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A comparison of various methods of estimating digestibility, voluntary intake or average daily gains for beef cattle fed mixed rations

Jimmy Howard Clark

To the Graduate Council:

I am submitting herewith a dissertation written by Jimmy Howard Clark entitled "A comparison of various methods of estimating digestibility, voluntary intake or average daily gains for beef cattle fed mixed rations." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

K.M. Barth, Major Professor

We have read this dissertation and recommend its acceptance:

C.S. Hobbs, R.R. Shrode, W.L. Sanders, W.T. Butts

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

August 4, 1967

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Charles S. Hobbs
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Graduate Studies and Research

A COMPARISON OF VARIOUS METHODS OF ESTIMATING DIGESTIBILITY, VOLUNTARY INTAKE OR AVERAGE DAILY GAINS FOR BEEF CATTLE FED MIXED RATIONS

A Dissertation

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

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by

Jimmy Howard Clark

August 1967

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CHAPTER I

INTRODUCTION

Since feedlot trials are the most useful and accurate method of determining nutritive value of feeds for beef cattle, they are the standard to which all other methods are compared. Considerable time, labor and expense are required to conduct feedlot trials; hence, the number of trials which can be conducted is limited. Therefore, accurate, simple, timesaving and cheap methods of estimating nutritive value of feeds need to be developed. These methods could be used to select the more desirable rations, which can then be fed in the feedlot for further evaluation. However, they probably will never replace feedlot trials. For many years, digestibility trials have been used to estimate nutritive value of feeds. However, it has recently been recognized that the amount of feed eaten by ruminants is also an important factor in assessing its nutritive value.

Numerous laboratory methods are being used to estimate *in vivo* digestibility and forage intake, which also give an indication of nutritive value of feeds. Using forages, several investigators have shown high correlations between results from laboratory evaluations and *in vivo* digestibility and/or feed intake. However, since forages are seldom fed alone, it would be advantageous to have a laboratory procedure to evaluate the total mixed ration rather than just the forage alone.

Therefore, the major objective of this study was to determine the relationship between various laboratory evaluations and *in vivo* digestibility, feed intake and animal performance (average daily gains) when mixed rations are used. The second objective was to determine the relationships among and/or between *in vivo* digestibility, feed intake, total digestible nutrient intake above maintenance, laboratory evaluation data and animal performance.

CHAPTER II

REVIEW OF LITERATURE

I. EXPLANATION OF TERMS

In order to better understand the material which is to follow, a few concepts should be explained:

Digestion was defined by Morrison (1956) as all the changes which food undergoes within the digestive tract to prepare it for absorption and use in the body.

Voluntary Intake (VI) is that amount of food which an animal voluntarily consumes. It is usually expressed on the basis of body weight or metabolic size.

Relative Intake (RI) was calculated by Crampton *et al.* (1960) as follows:

$$RI = \frac{\text{observed intake X 100}}{80\ (W_{kg.}{}^{.75})}$$

where W is body weight and observed intake is equal to VI.

Nutritive Value Index (NVI) was defined by Crampton *et al.* (1960) as the product of RI and per cent energy digestibility. In contrast, Ingalls *et al.* (1965) and Mohammed (1966) also calculated NVI from RI and per cent dry matter digestibility.

II. ANIMAL PERFORMANCE

Animal performance (average daily gains) is influenced by many factors, some of which have more influence than others. For many years *in vivo* digestion data have been used almost exclusively in estimating animal performance. However, the usefulness of digestion data alone is limited. One reason for this is the fact that digestibility measures do not include the voluntary consumption of feeds. Recent reports (Crampton *et al.*, 1960 and Byers and Ormiston, 1962) have indicated that VI of forages is of greater importance in determining animal performance than is the digestibility of forages. Hence, VI, digestibility and all factors affecting VI and digestibility influence animal performance. Also, Morrison (1956) stated that, on the average, fully one-half the feed eaten by farm animals is used for maintenance, and only the remainder can be converted into useful products. Therefore, feed intake above the maintenance requirement should be a good predictor of animal performance.

III. DIGESTIBILITY STUDIES

Digestibility is usually expressed as digestible dry matter (DDM), digestible organic matter (DOM), total digestible nutrients (TDN) or digestible energy (DE). Mohammed (1966) gives an excellent review of literature on these expressions of digestibility. These four expressions of digestibility are also discussed by Stallcup and Davis (1965). Also, a good discussion of factors affecting digestibility is presented by Morrison (1956).

Prediction of Digestibility

Studies on the role of rumen microorganisms have led to the development of many artificial rumen techniques. These techniques vary widely in the purpose for which they were developed. One of the goals was to estimate in vivo digestibility of forages. Marston (1948), Louw et al. (1949) and Burroughs et al. (1950) first suggested the use of artificial rumen techniques for measuring feeding value. Since the development of these techniques, several workers (Kamstra et al., 1955; Barnett, 1957; Hershberger et al., 1959; Quicke et al., 1959; Reid et al., 1960; Oh and Baumgardt, 1966; and Chalupa and Lee, 1966), using forages, have reported high correlations between various in vivo expressions of digestibility and in vitro cellulose digestion.

In vitro dry matter digestibility also has been used as an estimator of forage quality. Bowden and Church (1962) stated that the within-trial variation of in vitro DDM of all substrates digested for 48 hours was generally small while in vitro cellulose digestibility showed a slightly higher variability within trials. Tilley and Terry (1963) developed a two-stage technique for the in vitro digestion of forage crops which results in a very high correlation with in vivo DDM. Oh and Baumgardt (1966) reported a correlation of 0.88 between in vivo DDM and in vitro DDM using this procedure with forages. Likewise, Smith et al. (1965) and Barth and Mohammed (1966), using other techniques, reported that in vitro DDM values were significantly correlated with in vivo digestibility.

In reviewing in vitro digestibility work, Barnes (1965) stated that realistic estimates of digestibility can be obtained by in vitro techniques where forages are compared to each other in the same trial. However, a standard method remains to be established before reliable comparisons of in vitro results can be made between laboratories.

Several investigators (Norman, 1935; Crampton and Maynard, 1938; Phillips and Loughlin, 1949; Meyer and Lofgreen, 1956; Sullivan, 1955 and 1964; Simkins and Baumgardt, 1963; and Baumgardt and Oh, 1965) have indicated that the digestibility of any normal plant material is inversely proportional to the degree of lignification or its lignin content. Van Soest (1965a) derived the following prediction equation for DDM from data obtained from 30 different forages:

$$DDM = 0.98\ S + W\ (147.3 - 78.9 \log L) - 12.9$$

where S is available cell contents, L is lignin content, which controls cell wall constituent (W) digestibility.

Attempts have been made to relate solubility of forages in various solvents with forage digestibility. Thurman and Wehunt (1955) developed a laboratory method for determining Digestible Laboratory Nutrients, which involved autoclaving ground samples in dilute hydrochloric acid and weighing the dried insoluble residue. However, Baumgardt et al. (1962) and Simkins and Baumgardt (1963) reported that the value for Digestible Laboratory Nutrients was not significantly correlated with any of their digestibility data.

Dehority and Johnson (1963) developed another solubility technique based on forage cellulose solubility in cupriethylenediamine. They obtained significant correlations between solubility data and *in vivo* and *in vitro* cellulose digestion, as well as with *in vivo* dry matter and energy digestibility. Dehority and Johnson (1964) also found that dry matter solubility of forages in normal sulfuric acid was significantly correlated with *in vivo* DDM and DE.

IV. VOLUNTARY INTAKE STUDIES

Since adequate feed intake is essential for good animal performance, VI of feeds has gained much interest in the past few years. It has been suggested that the VI of a forage has a greater influence on animal performance than its digestibility (Crampton *et al.*, 1960; Byers and Ormiston, 1962; and Ingalls *et al.*, 1965). Moore (1966) stated that VI may be the most important biological criterion of forage nutritive value except for actual animal performance.

Prediction of Voluntary Intake

In vitro fermentation studies are often used to predict VI. One would expect results from short fermentation periods to be more closely correlated with the level of intake since short fermentation periods measure differences in rate of digestion and they, in turn, influence rumen fill which is believed to contribute to the regulation of VI. Several workers (Donefer *et al.*, 1960; Bratzler, 1961; Johnson *et al.*, 1962; Karn *et al.*, 1964; Reid and Jung, 1965; and Chalupa and Lee, 1966), using 4- to 18-hour *in vitro* fermentation periods on forages, have reported significant correlations between digestibility and *in vivo* VI.

Reid *et al.* (1960), however, indicated that there was no consistent relationship between VI and the rate of *in vitro* cellulose digestion of eight hays, at intervals of 4, 8, 12, 20, 32 and 48 hours.

Various investigators have suggested the use of specific components in forages as predictors of VI. Lignin appears to be one of the most promising components. Van Soest (1964), Reid and Jung (1965) and Van Soest (1965b) have reported positive relationships between lignin content and VI, when tall fescue was used. However, between species there was a significant negative relationship between lignin content and VI (Forbes and Garrigus, 1950; Van Soest, 1964; and Van Soest, 1965b). Van Soest and Marcus (1964), Van Soest (1965b) and Reid and Jung (1965) indicated that cell-wall components also can be used to predict VI. These workers reported significant negative correlations of -.65, -.65 and -.69, respectively, between cell-wall constituents and VI.

Acceptable results have been obtained from the use of other chemical components as predictors of VI. Hawkins *et al.* (1964) found a positive correlation between daily intake per 100 pounds of body weight of 15 samples of coastal Bermuda grass and its crude protein and ash content.

Dehority and Johnson (1963) developed a chemical method, based on the solubility of forage cellulose in cupriethylenediamine, to estimate Relative Intake (RI) of forages. Solubility values obtained were significantly correlated with RI. In a later study, Dehority and Johnson (1964) found that the dry matter solubility of a forage in normal sulfuric acid was significantly correlated with RI and other factors.

It is evident from the literature that most investigators obtained satisfactory estimates of forage VI either from short-term in vitro fermentation determinations, from certain chemical components or from solubility studies. However, optimum fermentation times for prediction of VI might not be the same for different plant species.

V. NUTRITIVE VALUE INDEX

Nutritive Value Index (NVI) is the product of RI and either energy digestibility or dry matter digestibility. Crampton et al. (1960) and Byers and Ormiston (1962) stated that the RI of a forage influenced NVI to a greater extent than digestible energy. Therefore, these workers proposed the best indicator of animal performance to be the product of RI and energy digestibility, which is NVI. Correlation coefficients of 0.88 to 0.94 were reported between NVI and animal performance by these workers. Ingalls et al. (1965), however, reported a lower coefficient of 0.59 when using individual animal values. Although most investigators calculate NVI from in vivo determinations, there are some who estimate NVI from in vitro determinations.

Several workers (Donefer et al., 1960; Johnson et al., 1964; Reid and Jung, 1965; and Chalupa and Lee, 1966) have indicated high correlations between in vitro fermentation studies and NVI. Dehority and Johnson (1963) found the solubility of grass forage cellulose in a chemical solvent, cupriethylenediamine, to be highly related to in vivo nutritive values. Using another solubility method (dry matter solubility of forages), similar relationships for mixed forages and legumes, as well as for grasses, were observed (Dehority and Johnson, 1964).

In summary, it appears that *in vitro* digestibility can be used to predict NVI of forages. Various solubility methods also have been shown to be acceptable for this purpose, especially dry matter solubility in normal sulfuric acid.

