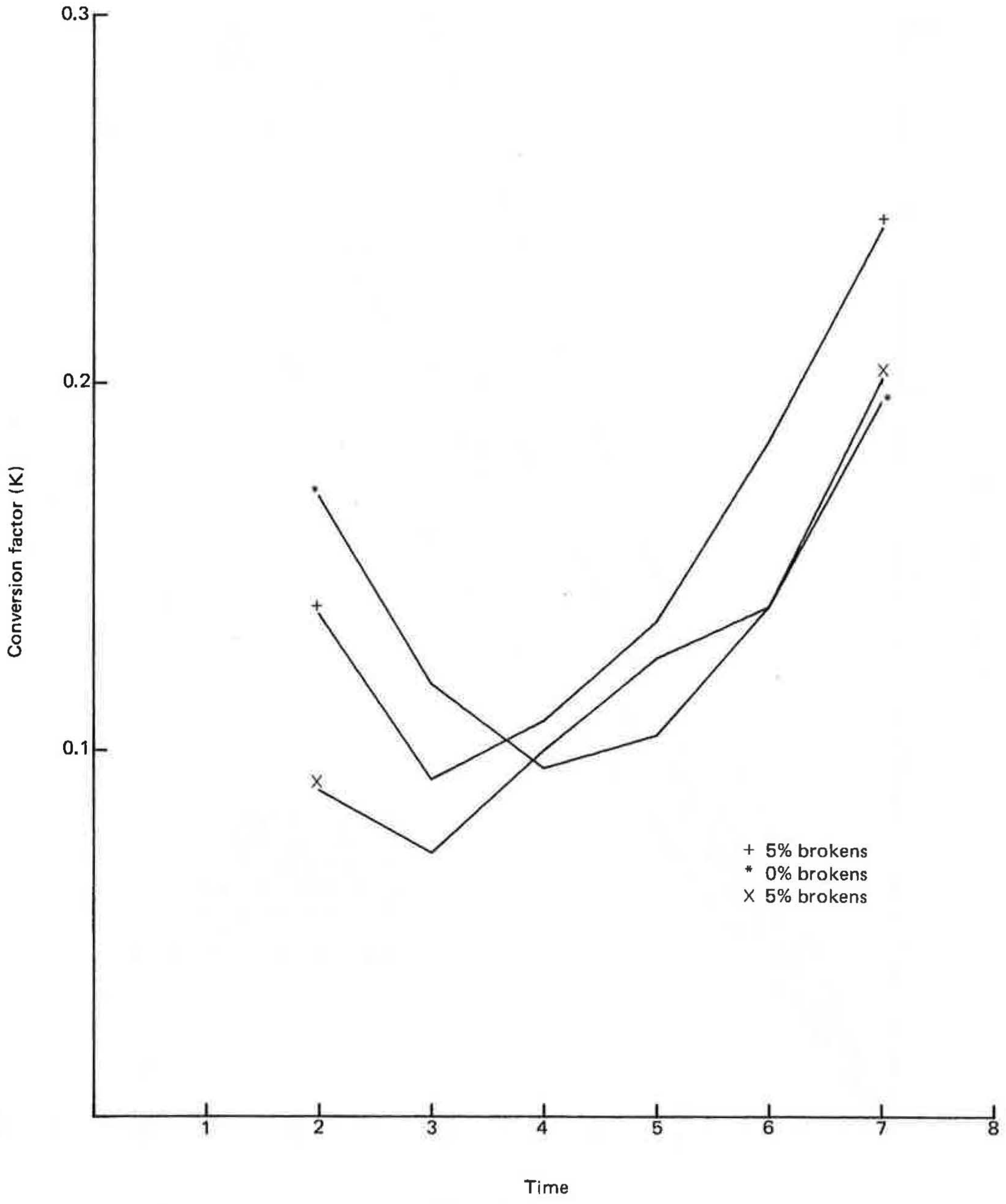


Figure 20

Reliability of percentage of damaged grains as a predictor of loss

