STATISTICAL APPRAISAL OF THE EFFECT OF FEED INTAKE ON DIGESTIBILITY OF DRY MATTER AND GROSS ENERGY OF HIGH CONCENTRATE RATIONS BY CATTLE

by

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A Thesis Submitted to the Faculty of the

DEPARTMENT OF ANIMAL SCIENCE

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1966

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ACKNOWLEDGMENTS

The author wishes to express particular thanks to Drs. William H. Hale and Robert O. Kuehl for their encouragement and suggestions, both in the writing of this thesis and throughout the entire project.

Special appreciation is extended to Dr. Bruce R. Taylor, the members of the Animal Science Department, and The University of Arizona for making this research possible.

Appreciation also goes to graduate students W. T. Husted, Clayton L. Lambeth, and Stephen M. Mehen for making their data available for this analysis.

Gratitude is expressed to the author's parents, Gwen and Osborne, for their continued encouragement throughout.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

To relate body weight and feed intake to the digestibility of dry matter and gross energy two exponential and one linear regression model were employed. Preliminary studies with these models were carried out on a 70 per cent concentrate ration for later analyses on a 77 per cent milo, 86 per cent barley, and all alfalfa rations. Digestibilities for milo and alfalfa showed a decline with increased intake levels. Barley results indicate increased digestibilities at higher levels of intake which is attributed to a buildup in microbial tissue to be regarded as a type of fecal metabolic energy. Orthogonal polynominals are a possible alternative to the models employed, but the difficulties in deriving a set of orthogonal coefficients precluded their use in these studies. Due to the magnitude of the regression coefficients on the models studied in the final analyses, limitations as to the weight ranges of cattle used in digestion trials are indicated. A high degree of correlation ($r^2 \geq .93$) between dry matter and gross energy digestibilities were found.

INTRODUCTION

Due to increased costs in the commercial feedlot, feedlot operators are interested in improving the efficiency of cattle on feed. The undigested energy in the feces of steers represents the major energy loss of the feed that the steer consumes. Thus one of the approaches to improved efficiency is to better the digestibility of the rations used in the feedlot. However, the factors responsible for the low digestibility of rations in ruminants are not fully understood.

Digestion trials have, historically, been conducted to determine the usefulness of the feedstuff to the animal. Interesting observations resulting from these trials are that as weight increases feed intake increases, and as intake increases digestibility of the ration declines. These observations have given rise to the following questions concerning the validity of standard digestion trial techniques: (i) If digestibility decreases with an increased intake does the feedstuff under study have a single mean digestion coefficient? (ii) Is there a family of digestion coefficients that pertain to the digestibility of the ration, i. e., one for each weight range through which the cattle pass in the fattening process?

This study was executed to secure answers to these questions and to determine the relationships between dry matter digestibility, gross energy digestibility, feed intake, actual weight, and metabolic body size. In addition the investigation pertained to milo, barley, a combination of milo and barley, and an alfalfa ration. Also sought were the following objectives:

1. Determination of the effect of feed intake (adjusted for weight) on the digestibility of dry matter or gross energy.
2. Measurement of the validity of a single digestion coefficient for each ration, or its replacement by a family of digestion coefficients, one for each weight range, or an intake level.
3. Evaluation of the decrease or increase in digestibility with an increase in feed intake. Is the increase or decrease strictly linear, or are there deviations that may necessitate changes in the method of conducting digestion trials ?
4. Assessment of the relationship between dry matter digestibility and gross energy digestibility and if existant the magnitude of the relationship as indicated by the regression analysis.

LITERATURE REVIEW

Research conducted in the area of digestion coefficients as related to weight and feed intake, has for the most part been limited to the following pairs of variables: intake and weight, digestibility and intake, and digestibility and weight.

Blaxter, Graham, and Wainman (3) proposed that regulation of feed intake is purely one of digestive tract distention, which is a function of digestibility of the feed and its rate of passage, and the amount of food residues present in their digestive tracts. These studies were performed with sheep on roughage rations.

Graham (13) in a later paper, working with sheep, stated that when the level of feeding is decreased the metabolizability of the gross energy changes only slightly. He also indicated that distensibility of the rumen is unlikely to exert any influence on appetite for concentrated rations.

In a study of steers on roughage rations and relations between digestibility and lignin content with a lignin-ratio technique, Forbes and Garrigus (11) found that dry matter digestibility and total digestible nutrient content of the forages studied varied inversely with the lignin content of the forage.

Blaxter (4) proposed that in order to equate for differences in body size, feed intake must be related to body weight or a function of body weight. With this relationship he found that intake increased as weight increased.

Garrett, Meyer, and Lofgreen (12) indicate that the use of digestible energy (gross energy digestibility) for practical purposes is the easiest and most accurate method of assessing the energy value of a feedstuff.

Lloyd, Peckam, and Crampton (20) state that with sheep on all roughage rations, little increase in precision in digestion coefficients resulted even when the preliminary feeding (adaptation) period was extended to 60 days, and that for practical purposes with sheep 10 days would eliminate previous treatment effects.

Blaxter (1) found that in sheep on roughage rations some rations show a statistically significant decline in digestibility with increasing levels of intake. Below the point of energy equilibrium (maintenance) curvature is greatest; above energy equilibrium the relation is almost linear.

Work with monogastric species indicates that food consumption is determined by the energy content of the ration. Bolton (5, 6) showed that with poultry the intake of digestible food nutrients by pullets and by laying hens is the same whether high or low energy diets are fed, which indicates that bird's intake was limited by energy content of the ration. Mayer (21) demonstrated that rats will increase their food intake when the concentration of the diet is reduced in order to maintain constant energy intake. Kennedy (17) showed the close relationship between energy requirement and voluntary intake of the normal lactating rat. Crasemen (10) working with rabbits and pigs stated that the satiety of nutrients and energy content of the nutrients is more important as a factory in feed intake than ballast.

Crampton (8) indicates that voluntary intake is the single most accurate estimator of forage quality, and available energy is the limiting factor in the nutritive value of forage.

Crampton, Lister, and Lloyd (9) in an effort to determine the usefulness of voluntary intake in evaluating forages fed sheep five forages ad libitum. They found that voluntary forage intake was a more precise criterion of forage feeding value than either total digestible nutrients or crude fiber content of the forage.

Walker (28) working with wethers and studying the digestibility of oat hay found that digestibility decreased toward the end of the study.