CHAPTER III

EXPERIMENTAL PROCEDURE

In this study, results of various *in vivo* and *in vitro* feed evaluation methods were compared as to their accuracy in estimating animal performance. Average daily gains (ADG), obtained from feedlot trials, were used as the standard to which results from other methods were compared. Three laboratory evaluations were compared also as to their usefulness in estimating VI and digestibility. Feedlot trials and conventional *in vivo* digestion trials involving 43 rations had been previously conducted in other studies. The all-forage rations consisted of three qualities of alfalfa hay, the forage-concentrate mixed rations contained cracked or ground ear corn with either silage or a combination of one silage and one hay, while the all-concentrate rations contained ground ear corn. The ration for each group of animals was supplemented with a high protein source, the amount of which was calculated to supply the protein requirement according to Morrison (1956).

The feedlot trials using the 43 rations had been conducted by the following people: B. B. Wilson (1964), rations 1-9 and 40-42; Chamberlain *et al.* (1966), rations 10-25, 37-39 and 43; Corrick et al. (1966), rations 26 and 27; Clark and Barth (1966), rations 28 and 29; G. R. Wilson (1964), rations 30-33; and Mohammed *et al.* (1967), rations 34-36. Digestion trials using steers also had been conducted with these rations by the same individuals who conducted the feeding trials, with the exception of rations 10-25 conducted by McConnell et al. (1967) and rations 37-39 and 43 conducted by Barth and Prigge (1966).

Each ingredient in the 43 rations had been analyzed for proximate composition according to A.O.A.C. (1960) methods and for gross energy in a Parr (1960) oxygen bomb calorimeter. The nutrient composition and gross energy of these ingredients are shown in Table IX of the Appendix.

I. FEEDLOT TRIALS

Description of Cattle

In the previously mentioned experiments, 317 Hereford, Angus and crossbred heifers grading low Standard to low Good in initial condition, low Standard to low Choice in type and averaging 176 to 336 kilograms in initial weight had been fed 32 different rations. Also included in this study were 116 Hereford, Angus and crossbred steers grading Standard to high Good in condition, Good to low Choice in type and averaging 234 to 331 kilograms in initial weight. These steers had been fed the other 11 rations.

Feeder calf sales or University of Tennessee herds had been the sources of cattle for rations 1-17, 26, 27, 30, 31, 34-39 and 40-43. Cattle fed rations 18-25, 28, 29, 32 and 33 had been fed high roughage rations before being switched to these finishing rations.

Experimental Procedure

The various rations had been fed to two replicate lots of animals, each consisting of four to ten animals. Within each feedlot trial, the cattle had been assigned to their respective lots on the basis of weight, type and condition. All cattle were graded for type and condition at the beginning and end of the experiment and were weighed at 14- or 28-day intervals. Averages of the two body weights determined on consecutive days were used as the beginning and ending experimental weights. ADG was calculated as the average change in body weight per day from the beginning to the end of each feedlot trial. The cattle were maintained on their respective ration from 42 to 141 days.

II. VOLUNTARY INTAKE

VI was determined from the feedlot trials. Free-choice feeding of one of the ration ingredients had been practiced in these trials, while a constant amount of all other ingredients had been fed. In this study, VI was expressed as Voluntary Intake-Body Weight (VI-BW), Voluntary Intake-Body Weight$^{.75}$ (VI-BW$^{.75}$) and Voluntary Intake-Body Weight$^{.84}$ (VI-BW$^{.84}$). The average of the beginning and ending body weights was used in the calculation of VI. These measures were calculated as follows:

1. $\text{VI-BW} = \dfrac{\text{gm. dry matter}}{\text{100 kg. body weight}}$.

2. $\text{VI-BW}^{.75} = \dfrac{\text{gm. dry matter}}{\text{body weight, kg.}^{.75}}$ (Crampton et al., 1960).

3. $\text{VI-BW}^{.84} = \dfrac{\text{gm. dry matter}}{\text{body weight, kg.}^{.84}}$ (Reid, 1967).

III. DIGESTION TRIALS

Groups of either three or four Hereford steers of similar breeding, type, condition and body weight had been used to determine the digestibility of the 43 rations. Metabolism stalls described by Hobbs *et al.* (1950) were used in these trials.

In each digestion trial a 10-day preliminary period, during which the steers were accustomed to the metabolism stalls and necessary adjustments made, was followed by a 7-day total collection period. With rations 30-33 the collection period had been of a 5-day duration. The same ration ingredients as used in the feeding trials were fed twice daily. The ingredient which was fed free-choice in the feedlot was also fed free-choice in the digestion trial, however, its consumption was usually less in the digestion trial. The small amount of hay fed in the feedlot in rations 1-9, 30-33 and 40-42 was not offered in these trials. The animals had access to water twice daily at feeding time. Refusals had been determined before the morning feeding and fecal material had been collected and weighed once daily during the collection period. The feces had been thoroughly mixed, and a 5 per cent aliquot had been stored under refrigeration. At the end of the collection period, two 500-gram representative fecal samples were taken, dried for 3 days at 70°C. and allowed to air equilibrate.

All ingredients in the rations and all fecal samples were then analyzed for nutrient composition according to A.O.A.C. (1960) methods and for gross energy in a Parr (1960) oxygen bomb calorimeter.

Digestibility coefficients were calculated for each nutrient, and digestibility of the rations was expressed as DDM, DOM, TDN and DE.

IV. CALCULATIONS OF NUTRITIVE VALUE INDEXES AND TDN INTAKE ABOVE MAINTENANCE

Crampton et al. (1960) proposed that the product of RI and per cent energy digestibility of a forage be used as a NVI. In this study, NVI was calculated four ways as shown below:

NVI ($BW^{.75}$-energy) = RI x per cent energy digestibility.

NVI ($BW^{.75}$-dry matter) = RI x per cent dry matter digestibility.

NVI ($BW^{.84}$-energy) = RI x per cent energy digestibility.

NVI ($BW^{.84}$-dry matter) = RI x per cent dry matter digestibility.

The energy requirement in pounds of TDN for maintenance was calculated using the equation of Winchester and Hendricks (1953):

$$\text{Maintenance} = 0.0553 \text{ (pounds body weight}^{2/3}\text{)}.$$

The daily TDN maintenance requirement was subtracted from the daily TDN intake to arrive at TDN intake above maintenance.

V. LABORATORY EVALUATIONS

A two-stage *in vitro* fermentation technique reported by Tilley and Terry (1963) for estimating digestibility of forage crops was used to determine *in vitro* DDM. Three replicate trials were conducted. Acid solubility of the rations was obtained by using a chemical method based on the solubility of dry matter in normal sulfuric acid, which was developed by Dehority and Johnson (1964). Acid insoluble lignin content in the rations was determined according to the Van Soest (1963) procedure. In these three laboratory evaluations (conducted in duplicate), the ingredients of the 43 rations were used in the same proportions in which they had been consumed in the feedlot.

VI. CORRELATION COEFFICIENTS

Either partial or simple correlations among ADG, NVI ($BW^{.75}$-energy), NVI ($BW^{.75}$-dry matter), NVI ($BW^{.84}$-energy), NVI ($BW^{.84}$-dry matter), TDN intake above maintenance, VI-BW, VI-$BW^{.75}$, VI-$BW^{.84}$, *in vivo* expressions of digestibility (DDM, DOM, TDN and DE), *in vitro* DDM, acid insoluble lignin and dry matter solubility were calculated.

Unequal distribution of sexes, types, conditions and body weights among rations resulted in considerable confounding of these effects in the feedlot data. Hence, in cases where variables from feedlot data were involved, the above-mentioned variables were absorbed and partial correlations were calculated. Simple correlations were calculated between the *in vivo* measures of digestibility and laboratory evaluations since there was no confounding involved.

VII. MULTIPLE REGRESSION EQUATIONS

Multiple regression equations for ADG, VI-BW, VI-$BW^{.75}$ and VI-$BW^{.84}$ were developed from a multiple regression analysis using the following model:

$$\hat{Y}_i = a + \sum_j b_j X_j$$

where $i = 1, 2, 3$ and 4

$j = 1, 2, . . ., k$

$a = \overline{Y} + \sum_j b_j (0-\overline{X}_j)$.

The b_j's are the partial coefficients of regression of the dependent variables on the independent variables.

The X_j's are the independent variables measured from the feedlot, digestion trials and laboratory evaluations (specifically defined later).

The Y_i's are the dependent variables ADG and VI, defined above.

The $\hat{Y}_i$'s are the predicted value of the i^{th} dependent variable for specified values of the X_j's.

The $\overline{Y}_i$'s are the means of the i^{th} dependent variable.

The $\overline{X}_k$'s are the means of the k^{th} independent variable.

When predicting ADG and VI, the effects of sex, type, condition and body weight were absorbed, i.e., the calculations were done on a within-subclass basis, the subclasses being those with respect to sex, type, condition and body weight.

Since the present study was admittedly undertaken as only an exploratory effort to assess the possibility of using laboratory evaluations as a means of ranking rations with respect to their relative potential value in the feedlot, no exhaustive investigation of errors of measurement or variation among animals fed the same ration was conducted. To give the reader of the present report an impression of the magnitude of variation encountered, statistics reflecting this in the data from some of the experiments are presented in Appendix Tables XVII, XVIII and XIX.

CHAPTER IV

RESULTS AND DISCUSSION

A description of the rations, the cattle and their performance in the feedlot trials, the *in vivo* digestibility of the rations, the VI of the rations, the NVI and TDN intake above maintenance of the rations and the results of the three laboratory evaluations of the rations are shown in Appendix Tables X to XV. *In vitro* dry matter digestibility coefficients (Tilley and Terry, 1963) of the three individual trials are shown in Appendix Table XVI.

I. CORRELATION COEFFICIENTS

Relationships Between Measures of *In Vivo* Digestibility

Simple correlations were calculated between the four *in vivo* measures of digestibility (DDM, DOM, TDN and DE) from the data obtained from the 43 previously mentioned mixed rations. These correlations are presented in Table I. The correlation coefficients obtained between these measures of digestibility were highly significant (P<.01). The correlation (0.89) between TDN and DE was similar to those of Swift (1957), Markley (1958), Barth *et al.* (1959), Heaney and Pigden (1963), Stallcup and Davis (1965) and Barth and Mohammed (1966) who reported correlations of 0.97, 0.86, 0.95, 0.97, 0.89 and 0.89, respectively, who also used ruminant animals. The correlations between DE and DDM (0.86), DE and DOM (0.86), TDN and DOM (0.96) and DDM and DOM (0.99) also are

TABLE I

SIMPLE CORRELATION COEFFICIENTS[a] BETWEEN IN VIVO AND IN VITRO EXPRESSIONS OF DIGESTIBILITY

	DDM	DOM	TDN	DE	In vitro DDM	Acid insoluble lignin
DOM	0.99					
TDN	0.95	0.96				
DE	0.86	0.86	0.89			
In vitro DDM	0.46	0.41	0.34	0.12		
Acid insoluble lignin	-.65	-.63	-.56	-.29	-.86	
Dry matter solubility	-.11	-.09	-.05	-.24	-.76	0.63

[a]Coefficients above 0.30 and below -.30 were significant ($P<.05$) and coefficients above 0.39 and below -.39 were highly significant ($P<.01$).

similar to those of Heaney and Pigden (1963), Stallcup and Davis (1965) and Barth and Mohammed (1966) who also reported highly significant relationships between these measures of digestibility. The correlation (0.95) between DDM and TDN was of approximately the same magnitude as the 0.87 and 0.98 simple correlations reported by Stallcup and Davis (1965) and Heaney and Pigden (1963), respectively. However, these correlations were considerably higher than the nonsignificant correlation (0.57) reported by Barth and Mohammed (1966). Therefore, there is a close relationship between these four measures of *in vivo* digestibility which indicates that it is feasible to calculate one from another.