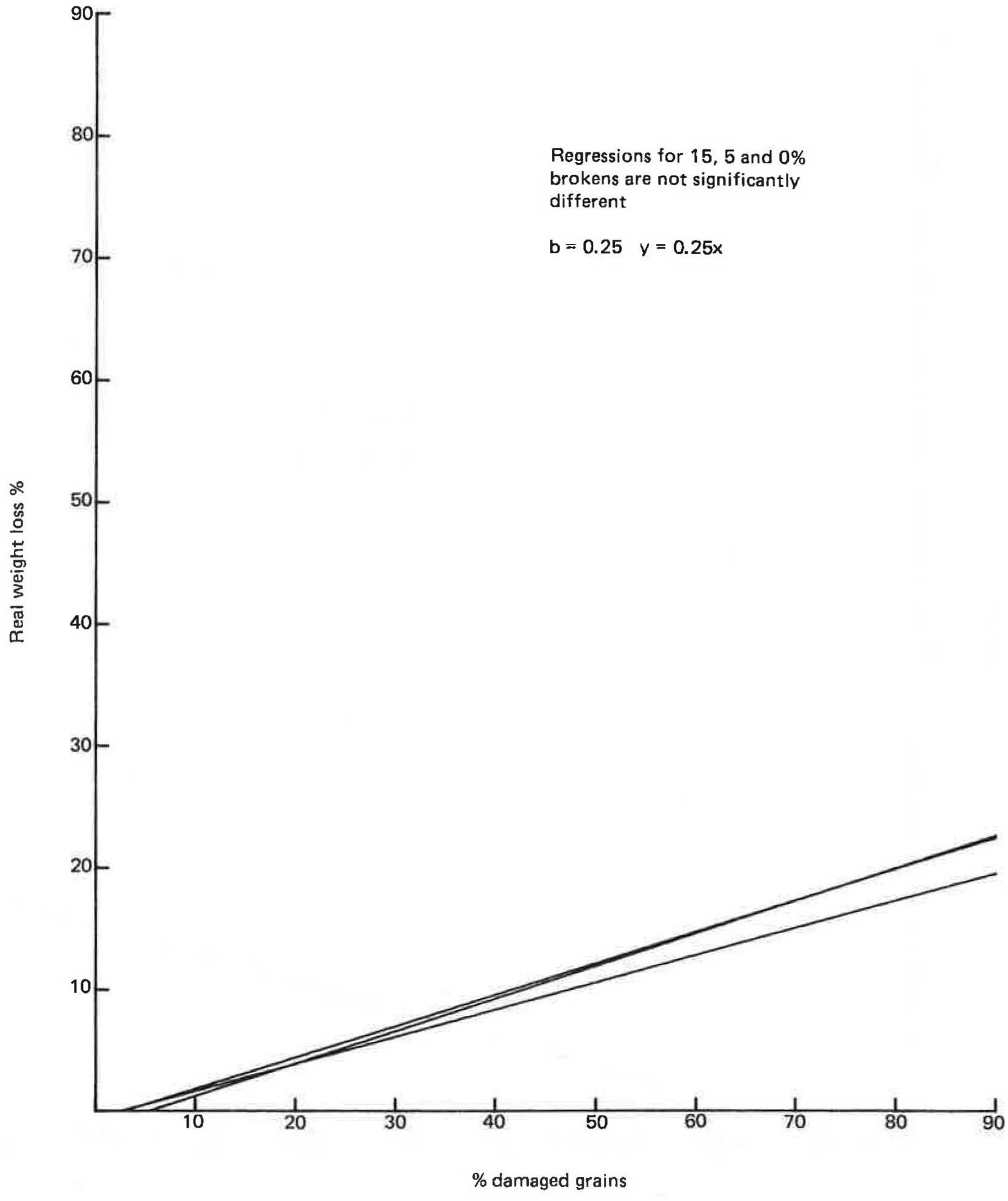


Figure 21

Reliability of percentage of damaged grains as a predictor of loss (all results combined)