Saba, et al (24) studied steers on high grain rations: 77 per cent milo with 11 and 14 per cent protein levels, 85 per cent barley with 11 per cent protein, and 76 per cent barley plus 9 per cent soybean meal to provide 14 per cent protein to the ration. Results of this study showed the digestibility of dry matter, crude protein, nitrogen free extract, starch, and gross energy were significantly higher in the barley rations than in the milo rations studied.

Blaxter (2) working with roughage rations in sheep states that energy retention was related to food intake at both sub-maintenance and super-maintenance levels of intake and that the resultant curves were exponential, which he attributed to: (i) the decline in digestibility with increased intake, and (ii) the fact that food is used more efficiently in sparing the oxidation of body fat than it is in promoting its synthesis.

As the present study was in its final stages, an excellent review pertaining to depression of digestibility at multiples of maintenance became available. The review of Brown (7) indicated depression of digestibility of dry matter occurred at increasing multiples of maintenance. Studies cited were related to roughage quality, in all roughage rations and grain-roughage rations. No references were made to low crude fiber rations such as those used in the present study.

SUMMARY OF LITERATURE REVIEW

Considerable work has been done with varying pairs of the variables employed in this study: dry matter digestibility and intake, energy intake and energy retention, intake and weight, and weight and digestibility. However, no work appears to have been conducted with high concentrate, low crude fiber rations, particularly milo and barley. Although some work with the above pairs has been pursued with roughage rations and some mixed rations, none is exactly applicable to this study. General indications are that digestibility of dry matter and gross energy (digestible energy) can be expected to decline as higher levels of intake or weight are attained.

EXPERIMENTAL PROCEDURE AND RESULTS

The data utilized in this study were made available for the analyses from four separate digestion studies run at the University of Arizona within the past two years. The data include studies on fat-mineral addition (27), milo (16), barley (22), and alfalfa (19) rations. All rations are from University of Arizona Master of Science Theses.

The four digestion trials have been examined to determine if there is a relationship between dry matter digestibility, gross energy digestibility, feed intake, actual weight, and metabolic body size. Initial examinations were performed on nineteen high concentrate milo and barley rations and three high roughage rations. The initial studies were carried out on a grain species basis of the ration, however due to large numbers of missing observations in the collection of rations studied a fat-mineral study was used as a preliminary study in fitting a model for the final examination of milo, barley, and alfalfa rations.

Experimental rations are listed in Table 1. The fat-mineral study was a 2 x 2 factorial design involving tallow, no tallow, added mineral, and no added mineral (27). This study provided 35 steers for the analyses. The barley trial was a simple reversal design involving dry rolled and steam processed barley, and contributed 24 steers to the final analyses (22). The milo study (16) was a 4 x 4 latin square

Table 1. Experimental Rations

	FAT MINERAL STUDY*				BARLEY*		MILO*				ALFALFA
	No Tallow		Tallow					Rolled	Cut	Soaked	
	No Mineral	Mineral	No Mineral	Mineral	D R	S P	D R	SP	S P	Cut	
Barley	33.00[a]	33.00	31.00	31.00	85.60	85.60	-	-	-	-	-
Milo	33.00[b]	33.00	31.00	31.00	-	-	77.10	78.70	78.70	81.89	-
C S Meal	6.00	6.00	6.0	6.00	-	-	-	-	-	-	-
Alfalfa	10.00[c]	10.00	10.00	10.00	-	-	-	-	-	-	100.00
C S Hulls	10.00	10.00	10.00	10.00	7.00	7.00	15.00	13.95	13.95	11.86	-
Molasses	6.80	6.00	6.70	6.00	5.00	5.00	5.00	4.65	4.65	3.95	-
Urea	.50	.50	.60	.60	.60	.60	1.10	1.02	1.02	.87	-
Salt and TM	.50	.50	.50	.50	.50 .05	.50 .05	.50 .05	.46 .05	.46 .05	.40 .04	-
Di Cal	-	1.00	-	1.00	-	-	-	-	-	-	-
Tri Cal	-	-	-	-	.75	.75	.75	.70	.70	.59	-
Limestone	.20	-	.20	-	.50	.50	.50	.46	.46	.40	-
Tallow	-	-	4.0	4.0	-	-	-	-	-	-	-
Cr. Fibre	14.68	13.69	14.89	14.17	8.40	7.75	9.66	8.19	9.13	8.75	38.26[d]

* 10 gms Vit A-10-P added/cwt. feed

a = Barley in Fat Mineral Study was Steam Rolled

b = Milo in Fat Mineral Study was Dry Rolled

c = Alfalfa in Fat Mineral Study was ground

d = Acid detergent crude fibre determination replicated three times. The rations employed in the milo study were dry rolled, steam processed rolled, steam processed cut, and soaked cut milo rations, and provided 48 steers to the analyses. The alfalfa data is one half of a roughage study involving 24 steers, of which the first phase is included in the present analysis. The alfalfa ration was 100 per cent long hay, and was included to provide a basis for comparison with the other rations.

Throughout this report the variables studied will be identified as X_1 = dry matter digestibility, X_2 = gross energy digestibility, X_3 = feed intake, X_4 = actual weight, and X_5 = metabolic body size.

The procedure employed in conducting the digestion trials on steers is defined by Saba (23). Digestion coefficients for dry matter (X_1) and gross energy (X_2) represent apparent digestibility of the two ration fractions.

Feed intake (X_3) is 90 per cent of ad libitum intake for the preceding adaptation period, and represents an average of actual daily feed intake during the collection period, in kilograms. The 90 per cent level of intake was used to establish steady-state flow of feces during the collection period (3).

Weights utilized were calculated from data obtained at the onset of the adaptation period and the conclusion of the collection period for each phase of the experiments. The weights represent changes in weight occurring within each portion of the digestion trial. The actual weight (X_4) is, therefore, the weight of the steer as the collection period began, arrived at by the average daily gain over the adjustment period and collection period, multiplied by the number of days between the most recent weigh date and the onset of the collection period, less five per cent shrink. The metabolic body size (X_5) and the actual weight (X_4) are both represented in kilograms, with metabolic body size derived by the following formula, according to Kleiber (18):

$$(\text{Weight}_{\text{kg.}})^{3/4} \qquad [1]$$

Experimental procedure, in the main, consisted of a series of regression analyses and was carried out in two parts by methods outlined in Steel and Torrie (26). Part I consisted of determining a regression model for the data. Part II was a test of Part I and a comparison of the results of the milo, barley, and alfalfa studies.