Relationships Between *In Vivo* Digestibility and Laboratory Evaluations

Correlations of the four *in vivo* expressions of digestibility (DDM, DOM, TDN and DE) with results from the three laboratory evaluations also are presented in Table I, page 19. Using forages alone, other workers reported considerably higher correlations than were obtained in the present study. Two facts may account for this. First, these laboratory techniques were developed to evaluate forages and not mixed rations. Secondly, in the laboratory evaluations the ration constituents were used in the same ratio as they had been consumed in the feedlot and not as consumed in the *in vivo* digestion trials. This was done because the major objective of this study was to estimate animal performance. It was therefore considered to be more important that the ratio of ration ingredients in the laboratory evaluations be the same as that in the feedlot and not that in the *in vivo* digestion trials, thus making possible a better estimate of animal performance.

Correlations between *in vitro* DDM and *in vivo* DDM and DOM were highly significant ($P<.01$). A significant ($P<.05$) relationship was shown to exist also between *in vitro* DDM and TDN, however, the correlation between *in vitro* DDM and DE was low and nonsignificant. The low magnitude of the latter correlation cannot be explained. Using this procedure on forages alone, Oh and Baumgardt (1966) also reported a significant correlation of 0.88 between *in vitro* DDM and *in vivo* DDM. Trends in the present data indicate that the greater the proportion of concentrate in the ration, the more this method overestimates *in vivo* digestibility of the ration. In this study varying levels of concentrate were used. However, the exact influence of the level of concentrate on *in vivo* digestibility was not measured since the ratio of ration ingredients used in the laboratory evaluation was not the same as had been consumed in the *in vivo* digestion trials. Therefore, a more meaningful determination of the effect of concentrate level and overestimation of *in vivo* digestibility could be made in a study where the ratio of ration ingredients is the same in the *in vivo* and *in vitro* digestion trials.

Using mixed rations, highly significant ($P<.01$) negative correlations (-.65, -.63 and -.56, respectively) were obtained between acid insoluble lignin and *in vivo* DDM, DOM and TDN. The negative correlation (-.29) obtained between acid insoluble lignin and DE was approaching significance. The -.65 correlation between acid insoluble lignin and *in vivo* DDM from the present data is of a similar magnitude to the -.68 correlation reported by Simkins and Baumgardt (1963) between acid insoluble lignin and *in vivo* DDM when using forages alone. Also using acid insoluble lignin, Oh and Baumgardt (1966) reported a lower correlation of -.46. These correlations, however, are slightly lower than the -.79 reported by Van Soest (1963) between acid insoluble lignin and *in vivo* DDM of forages alone.

Correlation coefficients between dry matter solubility and the four measures of *in vivo* digestibility were generally low and not significant. Trends in the dry matter solubility data indicate that the use of concentrates in this laboratory evaluation could be the reason for the low correlations, especially since this method was developed to estimate the digestibility of forages only. Also, a different ratio of ration ingredients was used in the laboratory evaluation than was consumed in the *in vivo* digestion trials which could have contributed to the lower correlations.

It is evident from this study that some laboratory evaluations are significantly correlated with *in vivo* digestibility, even when mixed rations are used. Both acid insoluble lignin and *in vitro* DDM are significantly correlated with *in vivo* DDM, DOM and TDN. However, dry matter solubility showed little relationship to any of the expressions of *in vivo* digestibility.

Relationships Between Voluntary Intake and Laboratory Evaluations

In this study, three measures of Voluntary Intake (VI-BW, VI-$BW^{.75}$ and VI-$BW^{.84}$) were correlated with three laboratory evaluations. Partial correlations involving these are shown in Table II. Correlations between

TABLE II

PARTIAL CORRELATION COEFFICIENTS[a,b] BETWEEN METHODS THAT EVALUATE RATION QUALITY

	ADG	TDN intake above maint.	NVI ($BW^{.75}$-energy)	NVI ($BW^{.75}$-dry matter)	NVI ($BW^{.84}$-energy)	NVI ($BW^{.84}$-dry matter)	VI (BW)	VI ($BW^{.75}$)	VI ($BW^{.84}$)
TDN intake above maint.	0.18								
NVI($BW^{.75}$-energy)	0.18	0.67							
NVI($BW^{.75}$-dry matter)	0.25	0.64	0.69						
NVI($BW^{.84}$-energy)	0.16	0.69	0.67	0.61					
NVI($BW^{.84}$-dry matter)	0.22	0.69	0.63	0.63	0.68				
VI(BW)	0.18	0.54	0.51	0.54	0.52	0.57			
VI($BW^{.75}$)	0.20	0.47	0.46	0.50	0.45	0.50	0.63		
VI($BW^{.84}$)	0.18	0.55	0.45	0.46	0.53	0.58	0.66	0.63	
DDM	0.27	0.62	0.62	0.59	0.61	0.60	0.20	0.18	0.23
DOM	0.21	0.60	0.60	0.55	0.60	0.57	0.15	0.18	0.19

TABLE II (continued)

	ADG	TDN intake above maint.	NVI ($BW^{.75}$-energy)	NVI ($BW^{.75}$-dry matter)	NVI ($BW^{.84}$-energy)	NVI ($BW^{.84}$-dry matter)	VI (BW)	VI ($BW^{.75}$)	VI ($BW^{.84}$)
TDN	0.16	0.62	0.60	0.55	0.59	0.56	0.19	0.17	0.21
DE	0.16	0.60	0.65	0.59	0.62	0.56	0.20	-.17	0.19
In vitro DDM	0.45	0.39	0.36	0.40	0.35	0.38	0.29	0.29	0.27
Acid insoluble lignin	-.37	-.33	-.34	-.33	-.31	-.31	-.07	-.08	-.08
Dry matter solubility	-.16	-.15	-.05	-.10	-.08	-.15	-.14	-.09	-.15

[a]Body weight, initial type and condition and sex were absorbed in calculating these correlations.

[b]Coefficients above 0.33 and below -.33 were significant ($P<.05$) and coefficients above 0.42 and below -.42 were highly significant ($P<.01$).

the laboratory evaluations and the various measures of VI indicated that they were not significantly related. Various workers (Donefer *et al.*, 1960; Bratzler, 1961; Johnson *et al.*, 1962; Karn *et al.*, 1964; Reid and Jung, 1965; and Chalupa and Lee, 1966) have indicated that short-term *in vitro* digestion was highly correlated with VI. However, in this study the results of the longer term *in vitro* fermentation method of Tilley and Terry (1963) were correlated with VI but this correlation only approached significance.

Using forages, Van Soest (1964 and 1965b), Reid and Jung (1965) and, using mixed rations, Barth and Mohammed (1966) indicated that lignin content could be used to predict VI. Dry matter solubility was reported to be a good predictor of VI by Dehority and Johnson (1964) who used forages alone and by Mohammed (1966) who used mixed rations.

General conclusions from the present study are that there is little relationship between VI and these laboratory procedures. However, of these laboratory evaluations, *in vitro* DDM (Tilley and Terry, 1963) is the best estimator of VI when mixed rations are used.

Relationships Between Nutritive Value Index and Laboratory Evaluations

The partial correlations between either NVI ($BW^{.75}$-energy), NVI ($BW^{.75}$-dry matter), NVI ($BW^{.84}$-energy) or NVI ($BW^{.84}$-dry matter) and one of the three laboratory evaluations (*in vitro* DDM, acid insoluble lignin and dry matter solubility) also were determined in this investigation and these results are presented in Table II, page 23. Essentially no difference was found in the correlations between the four expressions of NVI. Correlation coefficients between the four expressions of NVI and in vitro DDM were significant ($P<.05$), indicating in vitro DDM to be an estimator of NVI. Coefficients based on energy digestibility were slightly lower than those based on DDM, and coefficients where 0.75 was used as the exponent for body weight were slightly higher than those where 0.84 was used. Acid insoluble lignin also was significantly ($P<.05$) negatively correlated with NVI ($BW^{.75}$-energy) and NVI ($BW^{.75}$-dry matter) while negative correlations between acid insoluble lignin and NVI ($BW^{.84}$-energy), or NVI ($BW^{.84}$-dry matter) only approached significance. Correlations between dry matter solubility and the four expressions of NVI were low and nonsignificant showing little or no relationship. This is in contrast with the results of Dehority and Johnson (1964) who stated that there was a high relationship between dry matter solubility and NVI, when using forages alone.

In summary, these results show in vitro DDM to be a useful indicator of NVI, when using mixed rations. Acid insoluble lignin can be used also to estimate NVI; however, in vitro DDM seems to be the preferred method for mixed rations. Dry matter solubility probably should not be used to estimate NVI when using mixed rations.

Relationships Between Average Daily Gains and Digestibility

Partial correlation coefficients between ADG and the four in vivo measures of digestibility (DDM, DOM, TDN and DE) are presented in Table II, page 23. It may be observed that these correlations are quite small and nonsignificant. Of special interest is the fact that both DDM and DOM were more highly correlated with ADG than was TDN or DE. This was especially surprising since, in the past, TDN and DE have been the major criteria of determining nutritive value of forages.

Relationships Between Average Daily Gains and Voluntary Intake

ADG was correlated also with three measures of VI (VI-BW, VI-$BW^{.75}$ and VI-$BW^{.84}$), and the coefficients are shown in Table II, page 23. These partial correlations were small and nonsignificant. The partial correlation between VI-$BW^{.75}$ and ADG, however, was slightly larger (0.20 *vs.* 0.18) than the correlations between ADG and the two other measures of VI. In contrast, using forages, Crampton *et al.* (1960), Byers and Ormiston (1962) and Ingalls *et al.* (1965) have indicated a high relationship between ADG and VI.

Relationships Between Average Daily Gains and Nutritive Value Indexes or TDN Intake Above Maintenance

Crampton *et al.* (1960) and Byers and Ormiston (1962) have reported a high relationship between NVI and ADG. Therefore, NVI ($BW^{.75}$-energy), NVI ($BW^{.75}$-dry matter), NVI ($BW^{.84}$-energy) and NVI ($BW^{.84}$-dry matter) were correlated with ADG. These partial correlations are presented in Table II, page 23. Small, nonsignificant, partial correlations were obtained. NVI ($BW^{.75}$-dry matter) was the most highly correlated (0.25) with ADG, followed by NVI ($BW^{.84}$-dry matter), NVI ($BW^{.75}$-energy) and NVI ($BW^{.84}$-energy).

TDN intake above maintenance also was correlated with ADG (Table II, page 23) since intake above maintenance is generally considered as that portion of the ration which determines production. However, the partial correlation obtained was low and not significant.

Relationships Between Average Daily Gains and Laboratory Evaluations

Partial correlations were calculated between ADG and the three laboratory evaluations, and the results are presented in Table II, page 23. The highly significant ($P<.01$) partial correlation (0.45) between ADG and *in vitro* DDM indicated this laboratory procedure to be a useful estimator of ADG when mixed rations are fed. A somewhat lower but significant ($P<.05$) negative partial correlation was obtained between ADG and acid insoluble lignin, suggesting that this variable also may be used to estimate ADG. However, the partial correlation between ADG and dry matter solubility was low and not significant. Therefore, this procedure most probably should not be used to estimate ADG when mixed rations are to be used.