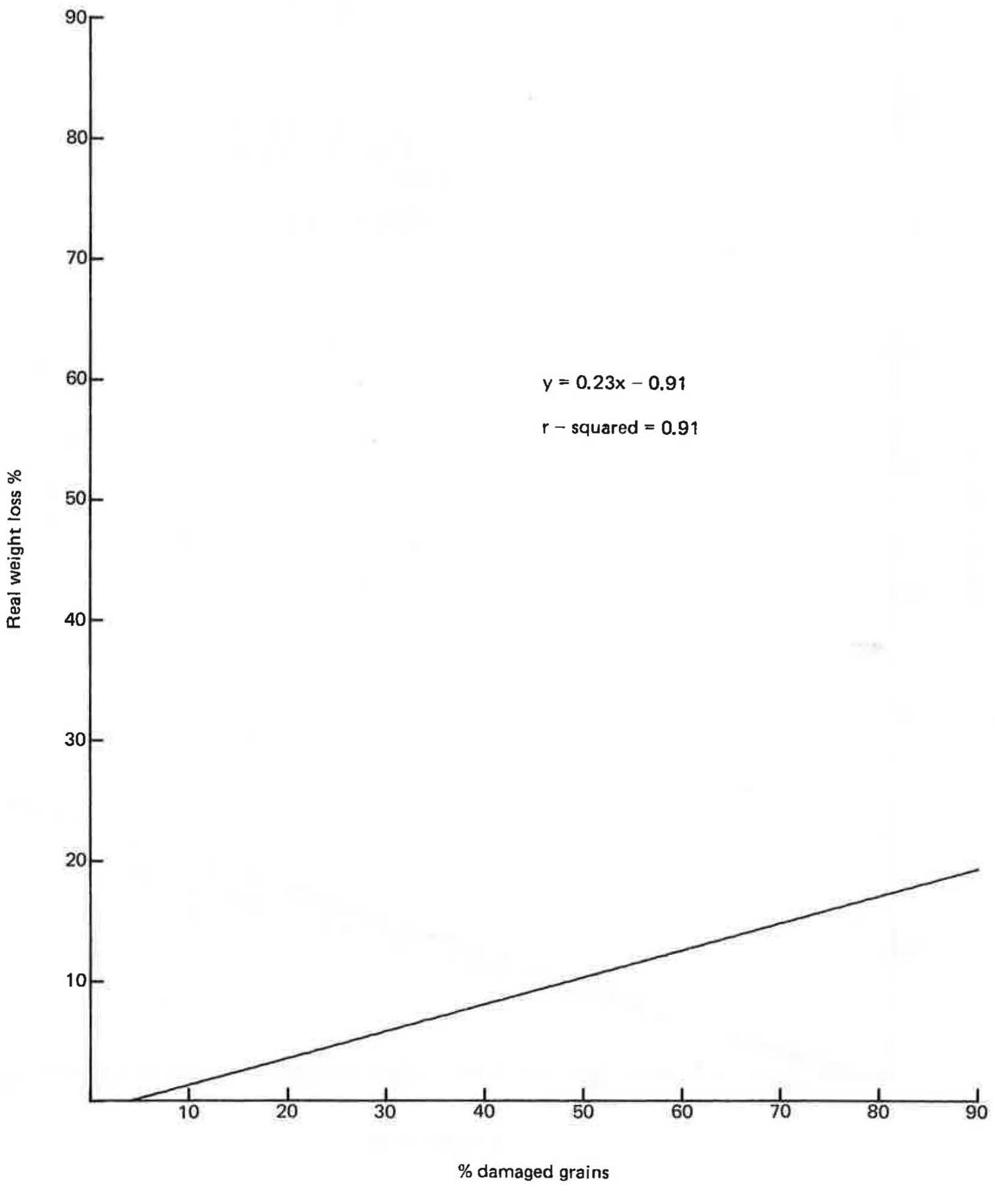


Figure 22

Relationship between percentage weight loss and percentage of damaged grains