Part I Determination of Regression Models

Initial studies were carried out on twenty-two rations combined on the basis of the grain species content of the ration and treatment of the grain employed. The analysis employed was a multiple-step-wise regression. The four different types of rations included were dry rolled milo, dry rolled barley, steam rolled milo, and a mixture of steam rolled barley and dry rolled milo. Blaxter's work (1) suggested that curvilinear regressions might best fit the data in this study. The regression was carried out using the following formulae:

$$X_1 = b_0 + b_1X_3 + b_2X_3^2 + b_3X_3^3 + b_4X_4 \qquad [2]$$

$$X_2 = b_0 + b_1X_3 + b_2X_3^2 + b_3X_3^3 + b_4X_4 \qquad [3]$$

$$X_1 = b_0 + b_1X_3 + b_2X_3^2 + b_3X_3^3 + b_4X_5 \qquad [4]$$

$$X_2 = b_0 + b_1X_3 + b_2X_3^2 + b_3X_3^3 + b_4X_5 \qquad [5]$$

Equation [2] represents dry matter digestibility (X_1) regressed on a cubic equation of feed intake (X_3) with an added adjustment for actual weight (X_4). Equation [3] is a regression of gross energy digestibility (X_2) on a cubic equation of feed intake (X_3) adjusted for actual weight (X_4). Equations [4] and [5] resemble equations [2] and [3] , respectively, except that the weight adjustment is for metabolic body size (X_5).

Although the data employed in the initial study did cover a wide range of weights, both sexes, varying combinations of grains and roughages, and varying combinations of grain treatments, it was felt that the fat-mineral study would prove a more valuable tool in terms of defining a model with which to handle the studies in Part II. The fat-mineral study was selected for its size, homogeneity of weights within periods, and lack of significant treatment effects for the variables under observation. Another important advantage that the fat-mineral study possessed was that it contained both milo and barley, and could be expected to produce results, by virtue of the combination of the two grains, that should be somewhere in the vicinity of the two independent grain-analyses in Part II. The fat-mineral study contained 36 steers, but one was removed from the trial due to an abscessed liver (27). In evaluation of the treatment effects in the fat-mineral study, it was found that there were no significant differences between treatments for either dry matter digestibility or gross energy digestibility, but that significant increases did occur between trial one and trials two and three (27).

The initial multiple regression analysis, equations [2] - [5], results are presented in Tables 2 and 3 for the fat mineral study. These results indicate that weight was the major source of variation in regression equations employed. Since the regression program utilized was a multiple-step-wise regression, variables were brought into the regression analysis in the order of their importance. In all four regressions the weight terms (either actual weight or metabolic body size) and the linear term of feed intake appeared to account for the maximum variation in digestibility. When the entire equations were entered in the analysis of variance table for regression, the significance of the linear effect of feed intake was reduced considerably. This reduction in the linear source of feed intake can be accounted for by the exceedingly high degree of correlation between feed intake, feed intake raised to the quadratic power, and feed intake raised to the cubic power.

The weight terms (either actual weight or metabolic body size) and the linear term of feed intake were both significant when regressed against the digestion coefficients for dry matter and gross energy. The resulting equations indicated that the curves would be decreasing at a decreasing rate or concave upward.

Table 2. Step-wise Entry of Variables - Equations [2] and [3]. Fat-Mineral Study.

Variable	Equation [2]			Equation [3]		
	b	s_{eb}	F	b	s_{eb}	F
Act. Wt.	.3414	.0962	12.60**	.4009	.1008	15.82**
Intake	-1.0122	.3369	9.03**	-.9477	.3542	7.16**
Act. Wt.	.4326	.0914	22.39**	.4833	.0973	24.67**
Intake	-.6588	2.3586	.08	-.7581	2.4938	.09
(Intake)^2	-.2581	1.7045	.02	-.1386	1.8044	.01
Act. Wt.	.4323	.0929	21.66**	.4830	.0990	23.81**
Intake	11.7967	10.7800	1.20	15.6216	11.2728	1.92
(Intake)^2	-20.0867	16.8364	1.42	-26.1760	17.5820	2.22
(Intake)^3	10.0146	8.4602	1.40	13.1314	8.8221	2.22
Act. Wt.	.4575	.0947	23.33**	.5133	.0992	26.80**

* $P < .05$ ** $P < .01$

Table 3. Step-wise Entry of Variables - Equations [4] and [5]. Fat-Mineral Study.

Variable	Equation [4]			Equation [5]		
	b	s_{eb}	F	b	s_{eb}	F
M B S	1.9911	.5592	12.68**	2.3280	.5872	15.72**
Intake	-1.0184	.3363	9.17**	-.9523	.3546	7.21**
M B S	2.5292	.5313	22.66**	2.8141	.5670	24.63**
Intake	-.5988	2.3513	.06	-.6864	2.4932	.08
(Intake)^2	-.3066	1.6997	.03	-.1945	1.8045	.01
M B S	2.5276	.5396	21.95**	2.8118	.5766	23.78**
Intake	11.9144	10.7508	1.23	15.7092	11.2782	1.94
(Intake)^2	-20.2242	16.7888	1.45	-26.2536	17.5887	2.23
(Intake)^3	10.0580	8.4351	1.42	13.1406	8.8243	2.22
M B S	2.6750	.5500	23.66**	2.9885	.5776	26.77**

* $P < .05$ ** $P < .01$

Step-wise entry of variables in equations [2] and [3] are presented in Table 2. Equation [2] is the regression of dry matter digestibility of feed intake with an added adjustment for actual weight. Equation [3] is a regression of gross energy digestibility on feed intake with an added adjustment for actual weight. Step-wise entry of variables in equations [4] and [5] are presented in Table 3. Equation [4] is a regression of dry matter digestibility of feed intake with an added adjustment for metabolic body size. Equation [5] is a step-wise regression of gross energy digestibility on feed intake with an added adjustment for metabolic body size. In all four regressions the feed intake variable is in the linear, quadratic, and cubic powers.

To more closely examine the relationships analyses of covariance, by treatments, were performed on the fat-mineral study. The covariance analyses computed for the fat-mineral study were by the following pairs of variables: dry matter digestibility (X_1) and actual weight (X_4), gross energy digestibility (X_2) and actual weight (X_4), feed intake (X_3) and actual weight (X_4), dry matter digestibility (X_1) and metabolic body size (X_5), gross energy digestibility (X_2) and metabolic body size (X_5), feed intake (X_3) and metabolic body size (X_5), dry matter digestibility (X_1) and feed intake (X_3), and gross energy digestibility (X_2) and feed intake (X_3). These covariance analyses were made with respect to treatment to determine if treatment effects altered the common regression of any of the eight pairs of variables.