II. MULTIPLE REGRESSION EQUATIONS

Multiple regression equations were calculated for the three measures of VI (VI-BW, VI-$BW^{.75}$ and VI-$BW^{.84}$) and for ADG, using various combinations of independent variables. The purpose of these analyses was to determine combinations of variables which would be relatively easy to obtain and which would be useful in estimating VI and ADG.

The general form in which these equations are presented is:

$$\hat{Y} = a + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n .$$

Where "a" is a constant, calculated as follows:

$$a = \overline{Y} - b_1 \overline{X}_1 - b_2 \overline{X}_2 - \ldots - b_n \overline{X}_n.$$

The b's are partial regression coefficients. For example, from Table III, equation two is the equation for estimating VI-BW from *in vitro* DDM, concentrate in the ration and length of feeding; i.e.,

$$\hat{Y} = 1.147 + 0.0224\ X_1 - 0.0056\ X_2 - 0.0018\ X_3.$$

Where $\hat{Y}$ = predicted value of VI-BW.

X_1 = *in vitro* DDM.

X_2 = per cent concentrate in the ration.

X_3 = length of feeding in days.

Voluntary Intake Estimated from Laboratory Evaluations and Other Variables

Multiple regression equations and coefficients of determination calculated to estimate VI-BW, VI-$BW^{.75}$ and VI-$BW^{.84}$ of mixed rations appear in Tables III, IV and V. The equations were calculated using either *in vitro* DDM, acid insoluble lignin or dry matter solubility and one or more other variables, consisting of per cent concentrate in the ration, length of feeding, per cent crude protein in the ration and $(\text{length of feeding})^2$. The quadratic "length of feeding" term was included to determine if a nonlinear relationship existed between length of feeding and these measures of VI.

Coefficients of determination for VI-BW, VI-$BW^{.75}$ and VI-$BW^{.84}$ obtained using the same combination of variables were of approximately the same magnitude. From these coefficients it appears that any one of

TABLE III

MULTIPLE REGRESSION EQUATIONS[a] FOR VI-BW

	Equation number											
	1	2	3	4	5	6	7	8	9	10	11	12
Constant, (a)	1.071	1.147	0.883	0.237	2.266	2.265	2.289	2.481	2.429	2.408	2.178	2.087
In vitro DDM	0.0204	0.0224	0.0239	0.0241								
Acid insoluble lignin					-.0119	-.0118	-.0107	-.0119				
Dry matter solubility									-.0099	-.0098	-.0236	-.0238
Concentrate in ration, %	-.0048	-.0056	-.0058	-.0065	-.0003	-.0003	-.0003	-.0007	-.0016	-.0016	-.0034	-.0032
Length of feeding, days		-.0018	-.0017	0.0051		0.0000	0.0000	-.0019		0.0002	0.0007	0.0016
Crude protein in ration, %			0.0120	0.0131			-.0021	-.0012			0.0358	0.0358
(Length of feeding)^2, days				0.0000				0.0000				0.0000
R^2	.159	.171	.179	.181	.006	.006	.006	.007	.025	.025	.048	.048

[a]Body weight, initial type, initial condition and sex were absorbed in developing these equations.

TABLE IV

MULTIPLE REGRESSION EQUATIONS[a] FOR VI-BW$^{.75}$

	Equation number											
	1	2	3	4	5	6	7	8	9	10	11	12
Constant, (a)	42.185	44.872	30.590	43.574	95.205	94.068	93.097	105.985	99.285	97.101	88.386	94.781
In vitro DDM	0.8947	0.9702	1.0503	1.0711								
Acid insoluble lignin					-.6112	-.5846	-.6263	-.7886				
Dry matter solubility									-.3347	-.3288	-.8627	-.8461
Concentrate in ration, %	-.2368	-.2665	-.2767	-.3362	0.0429	0.0404	-.0407	-.0933	-.0791	-.0747	-.1447	-.1646
Length of feeding, days		-.0661	-.0606	-.3664		0.0093	0.0099	-.2585		0.0193	0.0381	-.0866
Crude protein in ration, %			0.6481	0.7408			0.0827	0.2082			1.3811	1.3834
(Length of feeding)^2, days				0.0016				0.0014				0.0006
R^2	.149	.158	.168	.176	.009	.009	.009	.015	.015	.016	.032	.034

[a]Body weight, initial type, initial condition and sex were absorbed in developing these equations.

TABLE V

MULTIPLE REGRESSION EQUATIONS[a] FOR VI-BW·84

	Equation number											
	1	2	3	4	5	6	7	8	9	10	11	12
Constant, (a)	23.749	27.710	22.517	16.192	56.622	62.671	63.993	57.498	61.791	66.297	60.261	52.163
In vitro DDM	0.5524	0.6636	0.6927	0.6896								
Acid insoluble lignin					-.3975	-.5390	-.4823	-.4344				
Dry matter solubility									-.3205	-.3329	-.7011	-.7239
Concentrate in ration, %	-.1397	-.1834	-.1871	-.1783	-.0207	-.0340	-.0337	-.0181	-.0616	-.0708	-.1191	-.0917
Length of feeding, days		-.0974	-.0954	-.0502		-.0495	-.0503	-.0290		-.0408	-.0279	0.1442
Crude protein in ration, %			0.2357	0.2220			-.1123	-.1495			0.9524	0.9492
(Length of feeding)^2, days								0.0004				-.0009
R^2	.141	.189	.192	.193	.008	.021	.022	.023	.032	.041	.061	.067

[a]Body weight, initial type, initial condition and sex were absorbed in developing these equations.

these three measures of VI can be estimated with about the same degree of success when using these multiple regression equations. The magnitude of these coefficients of determination obtained for VI-BW, VI-$BW^{.75}$ and VI-$BW^{.84}$ were low and nonsignificant, suggesting that these multiple regression equations most probably should not be used to estimate VI of mixed rations. On the basis of these results it is evident that more work needs to be done concerning the estimation of VI of mixed rations from laboratory evaluations.

Coefficients of determination obtained with multiple regression equations in which *in vitro* DDM was used were larger than coefficients obtained with equations in which acid insoluble lignin or dry matter solubility was used. This indicates that even though these equations containing *in vitro* DDM are not very acceptable for estimating VI of mixed rations, they are more useful than equations in which acid insoluble lignin or dry matter solubility were used. These data show also that per cent concentrate in the ration, length of feeding, per cent crude protein in the ration and $(\text{length of feeding})^2$ contribute little to the estimation of VI, when either *in vitro* DDM, acid insoluble lignin or dry matter solubility also has been included in the regression equation.

Average Daily Gains Estimated from Voluntary Intake and *In Vivo* Digestibility

Multiple regression equations and coefficients of determination were calculated for ADG (Table VI) combining one of three measures of

TABLE VI

MULTIPLE REGRESSION EQUATIONS[a] FOR ADG CALCULATED FROM VOLUNTARY INTAKE AND *IN VIVO* DIGESTIBILITY

	Equation number											
	1	2	3	4	5	6	7	8	9	10	11	12
Constant, (a)	-.340	-.268	-.066	-.045	-.445	-.381	-.179	-.163	-.261	-.181	0.007	0.006
VI-BW	0.1872	0.2142	0.2181	0.2207								
$VI\text{-}BW^{.75}$					0.0060	0.0066	0.0067	0.0068				
$VI\text{-}BW^{.84}$									0.0064	0.0075	0.0078	0.0080
DDM	0.0097				0.0093				0.0095			
DOM		0.0076				0.0074				0.0073		
TDN			0.0045				0.0043				0.0043	
DE				0.0941				0.0899				0.0951
R^2	.096	.078	.061	.059	.113	.098	.080	.079	.093	.076	.060	.060

[a]Body weight, initial type, initial condition and sex were absorbed in developing these equations.

VI (VI-BW$^{.75}$ and VI-BW$^{.84}$) with one of four measures of in vivo digestibility (DDM, DOM, TDN and DE) in regression equations, until all possible combinations of VI and in vivo digestibility were used. These coefficients of determination for ADG were low and nonsignificant, indicating that VI and in vivo digestibility explained only a very small amount of the variation in ADG. Trends in these data show that equations containing in vivo DDM have larger coefficients of determination than those containing other expressions of digestibility. Also, equations containing VI-BW$^{.75}$ explained more of the variation in ADG than did those containing the other expressions of VI.

Since equation five, consisting of VI-BW$^{.75}$ and in vivo DDM, explained more of the variation in ADG (11 per cent) than did any of the other eleven regression equations, it was chosen to be expanded with other variables in order to establish the most accurate means of estimating ADG from several variables. In contrast to these results, it was indicated in the literature than VI and digestibility make a large contribution to animal performance. Therefore, this would indicate a need for additional work to determine the contribution of VI and digestibility on animal performance, when mixed rations are fed.

Average Daily Gains Estimated from Several Variables

VI-BW$^{.75}$, in vivo DDM and one or more other variables were used in calculating regression equations and coefficients of determination for ADG. These regression equations and coefficients of determination are presented in Table VII. The per cent concentrate in the ration

TABLE VII

MULTIPLE REGRESSION EQUATIONS[a] FOR ADG CALCULATED FROM SEVERAL VARIABLES

	Equation number					
	1	2	3	4	5	6
Constant, (a)	-.445	-.683	-.539	0.496	1.121	1.356
VI-BW$^{.75}$	0.0060	0.0068	0.0069	0.0072	0.0063	0.0063
DDM	0.0093	0.0078	0.0100	-.0004	0.0010	-.0017
Concentrate in ration, %		0.0060	0.0055	0.0040	0.0010	0.0002
Length of feeding, days			-.0029	-.0035	-.0192	-.0221
Acid insoluble lignin				-.0480	-.0513	-.0713
(Length of feeding)^2, days					0.0001	0.0001
Crude protein in ration, %						0.0260
R^2	.113	.293	.343	.408	.462	.498

[a]Body weight, initial type, initial condition and sex were absorbed in developing these equations.

accounted for more of the variation in ADG (18 per cent) than did any other variable. Each of the variables, length of feeding, lignin content, $(\text{length of feeding})^2$ and crude protein in the ration explained from 3 to 6.5 per cent of the variation in ADG when using these regression equations. These percentages were determined by subtracting the coefficient of determination for one equation from the coefficient of determination of another equation, when there was only one extra variable added to the last equation. For example, the coefficient of determination for equation two was subtracted from that of equation three yielding 5 per cent. Since length of feeding was the only variable in equation three, which was not in equation two, its contribution to ADG in this regression equation is 5 per cent.

All of the coefficients of determination calculated using the above variables were not significant, however, when all variables were combined in one equation (Equation 6), they explained approximately 50 per cent of the variation in ADG. These equations, in most cases, would be of usefulness in estimating ADG, when mixed rations are fed, since all the variables composing these equations can be easily determined.