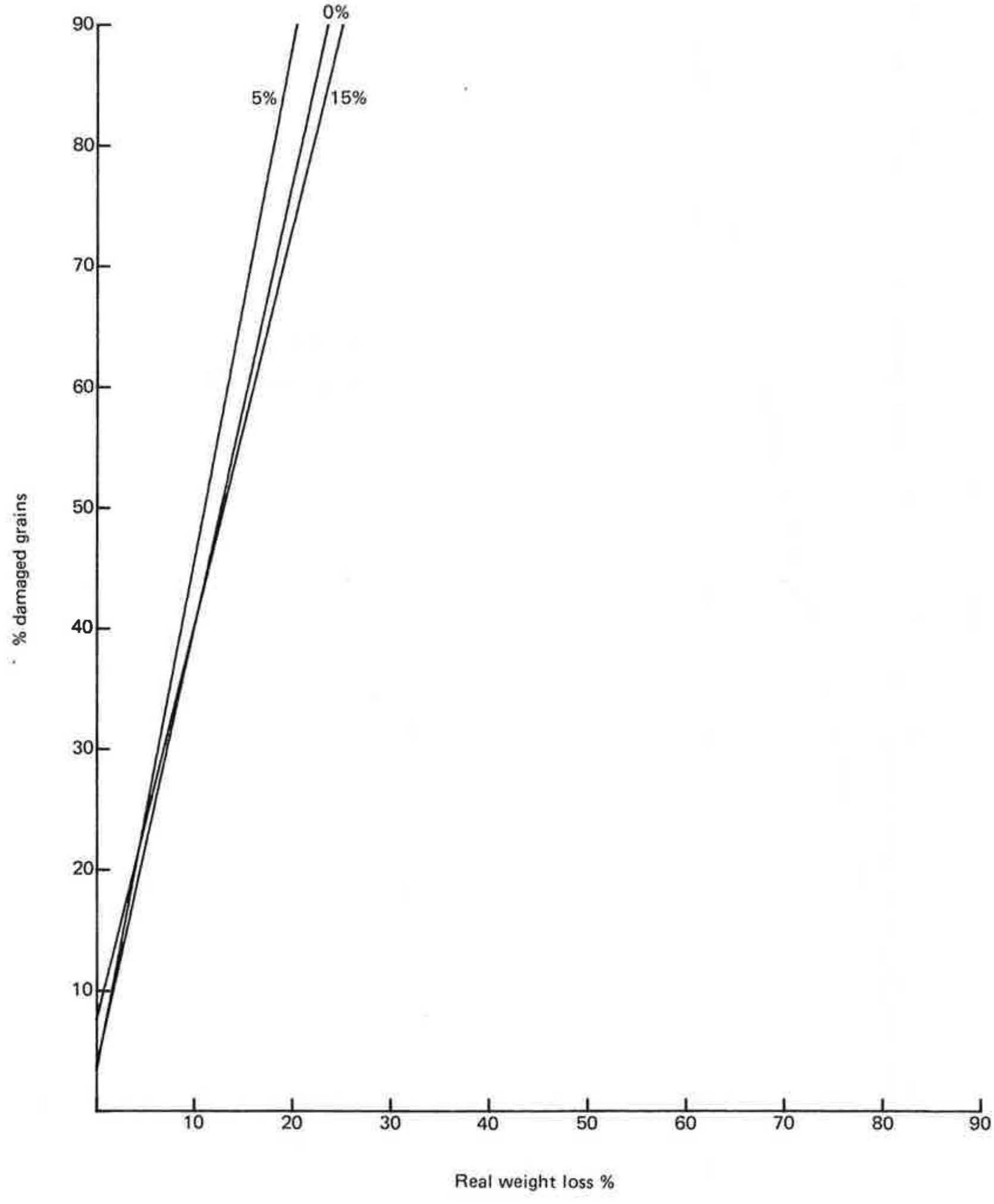


Figure 23

Relationship between percentage weight loss and percentage of damaged grains (all results combined)