Results of the analyses of covariance are summarized in Table 4. Lack of significant deviations from common regression suggested that a common regression for the entire trial could be employed in following steps of fitting a model. In one instance significant differences did occur between treatment regression for gross energy digestibility regressed on actual weight.

In addition, partial correlations pertaining to each of the analyses in equations [2] - [5] were then investigated. The partial correlations were computed as (25): (calculations in appendix)

$$r_{y1\cdot 2} = \frac{r_{y1} - (r_{y2})(r_{12})}{\sqrt{\left[1-(r_{y2})^2\right] \cdot \left[1-(r_{12})^2\right]}} \qquad [6]$$

where

y = digestion coefficient (dry matter or gross energy)
1 = feed intake
2 = weight (actual or metabolic body size)
$r_{y1\cdot 2}$ = correlation (partial) between digestibility and intake adjusted for weight

Adjustment for the correlation between digestibility and feed intake corrected for weight (either actual or metabolic body size) was employed. An increase by a multiple of 2.2 in the degree of correlation comparing correlation of dry matter digestibility and intake adjusted for weight over the simple correlation between dry matter digestibility and feed intake occurred. Similarly, there was an increase by a multiple

Table 4. Analysis of Covariance Results Summarized. Fat-Mineral Study.

Variables		Regression Coefficients[a]					Correlation	
Y	X	b_I[a]	b_{II}	b_{III}	b_{IV}	b_c	r_c	r_c^2
D M Dig	Act. Wt.	.046*	.043*	.022	.033	.036**	.5151**	.2652
G E Dig	Act. Wt.	.052*	.054*	.037	.034*	.043**	.5840**	.3411
Intake	Act. Wt.	.006	.018	.003	.008	.008**	.3327*	.1106
D M Dig	M B S	.262*	.249*	.130	.193	.208**	.5165**	.2667
G E Dig	M B S	.299*	.312*	.218	.193*	.250**	.5869**	.3444
Intake	M B S	.035	.102	.018	.050	.048	.3344*	.1117
D M Dig	Intake	-.269	-.226	-1.603*	.774	-.414	-.2176	.0473
G E Dig	Intake	-.169	-.087	-1.095	.497	-.244	-.1926	.0370

* $P < .05$

** $P < .01$

[a] Subscripts refer to treatments in the fat-mineral study

I No Tallow, No Mineral
II No Tallow, Mineral
III Tallow, No Mineral
IV Tallow, Mineral
C Common Regression

of 2.6 in the degree of correlation comparing the correlation of gross energy digestibility and intake adjusted for weights over gross energy digestibility and intake. Partial correlations were computed from the analyses of covariance data.

Examination of the partial correlations between digestibilities and intake adjusted for weight suggested a covariance adjustment of intake for weight to adjust the intake values to a mean weight basis. The covariance adjustment of intake for weight should, theoretically, eliminate the effect of weight upon intake. As a result of the increases in correlations between digestibility and intake adjusted for weight the covariance adjustment of intake for weight was employed. Individual feed intake values were then adjusted to a trial mean weight basis by the following formulae:

$$X_6 = X_{3i} - b_{3.4} (X_{4i} - \bar{X}_{4\cdot}) \qquad [7]$$

$$X_7 = X_{3i} - b_{3.5} (X_{5i} - \bar{X}_{5\cdot}) \qquad [8]$$

where

X_3 = feed intake
X_4 = actual weight
X_5 = metabolic body size
$b_{3.4}$ = regression of intake (X_3) on actual weight (X_4)
$b_{3.5}$ = regression of intake (X_3) on metabolic body size (X_5)

The regression coefficients used in the covariance adjustment of intake to a mean weight basis were from the corresponding covariance analysis.

Since considerable work seems to indicate that curvilinear regression best relates digestibility and levels of intake (1) a second curvilinear regression was attempted using the two new variables:

X_6 = feed intake adjusted for actual weight, and

X_7 = feed intake adjusted for metabolic body size.

This second curvilinear regression was conducted using the following formulae:

$$X_1 = b_0 + b_1X_6 + b_2X_6^2 + b_3X_6^3 \qquad [9]$$

$$X_2 = b_0 + b_1X_6 + b_2X_6^2 + b_3X_6^3 \qquad [10]$$

$$X_1 = b_0 + b_1X_7 + b_2X_7^2 + b_3X_7^3 \qquad [11]$$

$$X_2 = b_0 + b_1X_7 + b_2X_7^2 + b_3X_7^3 \qquad [12]$$

Equation [9] is a regression of dry matter digestibility (X_1) on a cubic equation of feed intake adjusted for actual weight (X_6). Equation [10] is a regression of gross energy digestibility (X_2) on a cubic equation of feed intake adjusted for actual weight (X_6). Equations [11] and [12] resemble equations [9] and [10] respectively, except that feed intake is adjusted for metabolic body size (X_7).

The results of the second curvilinear regression are presented in Table 5. In this second exponential regression, similar problems to those occurring in the first curvilinear regression were encountered. Principal among the problems in the second set of regression formulae, [9] - [12] , were low levels of correlations. Again the

Table 5. Curvilinear Regression with Intake Adjusted for Weight. Fat-Mineral Study.

Equation No.	Variables		Regression Coefficients ± s_{eb}				Correlation
	Y	X	b_0	b_1	b_2	b_3	r^2
[9]	D M Dig	Intake adj. Act. Wt.	53.73 ± 3.27	10.18 ± 15.68	-1.62 ± 2.28	.08 ± .11	.1666
[10]	G E Dig	Intake adj. Act. Wt.	53.73 ± 3.66	9.60 ± 17.52	-1.54 ± 2.55	.07 ± .12	.1145
[11]	D M Dig	Intake adj. M B S	58.43 ± 3.27	8.10 ± 15.58	-1.32 ± 2.27	.06 ± .11	.1674
[12]	G E Dig	Intake adj. M B S	60.84 ± 3.66	6.42 ± 17.44	-1.08 ± 2.54	.05 ± .12	.1137

difficulty of high correlations between the linear, quadratic, and cubic powers of intake reduced the correlation between digestibilities and the powers of intake.