Average Daily Gains Estimated from Laboratory Evaluations

Regression equations and coefficients of determination for estimating ADG from laboratory evaluations are presented in Table VIII. Regression equations one, two, three and four, containing *in vitro* DDM as the major laboratory evaluation, explained more of the variation in ADG than did similar equations containing either acid insoluble lignin

TABLE VIII

MULTIPLE REGRESSION EQUATIONS[a] FOR ADG CALCULATED FROM LABORATORY EVALUATIONS

	Equation number											
	1	2	3	4	5	6	7	8	9	10	11	12
Constant, (a)	-.326	0.721	-.345	-.191	1.440	2.067	1.904	1.226	1.114	1.831	1.931	1.057
In vitro DDM	0.0220	0.0194	0.0207	0.0244								
Acid insoluble lignin					-.0630	-.0588	-.0713	0.0722				
Dry matter solubility									-.0081	0.0002	0.0020	0.0156
Length of feeding, days	-.0042	-.0134	-.0137	-.0190	-.0042	-.0216	-.0230	-.0237	-.0028	-.0224	-.0230	-.0154
$(\text{Length of feeding})^2$, days		0.0001	0.0001	0.0001		0.0001	0.0001	0.0001		0.0001	0.0001	0.0001
Crude protein in ration, %			0.0147	0.0175			0.0261	0.0265			-.0053	-.0290
Concentration in ration, %				-.0030				-.0003				0.0056
R^2	.425*	.456*	.470	.487	.290	.415	.455	.456	.085	.211	.212	.273

[a]Body weight, initial type, initial condition and sex were absorbed in developing these equations.

*$P < .05$.

or dry matter solubility as the laboratory evaluation. Coefficients of determination for equations one, containing *in vitro* DDM and length of feeding and equation two, containing *in vitro* DDM, length of feeding and $(\text{length of feeding})^2$ were significant ($P<.05$). Equations three and four showed slightly higher coefficients of determination than did equations one and two, but they were not significant. This nonsignificance is probably due to the extra variables included in the equation, which made little contribution to the variation in ADG. Therefore, equations one or two would most probably be used in estimating ADG when mixed rations are being fed, since the addition of per cent crude protein in the ration and per cent concentrate in the ration explained only 3 per cent of the variation in ADG.

A considerable portion of the variation in ADG was explained when acid insoluble lignin was the laboratory evaluation. These coefficients were approaching significance. In cases where *in vitro* DDM cannot be determined due to a lack of ruminant animals from which to obtain rumen microorganisms, or due to a lack of appropriate equipment, equations six, seven or eight could be used to estimate ADG when mixed rations are fed. However, if these microorganisms are available, then *in vitro* DDM seems to be the variable of choice, since it gives a more accurate estimation of ADG and is an easier determination to conduct in the laboratory.

When dry matter solubility was used as the laboratory evaluation in regression equations, the coefficients of determination obtained were low and not significant. Since these coefficients were so low (the largest was 0.27), these equations probably should not be used to estimate ADG.

In summary, any of the regression equations containing in vitro DDM presented in Table VIII, page 38, can be used to estimate ADG when mixed rations are fed. However, on the basis of the results of this study, regression equation two seems to be the most useful estimator of ADG, even more useful than equations containing VI, in vivo digestibility and other variables, since this equation contains variables, the measurement of which is simple, relatively accurate and inexpensive, timesaving and does not involve feeding animals. This equation explains almost as much of the variation in ADG as does any other regression equation developed from these data (Tables VI, VII and VIII, pages 34, 36 and 38, respectively).

Investigations designed specifically to develop reliable methods for predicting feedlot performance of rations from laboratory evaluations should include plans to collect both laboratory and feedlot data in such a manner as to permit an adequate analysis and assessment of errors of measurement in all variables studied. The widely held opinion that feedlot data have inherent in them a much larger component of variance due to errors of measurement than do laboratory data should be tested as a hypothesis in a properly conducted statistical analysis.

CHAPTER V

SUMMARY

The purpose of this study was to determine how well various laboratory evaluations estimate _in vivo_ digestibility, Voluntary Intake (VI) and performance (average daily gains) of beef cattle fed mixed rations. The relationships among and/or between _in vivo_ digestibility, VI, Nutritive Value Indexes (NVI), total digestible nutrient (TDN) intake above maintenance, laboratory evaluations (_in vitro_ DDM, acid insoluble lignin and dry matter solubility) and average daily gains (ADG) also were determined. In contrast to other studies of this type, which used forages alone, the present study was conducted with mixed rations. All the data were based on results from 43 different rations.

ADG were used as the standard to which results from other methods were compared. In the present study, VI of the 43 rations was determined from long-term feedlot trials rather than from short-term studies used by most other workers. VI was expressed as dry matter intake per unit of body weight, dry matter intake per unit of body weight$^{.75}$ and dry matter intake per unit of body weight$^{.84}$.

Total collection digestion trials, using Hereford steers of similar breeding, type and condition had been used to determine the digestibility of the 43 rations. Four measures of _in vivo_ digestibility--digestible dry matter (DDM), digestible organic matter (DOM), TDN and digestible energy (DE)--had been determined.

Unequal distribution of sexes, types, conditions and body weights among rations resulted in considerable confounding of these effects in the feedlot data. Hence, where variables from feedlot data were involved, the above-mentioned variables were absorbed and partial correlations were calculated. Simple correlations were calculated between the in vivo measures of digestibility and laboratory evaluations since there was no confounding involved. Multiple regression equations for ADG and the expressions of VI were developed from a multiple regression analysis.

Results of this study are as follows:

1. There was a high correlation between the in vivo expressions of digestibility which indicates that it is feasible to calculate one from another.

2. Acid insoluble lignin and in vitro DDM were significantly ($P<.05$) correlated with in vivo DDM, DOM and TDN. However, dry matter solubility showed little relationship to any of the expressions of in vivo digestibility.

3. Results in this study show little relationship between VI and and the above-mentioned laboratory evaluations.

4. Results from both in vitro DDM and acid insoluble lignin show these laboratory methods to be useful estimators of NVI. However, dry matter solubility probably should not be used to estimate NVI when mixed rations are used.

5. Partial correlations between the four expressions of in vivo digestibility and ADG were small and nonsignificant; however, both DDM

and DOM were more highly correlated with ADG than was TDN or DE.

6. Relationships between VI and ADG were small and not significant.

7. Small nonsignificant partial correlations were obtained between NVI or TDN intake above maintenance and ADG.

8. A highly significant ($P<.01$) partial correlation between ADG and in vitro DDM and a significant ($P<.05$) negative partial correlation between ADG and acid insoluble lignin was obtained, suggesting that results from these methods may be used to estimate ADG. However, the partial correlation between ADG and dry matter solubility was low and not significant.

9. The inclusion of several other variables--per cent concentrate in the ration, length of feeding, per cent crude protein in the ration and (length of feeding)^2--in multiple regression equations, in addition to results from one of the laboratory evaluations, improved the VI coefficients of determination very little.

10. A multiple regression equation containing VI (dry matter intake per body weight$^{.75}$), in vivo DDM, per cent concentrate in the ration, length of feeding, acid insoluble lignin content, (length of feeding)^2 and per cent crude protein explained approximately 50 per cent of the variation in ADG.

11. Based on the results of this study, the equation which seems to be the most useful estimator of ADG is:

$$\hat{Y} = 0.721 + 0.0194 X_1 - 0.0134 X_2 + 0.0001 X_3.$$

Where $\hat{Y}$ = predicted value of ADG.

X_1 = *in vitro* DDM.

X_2 = length of feeding.

X_3 = (length of feeding)^2.

This equation explained 45.6 per cent of the variation in ADG. It is even more useful than equations containing VI, *in vivo* digestibility and other variables, since this equation contains variables, the measurement of which is simple, relatively accurate and inexpensive, timesaving and does not involve feeding animals.

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APPENDIX

TABLE IX

RATION INGREDIENTS AND THEIR NUTRIENT COMPOSITION

Ration number	Ingredient	Per cent in ration[a]	Dry matter	Organic matter[b]	Crude protein[b]	Ether extract[b]	Crude fiber[b]	N-free extract[b]	Ash[b]	Gross energy[b]
			%	%	%	%	%	%	%	kcal./gm.
1[c]	Corn silage	45.9	22.4	18.3	8.4	2.5	28.7	56.0	4.1	4.29
	Alfalfa-grass hay[d]	14.3	89.7	81.6	15.0	2.9	35.4	38.7	8.1	4.85
	Concentrate mix[e]	39.8	87.7	85.2	16.5	3.6	4.1	73.4	2.5	4.46
2[c]	Alfalfa silage	44.5	24.3	16.3	9.3	2.1	37.5	43.1	8.0	4.26
	Alfalfa-grass hay[d]	15.3	89.7	81.6	15.0	2.9	35.4	38.7	8.1	4.85
	Concentrate mix[e]	40.2	89.5	85.7	16.8	3.9	4.6	70.9	3.8	4.46
3[c]	Corn silage	74.7	24.0	19.9	10.5	2.5	27.5	55.5	4.1	4.34
	Alfalfa-grass hay[d]	16.3	89.7	81.6	15.0	2.9	35.4	38.7	8.1	4.46
	Cottonseed meal	9.0	94.3	87.9	43.9	3.6	15.2	30.9	6.4	4.85
4[c]	Alfalfa silage	73.7	25.5	16.4	15.3	3.3	36.3	36.0	9.1	4.35
	Alfalfa-grass hay[d]	17.2	89.7	81.6	15.0	2.9	35.4	38.7	8.1	4.46
	Cottonseed meal	9.1	94.3	87.9	43.9	3.6	15.2	30.9	6.4	4.85
5[c]	Corn silage	45.9	24.9	20.8	8.5	3.2	24.4	59.9	4.1	4.60
	Alfalfa-grass hay[d]	15.4	89.7	81.6	15.0	2.9	35.4	38.7	8.1	4.46
	Concentrate mix[e]	38.7	89.5	85.7	16.8	3.9	4.6	70.9	3.8	4.45
6[c]	Alfalfa silage	46.6	23.2	12.6	18.8	4.7	31.3	34.6	10.6	4.84
	Alfalfa-grass hay[d]	15.2	89.7	81.6	15.0	2.9	35.4	38.7	8.1	4.46
	Concentrate mix[e]	38.2	89.5	85.7	16.8	3.9	4.6	70.9	3.8	4.45

TABLE IX (continued)

Ration number	Ingredient	Per cent in ration[a]	Dry matter	Organic matter[b]	Crude protein[b]	Ether extract[b]	Crude fiber[b]	N-free extract[b]	Ash[b]	Gross energy[b]
			%	%	%	%	%	%	%	kcal./gm.
7[c]	Corn silage	72.5	21.4	16.7	9.9	2.6	27.3	55.6	4.7	4.54
	Alfalfa-grass hay[f]	18.3	89.2	82.3	16.1	1.9	35.5	39.2	6.9	4.46
	Cottonseed meal	9.2	92.2	86.3	43.3	4.4	12.7	33.7	5.9	4.97
8[c]	Alfalfa silage	67.7	20.1	8.2	14.1	2.9	38.9	32.3	11.9	4.92
	Alfalfa-grass hay[f]	21.5	89.2	82.3	16.1	1.9	35.5	39.2	6.9	4.46
	Cottonseed meal	10.8	92.2	86.3	43.3	4.4	12.7	33.7	5.9	4.97
9[c]	Corn silage	38.2	23.7	19.5	9.0	2.3	26.2	58.3	4.2	4.38
	Alfalfa-grass hay[f]	16.7	89.2	82.3	16.1	1.9	35.5	39.2	6.9	4.46
	Concentrate mix[e]	45.1	87.9	85.3	20.0	4.3	3.9	69.2	2.6	4.79
10[g,h]	Alfalfa hay	10.0	92.7	83.6	20.0	2.2	27.0	41.7	9.1	4.43
	Ground ear corn	85.0	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Urea supplement	5.0	94.6	79.1	49.8	5.9	2.2	26.7	15.5	3.49
11[g,h]	Ground ear corn	94.3	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Urea supplement	5.7	94.6	79.1	49.8	5.9	2.2	26.7	15.5	3.49
12[g,h]	Alfalfa hay	10.0	92.7	83.6	20.0	2.2	27.0	41.7	9.1	4.43
	Ground ear corn	83.7	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Cottonseed meal	6.3	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.88
13[g,h]	Ground ear corn	93.0	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Cottonseed meal	7.0	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.88