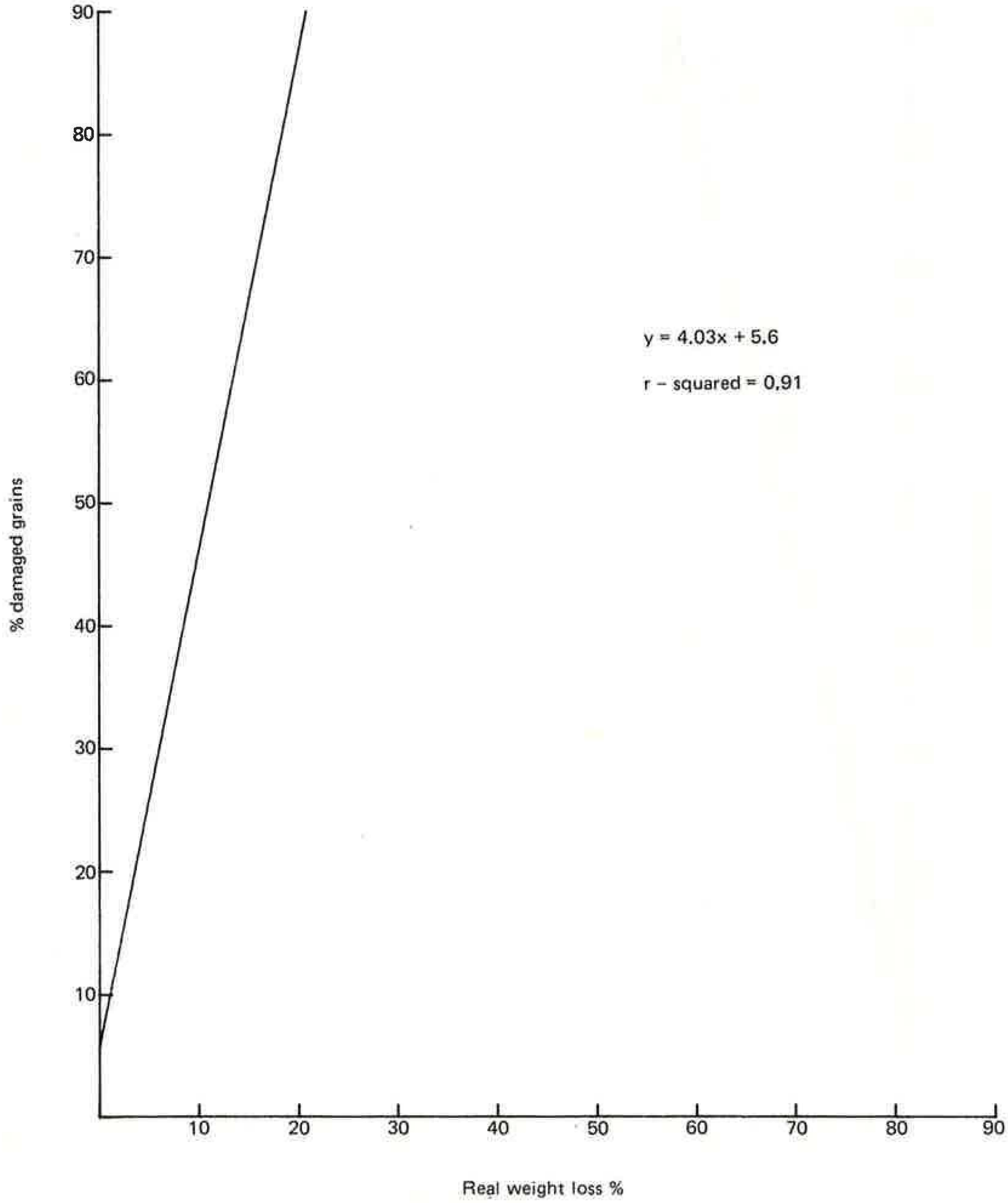


Figure 24

Correlation between real weight loss and conversion factor (K)