Plots and calculations of points in the solved equations [9] - [12] indicated that the second set of equations provided a virtually linear relation between digestibilities and intakes adjusted for actual weight and metabolic body size.

Garrett, Meyer, and Lofgreen (12) found that either linear regression or exponential regression could be employed in studies of this type with approximately the same accuracy.

Due to the insignificant addition of curvilinear terms to the model, linear regression was used solely for analyses of the milo, barley, and alfalfa studies. In the linear regression, feed intake adjusted for actual weight (X_6) and feed intake adjusted for metabolic body size (X_7) were again employed. The linear regressions were carried out under the following formulae:

$$X_1 = b_0 + b_1X_6 \qquad [13]$$

$$X_2 = b_0 + b_1X_6 \qquad [14]$$

$$X_1 = b_0 + b_1X_7 \qquad [15]$$

$$X_2 = b_0 + b_1X_7 \qquad [16]$$

Equation [13] is a linear regression of dry matter digestibility (X_1) on feed intake adjusted for actual weight (X_6). Equation [14] is a regression of gross energy digestibility (X_2) on feed intake adjusted for actual weight (X_6). Equations [15] and [16] are similar to [13] and [14] respectively, except that in equations [15] and [16] feed intake is adjusted for metabolic body size (X_7) instead of actual weight (X_6).

Results of linear regression, equations [13] - [16] , for the fat-mineral study are presented in Table 6, and illustrated in Figures 1A and 1B. In all four cases a highly significant decline in digestibility occurs with increasing levels of intake adjusted for either weight term, actual weight or metabolic body size.

Part II Evaluation of Regression Models and Comparison of Rations

All observations from both the milo trial and the barley trial were included to make the analyses a between grains study rather than a between treatment study. Indications are that previous treatment effects are eliminated if the animal is given ten to fifteen days for the rumen population to readjust to a new ration (3, 20).

The results of the linear regressions, formulae [13] - [16] , for the milo, barley, and alfalfa study are presented in Table 7, and illustrated in Figures 2A and 2B.

In general, results of the milo and alfalfa analyses are in agreement with Blaxter (1) and Forbes and Garrigus (11) in that as intake increases (in this case adjusted for either actual weight or metabolic body size) digestibility of both dry matter and gross energy decline.

Table 6. Regression Coefficients and Coefficients of Determination. Equations [13]-[16] Linear Regression - Fat-Mineral Study.

Equation	Y	X	Regression ± s_b	Determination
[13]	D M Dig.	Int. adj. Act. Wt.	-.975 ± .305 **	.1530
[14]	G E Dig.	Int. adj. Act. Wt.	-.873 ± .245 **	.1043
[15]	D M Dig.	Int. adj. MBS	-.993 ± .312 **	.1582
[16]	G E Dig.	Int. adj. MBS	-.891 ± .250 **	.1084

* $P < .05$

** $P < .01$

Figure 1A. Effect of Feed Intake Adjusted for Actual Weight on Digestibilities (Fat-Mineral Study)

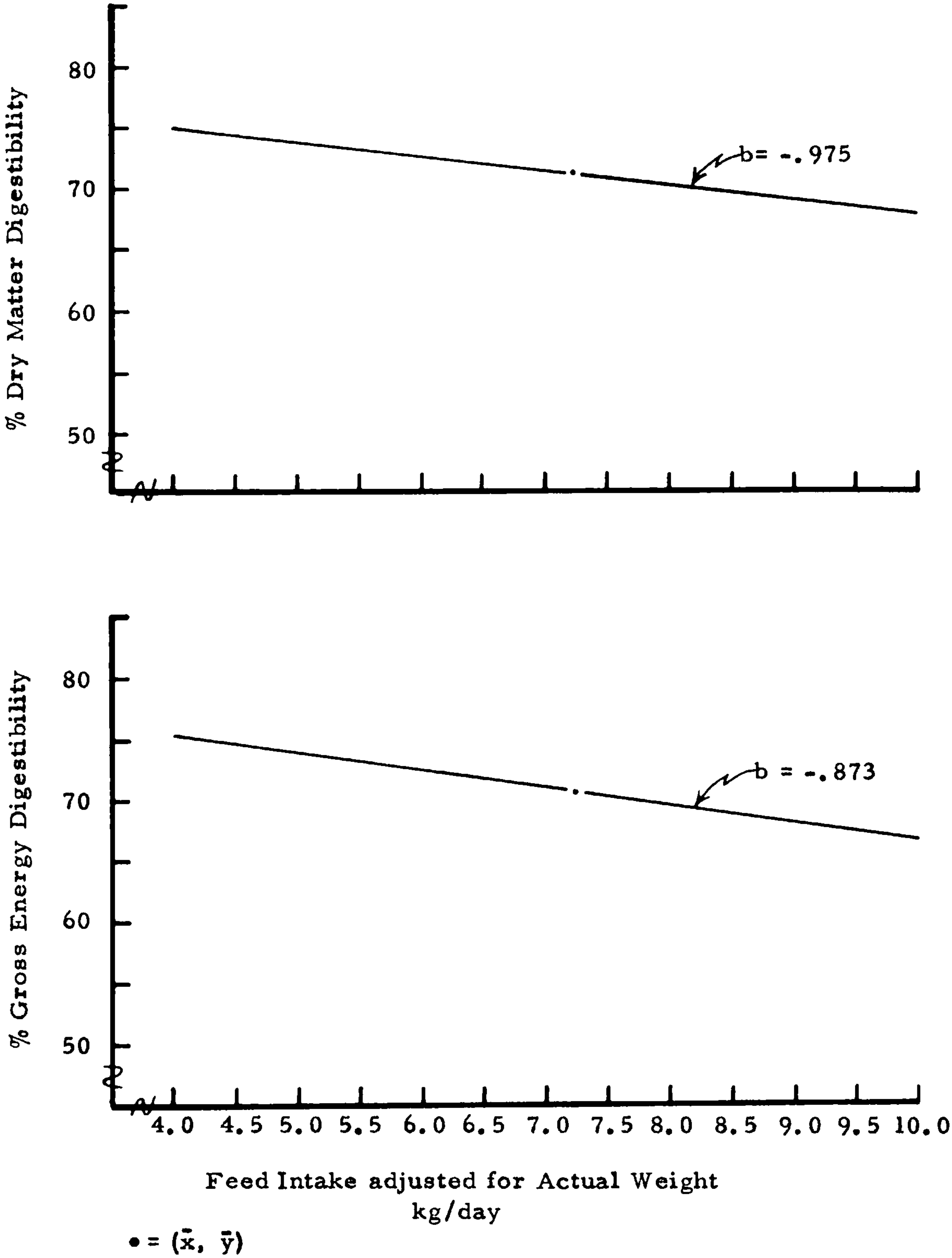


Figure 1B. Effect of Feed Intake Adjusted for Metabolic Body Size on Digestibilities (Fat-Mineral Study)