TABLE IX (continued)

Ration number	Ingredient	Per cent in ration[a]	Dry matter	Organic matter[b]	Crude protein[b]	Ether extract[b]	Crude fiber[b]	N-free extract[b]	Ash[b]	Gross energy[b]
			%	%	%	%	%	%	%	kcal./gm.
14[g,h]	Alfalfa hay	11.3	92.7	83.6	20.0	2.2	27.0	41.7	9.1	4.43
	Ground ear corn	83.0	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Urea supplement	5.7	94.6	79.1	49.8	5.9	2.2	26.7	15.5	3.49
15[g,h]	Ground ear corn	94.7	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Urea supplement	5.3	94.6	79.1	49.8	5.9	2.2	26.7	15.5	3.49
16[g,h]	Alfalfa hay	11.4	92.7	83.6	20.0	2.2	27.0	41.7	9.1	4.43
	Ground ear corn	81.4	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Cottonseed meal	7.2	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.88
17[g,h]	Ground ear corn	92.4	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Cottonseed meal	7.6	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.88
18[g,h]	Corn silage	50.1	27.7	22.9	9.1	2.7	28.7	54.7	4.8	4.45
	Alfalfa hay	12.0	92.7	83.6	20.0	2.2	27.0	41.7	9.1	4.43
	Ground ear corn	31.9	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Urea supplement	6.0	94.6	79.1	49.8	5.9	2.2	26.7	15.5	3.49
19[g,h]	Corn silage	59.2	27.7	22.9	9.1	2.7	28.7	54.7	4.8	4.45
	Ground ear corn	34.3	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Urea supplement	6.5	94.6	79.1	49.8	5.9	2.2	26.7	15.5	3.49
20[g,h]	Corn silage	49.1	27.7	22.9	9.1	2.7	28.7	54.7	4.8	4.45
	Alfalfa hay	12.4	92.7	83.6	20.0	2.2	27.0	41.7	9.1	4.43
	Ground ear corn	32.3	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Cottonseed meal	6.2	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.88

TABLE IX (continued)

Ration number	Ingredient	Per cent in ration[a]	Dry matter	Organic matter[b]	Crude protein[b]	Ether extract[b]	Crude fiber[b]	N-free extract[b]	Ash[b]	Gross energy[b]
			%	%	%	%	%	%	%	kcal./gm.
21[g,h]	Corn silage	58.9	27.7	22.9	9.1	2.7	28.7	54.7	4.8	4.45
	Ground ear corn	34.6	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Cottonseed meal	6.5	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.88
22[g,h]	Corn silage	45.8	27.7	22.9	9.1	2.7	28.7	54.7	4.8	4.45
	Alfalfa hay	13.2	92.7	83.6	20.0	2.2	27.0	41.7	9.1	4.43
	Ground ear corn	34.4	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Urea supplement	6.6	94.6	79.1	49.8	5.9	2.2	26.7	15.5	3.49
23[g,h]	Corn silage	55.3	27.7	22.9	9.1	2.7	28.7	54.7	4.8	4.45
	Ground ear corn	37.6	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Urea supplement	7.1	94.6	79.1	49.8	5.9	2.2	26.7	15.5	3.49
24[g,h]	Corn silage	44.7	27.7	22.9	9.1	2.7	28.7	54.7	4.8	4.45
	Alfalfa hay	13.3	92.7	83.6	20.0	2.2	27.0	41.7	9.1	4.43
	Ground ear corn	35.3	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Cottonseed meal	6.7	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.88
25[g,h]	Corn silage	54.1	27.7	22.9	9.1	2.7	28.7	54.7	4.8	4.45
	Ground ear corn	38.5	92.2	90.8	7.9	3.8	10.3	76.6	1.4	4.37
	Cottonseed meal	7.4	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.88
26[i]	Corn silage	52.7	35.0	30.8	8.5	1.3	28.6	57.4	4.2	4.53
	Alfalfa hay	12.6	92.0	85.3	17.8	2.2	27.3	46.0	6.7	4.55
	Cracked corn	25.2	89.8	88.5	10.8	4.6	2.1	81.3	1.3	4.55
	Cottonseed meal	9.5	92.5	86.7	41.2	4.0	23.4	25.5	5.8	4.86

TABLE IX (continued)

Ration number	Ingredient	Per cent in ration[a]	Dry matter	Organic matter[b]	Crude protein[b]	Ether extract[b]	Crude fiber[b]	N-free extract[b]	Ash[b]	Gross energy[b]
			%	%	%	%	%	%	%	kcal./gm.
27[i]	Corn silage	45.6	30.0	24.8	8.7	1.1	25.7	59.3	5.2	4.30
	Alfalfa hay	13.6	92.0	85.3	17.8	2.2	27.3	46.0	6.7	4.55
	Cracked corn	34.0	89.8	88.5	10.8	4.6	2.1	81.3	1.3	4.55
	Cottonseed meal	6.8	92.5	86.7	41.2	4.0	23.4	25.5	5.8	4.86
28[j]	Alfalfa-grass hay	20.1	89.7	81.6	15.0	2.9	35.4	38.7	8.1	4.46
	Cracked corn	69.9	87.0	85.6	10.0	4.4	1.6	82.7	1.4	4.45
	Cottonseed meal	10.0	91.5	85.3	44.2	3.9	12.8	33.0	6.2	4.82
29[j]	Alfalfa-grass hay	73.8	89.7	81.6	15.0	2.9	35.4	38.7	8.1	4.46
	Cracked corn	15.7	87.0	85.6	10.0	4.4	1.6	82.7	1.4	4.45
	Cottonseed meal	10.5	91.5	85.3	44.2	3.9	12.8	33.0	6.2	4.82
30[k]	Corn silage	48.0	30.8	26.4	8.0	2.6	25.5	59.5	4.4	4.58
	Alfalfa hay[d]	14.8	89.3	82.9	15.9	1.5	35.4	40.1	6.4	4.61
	Concentrate mix[l]	37.2	89.2	86.7	17.9	4.0	4.5	71.1	2.5	4.65
31[k]	Corn silage	45.7	27.6	22.7	8.0	2.8	24.8	59.7	4.9	4.67
	Alfalfa hay[d]	15.5	89.3	82.9	15.9	1.5	35.4	40.1	6.4	4.61
	Concentrate mix[l]	38.8	89.2	86.7	17.9	4.0	4.5	71.1	2.5	4.65
32[k]	Alfalfa hay[d]	11.0	89.3	82.9	15.9	1.5	35.4	40.1	6.4	4.61
	Corn silage	1.9	30.8	26.4	8.0	2.6	25.5	59.5	4.4	4.58
	Concentrate mix[m]	87.1	89.2	86.7	17.9	4.0	4.5	71.1	2.5	4.65

TABLE IX (continued)

Ration number	Ingredient	Per cent in ration[a]	Dry matter	Organic matter[b]	Crude protein[b]	Ether extract[b]	Crude fiber[b]	N-free extract[b]	Ash[b]	Gross energy[b]
			%	%	%	%	%	%	%	kcal./gm.
33[k]	Alfalfa hay[d]	10.9	89.3	82.9	15.9	1.5	35.4	40.1	6.4	4.61
	Corn silage	1.7	27.6	22.7	8.0	2.8	24.8	59.7	4.9	4.67
	Concentrate mix[m]	87.4	89.2	86.7	17.9	4.0	4.5	71.1	2.5	4.65
34[n]	Good alfalfa hay	100.0	90.1	82.6	18.7	1.9	29.4	41.7	7.5	4.55
35[n]	Fair alfalfa hay	100.0	89.3	82.9	15.9	1.5	35.4	40.7	6.4	4.61
36[n]	Poor alfalfa hay	100.0	91.5	87.1	13.7	1.1	46.7	33.7	4.4	4.59
37[g,o]	1st cut corn silage	67.3	23.3	17.3	11.1	1.4	24.7	56.9	6.0	4.40
	Alfalfa hay	14.0	94.1	86.0	17.9	1.5	29.4	43.1	8.1	4.46
	Cottonseed meal	18.7	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.94
38[g,o]	2nd cut corn silage	68.5	25.9	19.8	11.1	1.6	23.7	57.7	6.1	4.43
	Alfalfa hay	13.5	94.1	86.0	17.9	1.5	29.4	43.1	8.1	4.46
	Cottonseed meal	18.0	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.94
39[g,o]	4th cut corn silage	65.4	32.7	25.0	9.7	1.2	27.7	53.7	7.7	4.27
	Alfalfa hay	14.9	94.1	86.0	17.9	1.5	29.4	43.1	8.1	4.46
	Cottonseed meal	19.8	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.94
40[c]	Corn silage	75.4	26.3	22.7	9.0	2.7	24.0	60.7	3.6	4.46
	Alfalfa-grass hay[d]	16.4	89.7	81.6	15.0	2.9	35.4	38.7	8.1	4.46
	Cottonseed meal	8.2	89.7	84.1	43.3	3.3	16.5	43.9	5.6	4.80

TABLE IX (continued)

Ration number	Ingredient	Per cent in ration[a]	Dry matter	Organic matter[b]	Crude protein[b]	Ether extract[b]	Crude fiber[b]	N-free extract[b]	Ash[b]	Gross energy[b]
			%	%	%	%	%	%	%	kcal./gm.
41[c]	Alfalfa silage	75.4	22.8	12.3	16.3	4.1	30.6	38.5	10.5	4.71
	Alfalfa-grass hay[d]	16.4	89.7	81.6	15.0	2.9	35.4	38.7	8.1	4.46
	Cottonseed meal	8.2	89.7	84.1	34.3	3.3	16.5	43.9	5.6	4.80
42[c]	Alfalfa silage	33.6	15.8	4.3	14.0	3.0	40.0	31.4	11.5	4.86
	Alfalfa-grass hay[f]	17.9	89.2	82.3	16.1	1.9	35.4	39.2	6.9	4.46
	Concentrate mix[e]	48.5	87.9	85.3	20.0	4.3	3.9	69.2	2.6	4.79
43[g,o]	3rd cut corn silage	70.1	29.8	23.2	10.5	1.8	24.1	57.1	6.6	4.38
	Alfalfa hay	12.8	94.1	86.0	17.9	1.5	29.4	43.1	8.1	4.46
	Cottonseed meal	17.1	94.9	93.7	40.3	3.6	14.1	40.7	1.2	4.94

[a]Feedlot and laboratory evaluations, dry matter basis.

[b]Dry matter basis.

[c]B. B. Wilson, 1964.

[d]This hay was substituted in the laboratory evaluations. The nutrient composition of the hay used in the feedlot is not known.

[e]Four parts cracked corn and one part cottonseed meal.

[f]Nutrient composition applies to hay fed in the feedlot. In the laboratory evaluations the hay as described in footnote d was substituted.

TABLE IX (continued)

[g]Chamberlain et al., 1966.

[h]McConnell et al., 1967.

[i]Corrick et al., 1966.

[j]Clark and Barth, 1966.

[k]G. R. Wilson, 1964.

[l]Four parts ground ear corn and one part cottonseed meal.

[m]Seven parts ground ear corn and one part cottonseed meal.

[n]Mohammed et al., 1967.

[o]Barth and Prigge, 1966.