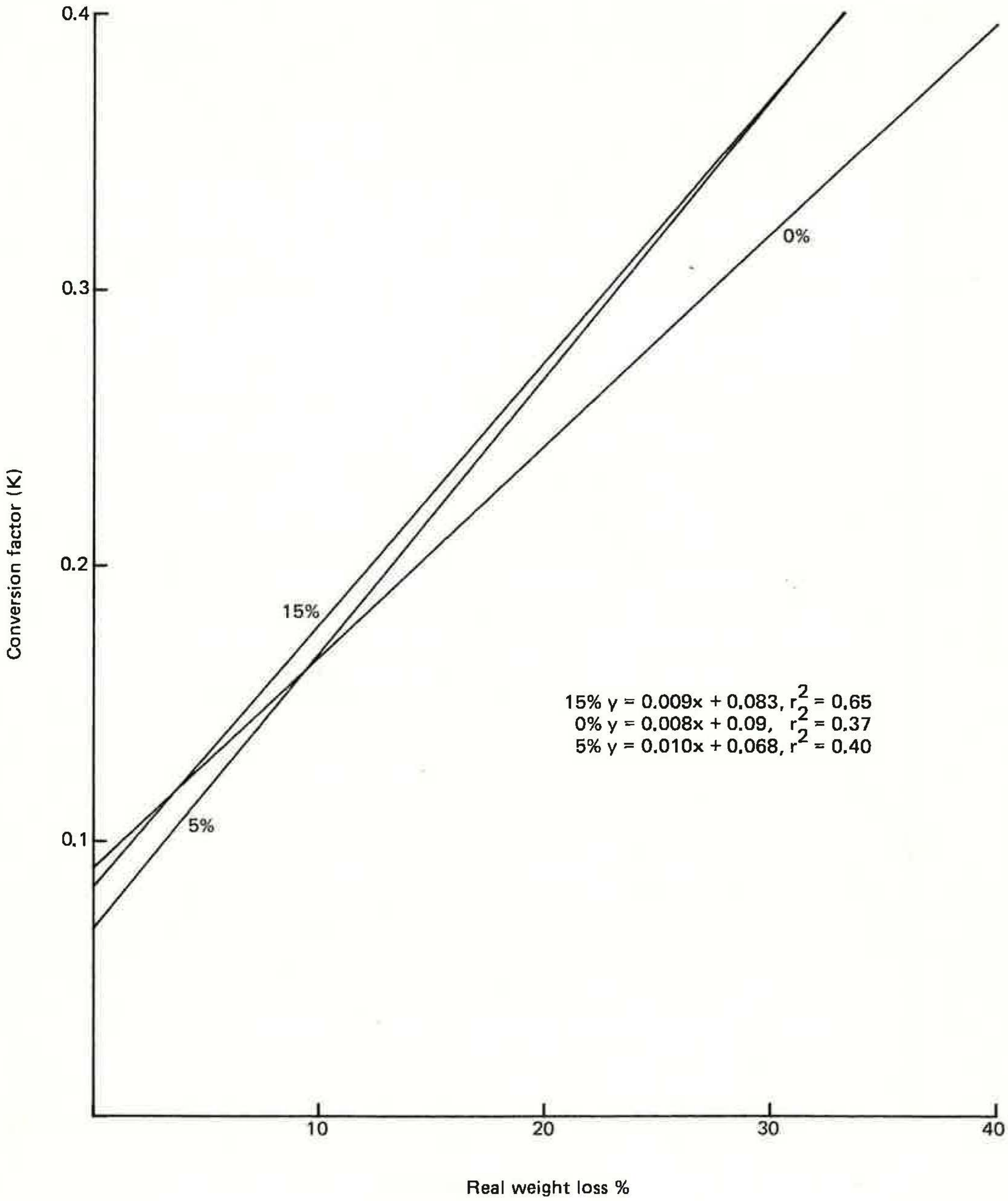
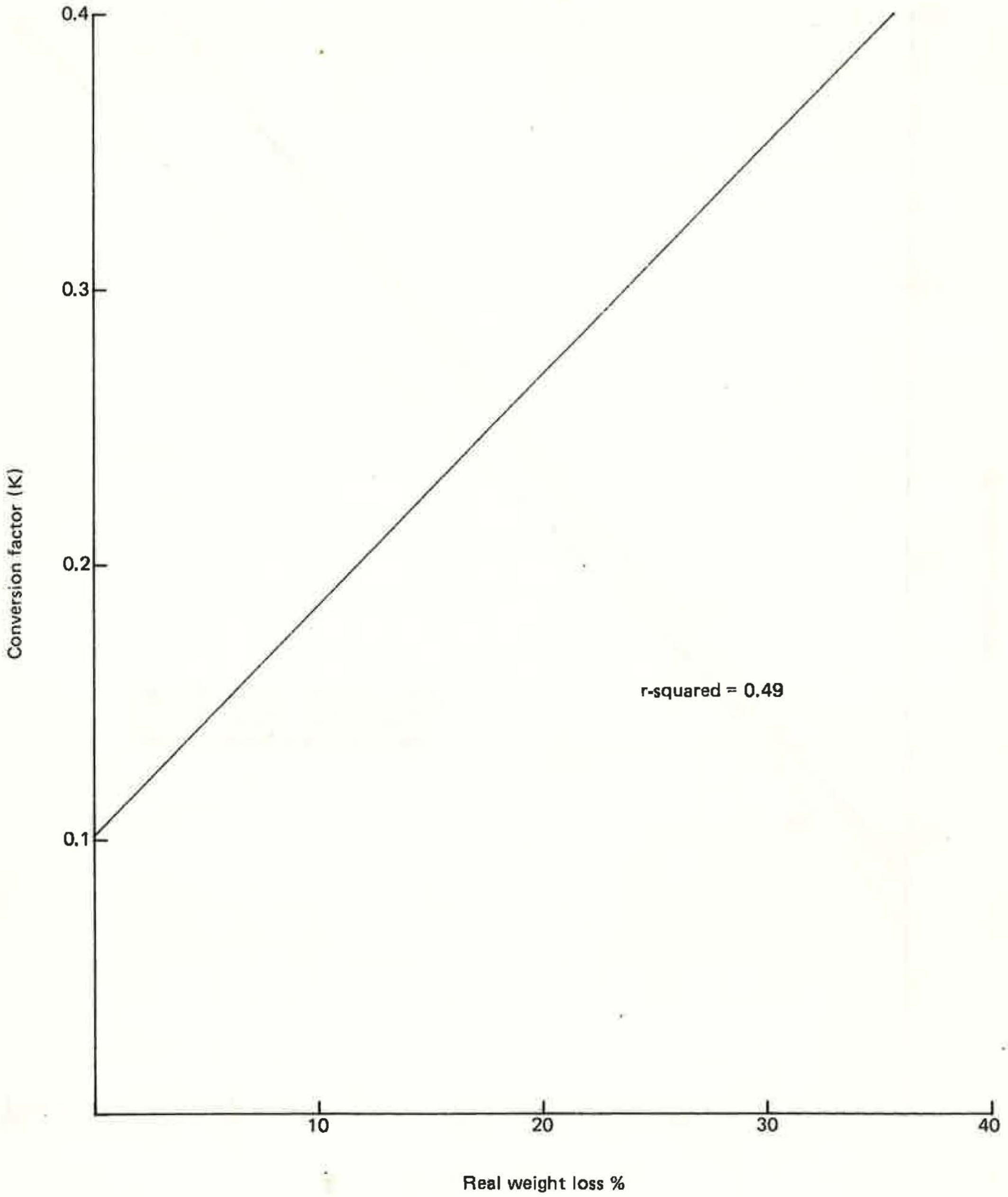


Figure 25

Correlation between real weight loss and conversion factor (K) (all results combined)



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