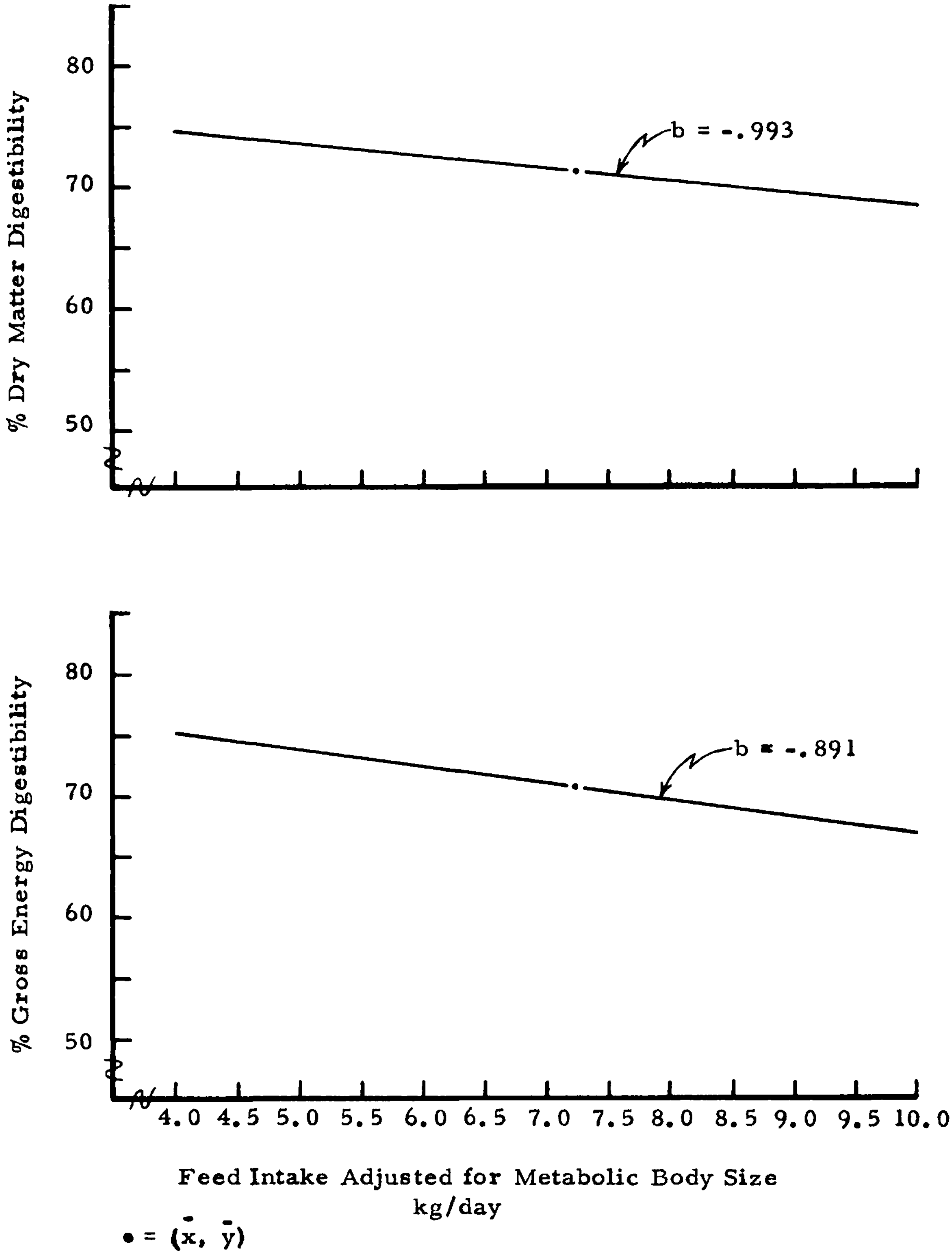


Table 7. Linear Regression of Digestibility on Intake Adjusted for Weight. Milo, Barley, and Alfalfa Rations. Equations [13] - [16].

Variables Y X	Intercept b_0	Regression Coefficient $\pm s_e$ $b_1 \pm s_b$	r^2
X_1 X_6			
Milo	80.80	$-2.035 \pm .8123^{*}$	.1201
Barley	64.74	$1.646 \pm .3774^{**}$	.4638
Alfalfa	64.20	$-.655 \pm .7503^{ns}$	.0708
X_2 X_6			
Milo	77.82	$-1.825 \pm .8201^{*}$	.0972
Barley	62.36	$1.905 \pm .4443^{**}$	.4550
Alfalfa	63.83	$-.697 \pm .7832^{ns}$	.0734
X_1 X_7			
Milo	80.88	$-2.047 \pm .8119^{*}$	.1214
Barley	64.77	$1.642 \pm .3770^{**}$	.4630
Alfalfa	64.22	$-.658 \pm .7519^{ns}$	.0712
X_2 X_7			
Milo	77.90	$-1.837 \pm .8198^{*}$	.0984
Barley	62.41	$1.898 \pm .4443^{**}$	.4534
Alfalfa	63.87	$-.705 \pm .7849^{ns}$	.0746

$^{*}\ P < .05$ $^{**}\ P < .01$

$$Y\begin{cases} X_1 = \text{Dry matter digestibility} & X_6 = \text{Intake adjusted for actual weight} \\ X_2 = \text{Gross energy digestibility} & X_7 = \text{Intake adjusted for M B S} \end{cases}$$

Figure 2A. Effect of Feed Intake Adjusted for Actual Weight on Digestibilities (Milo, Barley and Alfalfa Studies)