TABLE X

DESCRIPTION OF THE RATIONS

Ration number	Major forage[a]	Number of forages[b]	Dry matter in silage	Roughage in ration[c]	Concentrate in ration[c]	Crude protein in ration[c]
			%	%	%	%
1	11	2	22.4	60.2	39.8	12.3
2	12	2	24.3	59.8	40.2	13.1
3	11	2	24.0	91.0	9.0	14.2
4	12	2	25.5	90.9	9.1	17.8
5	11	2	24.9	61.3	38.7	12.6
6	12	2	23.2	61.8	38.2	17.5
7	11	2	21.4	90.8	9.2	14.1
8	12	2	20.1	89.3	10.7	17.8
9	11	2	23.7	54.9	45.1	14.9
10	22	1	----[e]	10.0	90.0	11.3
11	--[d]	0	----[e]	0.0	100.0	10.3
12	22	1	----[e]	10.0	90.0	11.2
13	--[d]	0	----[e]	0.0	100.0	10.2
14	22	1	----[e]	11.4	88.6	11.7
15	--[d]	0	----[e]	0.0	100.0	10.1
16	22	1	----[e]	11.4	88.6	11.6
17	--[d]	0	----[e]	0.0	100.0	10.4
18	11	2	27.7	62.1	37.9	12.4

TABLE X (continued)

Ration number	Major forage[a]	Number of forages[b]	Dry matter in silage	Roughage in ration[c]	Concentrate in ration[c]	Crude protein in ration[c]
			%	%	%	%
19	11	1	27.7	59.2	40.8	11.3
20	11	2	27.7	61.5	38.5	11.9
21	11	1	27.7	58.9	41.1	10.7
22	11	2	27.7	59.0	41.0	12.7
23	11	1	27.7	55.3	44.7	11.5
24	11	2	27.7	58.0	42.0	12.2
25	11	1	27.7	54.1	45.9	11.0
26	11	2	35.0	65.3	34.7	13.3
27	11	2	30.0	59.2	40.8	12.8
28	23	1	----[e]	20.0	80.0	14.6
29	23	1	----[e]	73.8	26.2	17.4
30	11	2	30.8	62.8	37.2	12.5
31	11	2	27.6	61.2	38.8	12.8
32	22	2	30.8	12.9	87.1	17.5
33	22	2	27.6	12.6	87.4	17.5
34	22	1	----[e]	100.0	0.0	18.7
35	22	1	----[e]	100.0	0.0	15.9
36	22	1	----[e]	100.0	0.0	13.7

TABLE X (continued)

Ration number	Major forage[a]	Number of forages[b]	Dry matter in silage	Roughage in ration[c]	Concentrate in ration[c]	Crude protein in ration[c]
			%	%	%	%
37	11	2	23.3	81.3	18.7	17.4
38	11	2	25.9	82.0	18.0	17.4
39	11	2	32.7	80.2	19.8	16.6
40	11	2	26.3	91.8	8.2	12.0
41	12	2	22.8	91.8	8.2	17.6
42	12	2	15.8	51.5	48.5	17.2
43	11	2	29.8	82.9	17.1	16.4

[a]Corn silage = 11, alfalfa silage = 12, legume hay = 22, alfalfa-grass hay = 23.

[b]Number of forages fed per ration.

[c]Dry matter basis.

[d]No forage fed.

[e]No silage fed.

TABLE XI

DESCRIPTION OF ANIMALS AND FEEDLOT TRIALS

Ration number	Sex[a]	Initial weight kg.	Initial cond.[b]	Initial type[b]	Length of feeding days	Av. daily gain kg.
1	1	230	8.0	11.8	113	0.61
2	1	231	8.0	12.1	113	0.51
3	2	234	7.4	10.6	113	0.60
4	2	236	7.3	10.4	113	0.36
5	1	209	8.2	11.0	112	0.64
6	1	207	8.0	11.2	112	0.65
7	2	241	8.1	10.6	141	0.68
8	2	239	8.1	11.1	141	0.39
9	1	176	7.4	10.5	141	0.73
10	1	330	6.3	8.4	48	1.06
11	1	315	6.6	8.0	48	0.96
12	1	336	6.6	8.4	48	1.04
13	1	324	6.7	8.2	48	0.83
14	1	280	5.6	7.0	48	1.13
15	1	295	6.3	7.7	48	0.94
16	1	285	6.0	7.7	48	0.90
17	1	281	5.4	6.3	48	0.99
18	1	266	6.3	8.4	112	0.55

TABLE XI (continued)

Ration number	Sex[a]	Initial weight	Initial cond.[b]	Initial type[b]	Length of feeding	Av. daily gain
		kg.			days	kg.
19	1	258	6.6	8.0	112	0.52
20	1	266	6.6	8.4	112	0.63
21	1	262	6.7	8.2	112	0.55
22	1	207	5.6	7.0	112	0.65
23	1	217	6.3	7.7	112	0.69
24	1	208	6.0	7.7	112	0.69
25	1	202	5.4	6.3	112	0.71
26	1	205	8.4	10.6	140	0.75
27	1	207	8.3	10.3	140	0.93
28	2	325	10.4	12.0	42	1.16
29	2	331	10.6	11.7	42	0.59
30	1	213	7.8	11.0	113	0.80
31	1	213	7.5	11.0	113	0.79
32	1	305	8.5	11.0	80	0.73
33	1	302	8.5	11.0	80	0.74
34	2	258	7.7	10.2	71	0.84
35	2	262	7.6	10.1	71	0.68
36	2	257	7.9	10.1	71	0.00

TABLE XI (continued)

Ration number	Sex[a]	Initial weight kg.	Initial cond.[b]	Initial type[b]	Length of feeding days	Av. daily gain kg.
37	1	212	8.4	10.7	98	0.70
38	1	213	8.5	10.6	98	0.76
39	1	212	8.5	10.6	98	0.56
40	2	248	8.6	12.1	112	0.58
41	2	250	9.1	12.2	112	0.49
42	1	177	7.6	10.5	141	0.66
43	1	212	8.4	10.7	98	0.72

[a]Heifer--1, steer--2.

[b]Low Standard--6, high Choice--14.

TABLE XII

IN VIVO EXPRESSIONS OF DIGESTIBILITY OF THE RATIONS

Ration number	DDM[a]	DOM[a]	TDN[a]	DE[a]
	%	%	%	kcal./gm.
1	69.4	70.9	71.2	3.02
2	54.4	56.1	53.7	2.34
3	69.4	71.0	70.8	3.04
4	54.7	56.0	53.5	2.41
5	72.5	73.6	79.4	3.25
6	67.3	68.0	72.0	3.10
7	62.3	64.1	65.6	2.84
8	53.0	52.8	49.2	2.65
9	77.1	77.9	78.5	3.48
10	69.3	70.2	65.0	2.91
11	68.4	79.1	65.6	2.85
12	60.3	60.8	57.4	2.25
13	63.6	64.3	61.7	2.38
14	69.3	70.2	65.0	2.91
15	68.4	69.1	65.6	2.85
16	60.3	60.8	57.4	2.25
17	63.6	64.3	61.7	2.38
18	74.2	75.6	74.4	3.28

TABLE XII (continued)

Ration number	DDM[a] %	DOM[a] %	TDN[a] %	DE[a] kcal./gm.
19	72.9	74.5	74.4	3.11
20	68.4	69.6	69.5	2.99
21	65.9	67.4	68.8	2.93
22	74.2	75.6	74.4	3.28
23	72.9	74.5	74.4	3.11
24	68.4	69.6	69.5	2.99
25	65.9	67.4	68.8	2.93
26	69.8	68.1	69.7	2.99
27	67.5	66.0	68.2	2.92
28	63.2	63.5	64.2	2.73
29	63.1	63.9	62.5	2.70
30	68.2	68.8	70.7	3.11
31	69.4	71.3	71.8	3.20
32	68.2	68.8	70.7	3.11
33	69.4	71.3	71.8	3.20
34	59.5	60.1	56.6	2.63
35	59.5	59.6	56.7	2.67
36	45.0	46.8	44.9	1.97

TABLE XII (continued)

Ration number	DDM[a]	DOM[a]	TDN[a]	DE[a]
	%	%	%	kcal./gm.
37	68.9	70.8	68.9	3.11
38	68.0	69.2	68.0	3.01
39	66.7	68.1	66.5	2.90
40	71.1	71.8	70.6	3.15
41	59.0	60.0	57.1	2.84
42	66.0	66.9	65.8	3.19
43	66.4	67.5	66.7	2.91

[a]Dry matter basis.

TABLE XIII

VOLUNTARY INTAKE OF THE RATIONS

Ration number	VI[a] (BW)	VI[b] ($BW^{.75}$)	VI[c] ($BW^{.84}$)
1	2.02	81.5	49.3
2	1.95	78.5	47.5
3	1.76	71.2	43.0
4	1.85	74.2	45.0
5	2.17	85.9	52.3
6	2.19	86.7	52.8
7	1.89	77.4	39.3
8	1.82	74.5	35.1
9	2.09	81.1	49.8
10	2.36	102.6	60.5
11	2.16	92.6	54.8
12	2.32	110.2	59.5
13	2.18	93.9	55.5
14	2.41	100.5	60.0
15	2.49	105.3	62.7
16	2.41	100.6	60.1
17	2.28	95.2	56.9
18	2.44	101.3	60.7

TABLE XIII (continued)

Ration number	VI[a] (BW)	VI[b] ($BW^{.75}$)	VI[c] ($BW^{.84}$)
19	2.37	97.7	58.7
20	2.34	97.7	58.2
21	2.31	95.3	57.2
22	2.71	106.9	65.2
23	2.41	96.7	58.6
24	2.65	105.1	62.5
25	2.45	96.6	58.9
26	2.59	103.9	63.0
27	2.29	92.9	56.1
28	2.29	96.5	58.3
29	2.26	97.2	57.5
30	2.25	90.4	54.8
31	2.12	85.4	51.6
32	2.19	93.8	55.6
33	2.22	94.6	56.2
34	2.43	101.6	60.2
35	2.34	96.3	57.9
36	1.88	75.2	45.6

TABLE XIII (continued)

Ration number	VI[a] (BW)	VI[b] ($BW^{.75}$)	VI[c] ($BW^{.84}$)
37	1.91	75.6	46.2
38	1.87	79.6	45.4
39	1.91	74.9	46.1
40	1.82	74.7	45.0
41	1.82	74.3	44.8
42	1.95	75.2	46.3
43	2.09	83.1	50.9

[a] $\frac{\text{Gm. dry matter intake}}{\text{100 kg. body weight}}$.

[b] $\frac{\text{Gm. dry matter intake}}{\text{body weight, kg.}^{.75}}$.

[c] $\frac{\text{Gm. dry matter intake}}{\text{body weight, kg.}^{.84}}$.