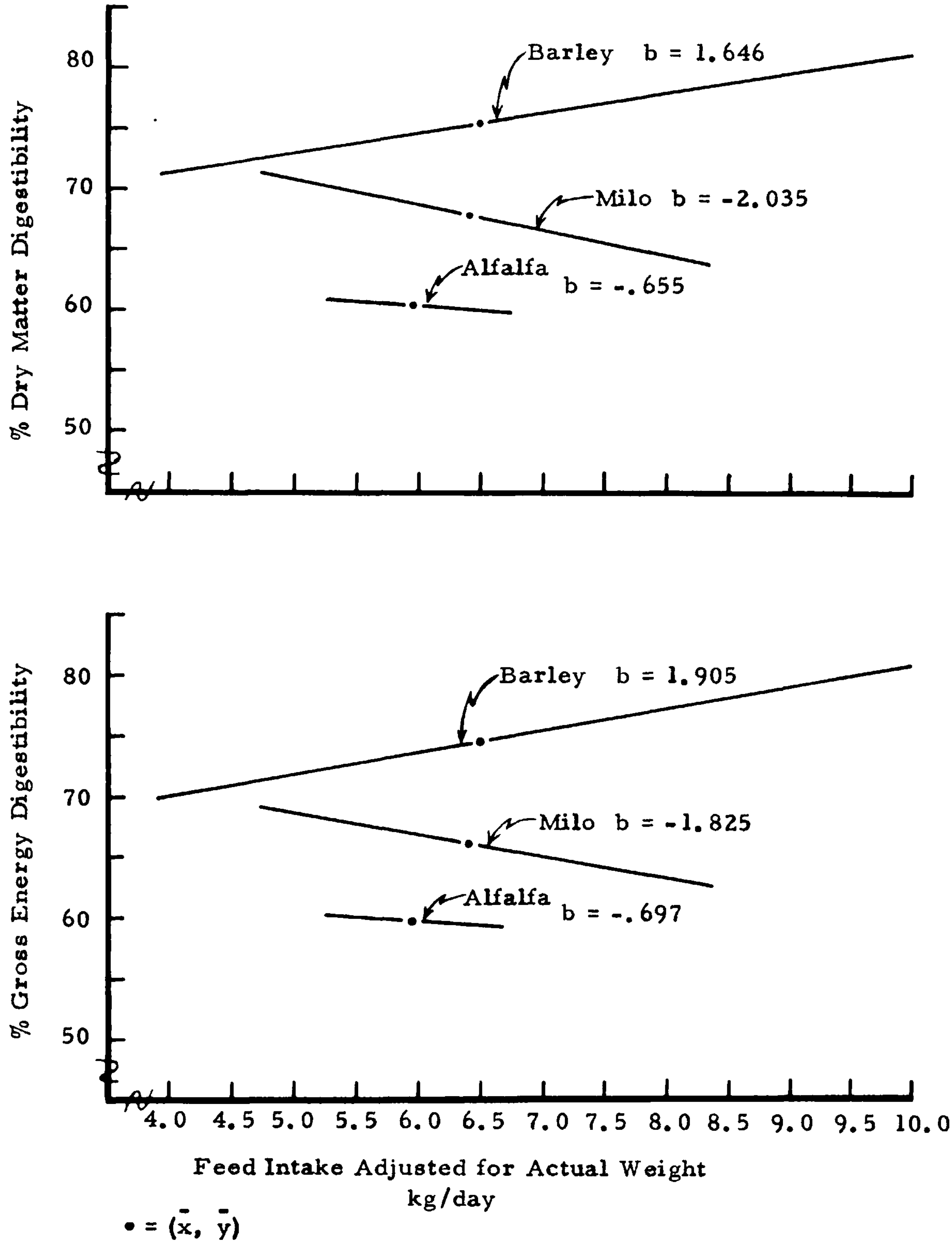
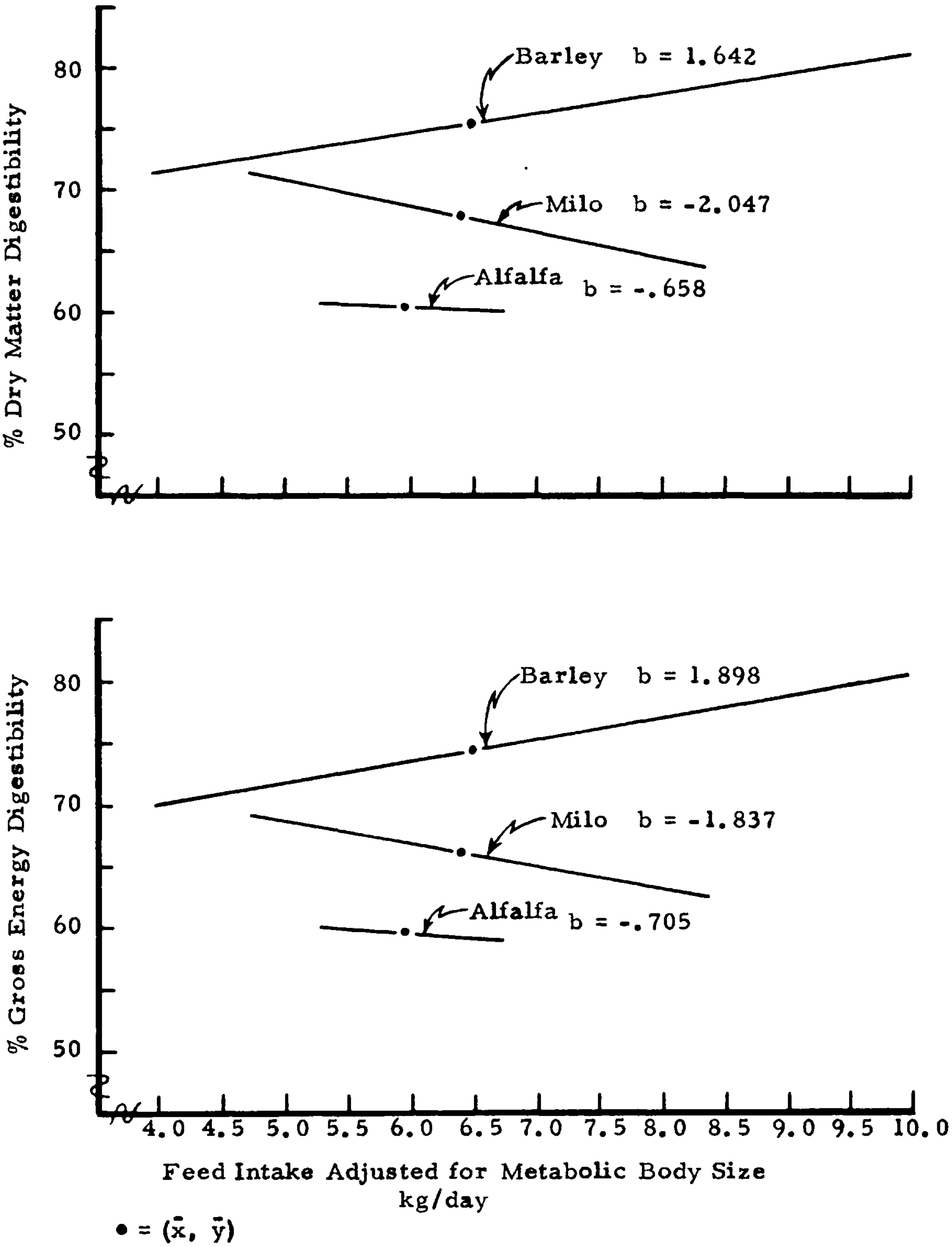