TABLE XIV

NUTRITIVE VALUE INDEXES AND TDN INTAKE ABOVE MAINTENANCE OF THE RATIONS

Ration number	NVI[a] (BW·75-energy)	NVI[b] (BW·75-dry matter)	NVI[c] (BW·84-energy)	NVI[d] (BW·84-dry matter)	TDN intake above maint. kg.
1	70.2	70.7	42.5	42.8	2.06
2	50.1	50.7	32.0	32.3	0.99
3	61.4	61.8	37.1	37.3	1.58
4	50.4	50.7	30.5	30.7	0.83
5	77.1	77.9	47.0	47.4	2.56
6	71.9	72.9	43.8	44.4	2.20
7	67.5	68.8	30.3	30.6	1.15
8	56.0	60.7	23.6	23.3	0.12
9	77.3	78.1	47.4	48.0	2.15
10	86.4	88.9	51.0	52.4	3.32
11	76.6	79.2	45.4	46.9	2.72
12	75.8	83.1	40.9	44.8	2.65
13	69.1	74.6	40.9	44.1	2.54
14	84.7	87.1	50.6	52.0	2.86
15	87.1	90.0	51.9	53.6	3.22
16	69.2	75.9	41.4	45.3	2.30
17	70.1	75.7	41.9	45.2	2.37
18	94.5	93.9	56.6	56.2	3.52

TABLE XIV (continued)

Ration number	NVI[a] (BW·75_ energy)	NVI[b] (BW·75_ dry matter)	NVI[c] (BW·84_ energy)	NVI[d] (BW·84_ dry matter)	TDN intake above maint. kg.
19	93.9	89.0	56.4	53.5	3.21
20	81.1	83.5	48.3	49.8	2.98
21	86.2	78.6	51.7	47.2	2.77
22	99.8	99.2	60.8	60.5	3.25
23	92.9	88.0	56.3	53.4	2.89
24	87.3	89.8	51.9	53.5	2.87
25	87.3	79.6	53.2	48.5	2.43
26	87.7	90.6	53.2	55.0	2.93
27	76.3	78.3	46.1	47.4	2.44
28	73.3	76.3	44.3	46.1	3.02
29	72.7	76.7	43.0	45.4	2.76
30	76.4	77.1	46.3	46.8	2.40
31	73.5	74.1	44.7	44.3	2.21
32	79.3	80.0	47.0	47.4	3.13
33	81.4	82.1	48.3	48.7	3.26
34	73.5	76.6	43.5	44.7	2.11
35	69.7	71.6	41.8	43.0	1.95
36	40.3	42.3	24.5	25.7	0.44

TABLE XIV (continued)

Ration number	NVI[a] ($BW^{.75}$-energy)	NVI[b] ($BW^{.75}$-dry matter)	NVI[c] ($BW^{.84}$-energy)	NVI[d] ($BW^{.84}$-dry matter)	TDN intake above maint. kg.
37	65.1	64.2	39.6	39.8	1.58
38	67.7	67.4	41.2	38.6	1.51
39	62.4	67.3	37.4	38.4	1.41
40	65.2	66.4	39.2	39.9	1.79
41	55.8	54.8	33.7	33.0	1.08
42	62.2	62.1	38.3	38.2	1.29
43	68.9	61.6	41.9	42.3	1.80

[a]Product of energy digestion coefficient and Relative Intake based on metabolic size$^{.75}$.

[b]Product of dry matter digestion coefficient and Relative Intake based on metabolic size$^{.75}$.

[c]Product of energy digestion coefficient and Relative Intake based on metabolic size$^{.84}$.

[d]Product of dry matter digestion coefficient and Relative Intake based on metabolic size$^{.84}$.

TABLE XV

LABORATORY EVALUATIONS OF THE RATIONS

Ration number	In vitro DDM[a]	Dry matter solubility[b]	Acid insoluble lignin[c]
	%	%	%
1	63.7	14.7	4.5
2	57.0	14.3	6.4
3	58.9	23.0	4.9
4	49.2	24.0	9.0
5	63.4	14.3	4.2
6	62.1	19.2	6.5
7	57.3	19.1	5.9
8	54.1	27.6	9.9
9	64.7	15.1	4.6
10	75.7	9.1	2.5
11	79.2	6.4	2.1
12	75.1	10.0	2.8
13	77.2	5.9	2.4
14	76.6	9.1	2.8
15	77.9	6.4	2.1
16	75.8	10.0	3.4
17	76.8	6.4	3.4
18	68.6	18.2	4.4

TABLE XV (continued)

Ration number	*In vitro* DDM[a]	Dry matter solubility[b]	Acid insoluble lignin[c]
	%	%	%
19	66.8	16.9	3.3
20	67.0	17.9	4.4
21	65.7	16.8	3.9
22	67.6	18.2	4.8
23	68.0	16.9	3.8
24	65.3	17.9	4.8
25	66.8	16.8	5.1
26	72.0	14.7	4.4
27	73.0	12.9	4.1
28	80.4	8.9	3.3
29	64.3	15.8	7.6
30	67.1	16.2	5.4
31	66.2	17.1	5.2
32	75.2	16.2	4.2
33	73.5	17.1	3.8
34	59.8	26.9	8.0
35	55.4	24.0	10.4
36	38.5	15.6	13.5

TABLE XV (continued)

Ration number	*In vitro* DDM[a]	Dry matter solubility[b]	Acid insoluble lignin[c]
	%	%	%
37	54.1	31.8	5.7
38	58.5	28.0	5.8
39	52.3	23.7	6.0
40	63.4[d]	14.3[d]	4.2[d]
41	62.1[d]	19.2[d]	6.5[d]
42	54.1[d]	27.6[d]	9.9[d]
43	55.4[e]	26.9	5.9[e]

[a]Tilley and Terry, 1963.

[b]Dehority and Johnson, 1964.

[c]Van Soest, 1963.

[d]Estimated from similar ration fed in the same year.

[e]Estimated--average of rations 38 and 39.

TABLE XVI

IN VITRO DRY MATTER DIGESTION OF THE RATIONS[a]

Ration number	Trial number		
	1	2	3
	%	%	%
1	64.7	62.5	63.8
2	58.6	56.8	55.7
3	59.9	61.5	55.3
4	52.6	47.8	47.1
5	64.7	62.9	62.6
6	65.5	59.7	61.1
7	61.1	56.1	54.7
8	57.4	50.8	54.0
9	66.2	65.0	62.8
10	77.4	74.1	75.5
11	78.5	77.0	82.0
12	75.8	74.0	75.5
13	77.1	77.7	76.8
14	75.5	77.5	76.9
15	77.8	78.1	77.9
16	75.1	77.9	74.3
17	75.6	79.0	75.8
18	68.7	71.5	65.7

TABLE XVI (continued)

Ration number	Trial number 1	2	3
	%	%	%
19	70.7	64.8	64.9
20	69.0	67.8	64.1
21	68.4	63.6	65.2
22	70.2	66.2	66.4
23	72.5	65.6	65.9
24	68.5	64.8	62.7
25	68.4	67.1	65.0
26	73.2	71.7	71.0
27	75.5	73.0	70.4
28	81.1	81.2	79.0
29	65.4	65.0	62.6
30	69.9	66.0	65.5
31	64.6	68.8	65.1
32	74.2	77.1	74.2
33	72.6	74.5	73.5
34	59.9	59.8	59.8
35	55.0	56.5	54.7
36	37.5	39.4	38.6

TABLE XVI (continued)

Ration number	Trial number 1 %	2 %	3 %
37	55.0	56.3	51.1
38	60.6	60.9	54.1
39	52.5	53.3	51.0
40	----[b]	----[b]	----[b]
41	----[b]	----[b]	----[b]
42	----[b]	----[b]	----[b]
43	----[b]	----[b]	----[b]

[a]Tilley and Terry, 1963.

[b]*In vitro* digestible dry matter was not determined on these rations due to a lack of samples.

TABLE XVII

MEANS AND STANDARD ERRORS OF BODY WEIGHTS

Lot number	Initial wt.		Final wt.	
	Mean[a]	Std. err. of dup. wt. diff.	Mean[a]	Std. err. of dup. wt. diff.
	kg.	kg.	kg.	kg.
1	256±11	2.0	335±18	3.1
2	261±26	4.4	315±18	1.1
3	261±26	4.2	323±31	3.4
4	268±11	3.1	344± 9	1.1
5	255±36	5.8	368±24	5.8
6	259±16	4.7	340±26	3.7
7	254±25	3.1	312±43	2.4
8	256±22	6.5	315±33	2.0
9	221±13	4.1	292±25	2.2
10	225±25	3.0	307±18	4.1
11	223±11	2.8	303± 7	2.2
12	219±10	6.4	295±19	4.3
13	187±17	5.3	291±16	3.7
14	189±13	4.3	302±30	3.0
15	188±12	7.4	287±23	4.0
16	191±13	2.8	287±14	1.3
17	349±44	3.2	375±48	3.6
18	356±57	3.7	384±56	5.2
19	342±32	3.2	392±28	2.0
20	351±43	6.2	405±40	5.5

[a]Means of body weights determined on two consecutive days.

TABLE XVIII

MEAN DIGESTION COEFFICIENTS AND THEIR STANDARD ERRORS FROM TEN RATIONS

Ration number	Number of animals used	DDM[a] %	DOM[a] %	TDN[a] %	DE[a] kcal./gm.
1	4	59.5±1.6	60.1±1.7	56.6±1.2	2.63±0.07
2	4	59.5±0.8	59.6±0.8	56.7±0.5	2.67±0.02
3	4	44.9±1.1	46.8±2.1	44.9±1.0	1.97±0.05
4	4	67.4±8.4	67.7±8.4	68.2±8.1	2.92±0.38
5	4	63.1±1.2	63.9±1.2	62.5±0.6	2.70±0.05
6	4	69.6±0.5	68.1±0.6	69.6±0.7	2.99±0.01
7	4	67.5±2.3	66.1±2.0	68.3±2.2	2.92±0.11
8	3	68.9±4.6	70.7±3.5	68.9±3.7	3.10±0.22
9	3	68.0±0.9	69.2±0.9	68.0±1.1	3.01±0.05
10	3	66.4±2.0	67.5±2.2	66.6±2.2	2.91±0.09

[a]Dry matter basis.

TABLE XIX

MEANS AND STANDARD ERRORS OF DIFFERENCES BETWEEN DUPLICATE LABORATORY DETERMINATIONS ON 37 RATIONS

Ration number	*In vitro* DDM[a]	Dry matter solubility[b]	Acid insoluble lignin[c]
	%	%	%
1	64.7	14.7	4.5
2	58.6	14.3	6.4
3	59.9	23.0	4.9
4	52.6	24.0	9.0
5	64.7	14.3	4.2
6	65.5	19.2	6.5
7	61.1	19.1	5.9
8	57.4	27.6	9.9
9	66.2	15.1	4.6
10	77.4	9.1	2.5
11	78.5	6.4	2.1
12	75.8	10.0	2.8
13	77.1	5.9	2.4
14	75.5	9.1	2.8
15	77.8	6.4	2.1
16	75.1	10.0	3.4
17	75.6	6.4	3.4
18	68.7	18.2	4.4

TABLE XIX (continued)

Ration number	*In vitro* DDM[a]	Dry matter solubility[b]	Acid insoluble lignin[c]
	%	%	%
19	70.7	16.9	3.3
20	69.0	17.9	4.4
21	68.4	16.8	3.9
22	70.2	18.2	4.8
23	72.5	16.9	3.8
24	68.5	17.9	4.8
25	68.4	16.8	5.1
26	73.2	14.7	4.4
27	75.5	12.9	4.1
28	81.1	8.9	3.3
29	65.4	15.8	7.6
30	69.9	16.2	5.4
31	64.6	17.1	5.2
32	74.2	16.2	4.2
33	72.6	17.1	3.8
34	59.9	26.9	8.0
35	55.0	24.0	10.4
36	37.5	15.6	13.5

TABLE XIX (continued)

Ration number	*In vitro* DDM[a]	Dry matter solubility[b]	Acid insoluble lignin[c]
	%	%	%
37	55.0	31.8	5.7
Std. err. of dup. diff.	1.6	1.9	0.4

[a]Tilley and Terry, 1963.

[b]Dehority and Johnson, 1964.

[c]Van Soest, 1963.