Figure 2B. Effect of Feed Intake Adjusted for Metabolic Body Size on Digestibilities (Milo, Barley and Alfalfa Studies)



In the first regression, dry matter digestibility on feed intake adjusted for actual weight, both the milo and alfalfa rations showed a decline. Significance occurred only in the milo ration, indicating for every kilogram of increased intake there will occur a proportional (2.04 percentage points) decline in dry matter digestibility. While results of the alfalfa study were nonsignificant, it is felt that a significant decline might have occurred had there been more information available on the alfalfa ration.

In the second regression, gross energy digestibility regressed on feed intake adjusted for actual weight, similar to results occurred. With an increase in feed intake, a significant decline in milo digestibility (1.8 percentage points per kilogram of intake) occurred. The alfalfa regression under this model was nonsignificant.

Dry matter digestibility regressed on feed intake adjusted for metabolic size, equation [15], a significant decline in digestibility of 2.05 percentage points per increased kilogram of intake appeared. Dry matter digestibility of alfalfa declined, but was not significant.

The final regression, gross energy digestibility on feed intake adjusted for metabolic body size, showed similar results. For each added kilogram of milo intake a decrease of 1.84 percentage points occurred. Similar to the above regressions, the drop in digestible energy of alfalfa was nonsignificant, but did follow the trend of a gradual decrease with increased intake.

Results of the regressions concerning the barley rations, however, showed exactly opposite information. A highly significant increase in digestibility of dry matter and gross energy occurred whether the intake was adjusted for either actual weight or metabolic body size. Results of the barley analyses are contained in Table 7. These results indicated an increase in both dry matter and gross energy digestibility per unit of added feed intake adjusted for weight. The amount of increase in digestion coefficients is represented by the regression coefficient.

It is felt that curvilinear regression is not the most efficient method of examining the relationships between dry matter and gross energy digestibilities and feed intake whether adjusted for actual weight or metabolic body size or if feed intake is left unadjusted. The use of orthogonal polynomials could possibly provide an effective curvilinear analysis of the data. This method may prove impossible due to the complexities involved in providing an orthogonal set of coefficients for feed intakes. The principal advantage of orthogonal polynomials would be that the high correlations between feed intake in its linear, quadratic, and cubic powers encountered in this study would not be a problem.

An interesting observation made from this study is the similarity of feed intake adjusted for actual weight and feed intake adjusted for metabolic body size. In virtually all cases, the differences that occurred were due to rounding. This is demonstrated by the numerical differences in the regression coefficients used to adjust feed intake to a trial mean actual weight and a trial mean metabolic body size. The regression coefficient adjusting intake for actual weight was considerably smaller than the corresponding regression coefficient adjusting intake for metabolic body size. The numerical similarity of the adjusted feed intakes was borne out by closeness of the regression coefficients for dry matter digestibility on feed intake adjusted for either actual weight or metabolic body size. Similarly, the regression coefficients of gross energy digestibility on feed intake adjusted for either actual weight or metabolic body size, were in good agreement.

Coefficient of determination of the relationship between dry matter digestibility (X_1) and gross energy digestibility (X_2) was computed for all rations to measure the relationship, if any, between these two variables. Coefficients of determination for all of the rations studied herein are presented in Table 8. The tabled values show these two variables to be highly correlated. This is to be expected as gross energy content of a ration is determined by its organic matter content. Dry matter digestibility is primarily determined by the organic matter digestibility, as ash content of these high-concentrate rations was very low. If ash content in a ration were non-existant, and there was no excretion of minerals into the lumen of the large intestine, a perfect correlation is theoretically possible.

Table 8. Correlation between Dry Matter Digestibility and Gross Energy Digestibility

Trial	No. Steers	R^2
Fat-Mineral	35	.9432
Milo	48	.9790
Barley	24	.9413
Alfalfa	12	.9330

DISCUSSION

The factors affecting digestibility of rations in ruminants are not concretely established although some work indicates that weight by virtue of its effect on intake does affect digestibility. The use of the covariance adjustment of intake to a mean trial weight basis is supported also by the results of the multiple-step-wise regression employed in Part I where weight was the first variable entered in the analysis of variance for regression.

The high degree of similarity between the curvilinear regressions and the linear regression employed finally in Part I would indicate that the rations, for the limits of feed intake studied, provided sufficient energy to be above maintenance (1). The indication is supported by the fact that with only one exception all 119 steers gained weight throughout the trials studied. Linear regression may be equivalent to exponential regressions in this instance because the steers were on 90 per cent of ad libitum feed intake and were not allowed to consume feed until appetite failed.

Blaxter, Graham, and Wainman (3) found with sheep on roughage rations that an asymptotic limit of digestibility of dry matter occurred at 81 per cent digestibility. However, the sheep in his study (3) were on ad libitum feed intake, and appetite failed before the theoretical limit of digestibility was reached.

In view of research information available the observations made with the barley ration was somewhat surprising. However, it does aid in explaining observations from feedlot trials conducted with barley at the University of Arizona (14). The feedlot trials have shown that by proper processing of barley it is possible to improve gains yet not affect feed efficiency. Hastings (15) indicated that the amount of fecal material excreted from an animal will not decrease appreciably if feed intake is reduced, particularly if the feed is highly digestible due to the bacterial content of the feces. In cattle a large portion of fecal material is of bacterial origin which is probably poorly digestible. With cattle above the maintenance level on a highly digestible ration such as barley it is probable that there is a minimum fecal excretion due to undigestible bacterial content of the gut. If feed intake is increased with the highly digestible feed then it is possible for apparent digestibility also to increase as the minimal fecal excretion will probably remain constant and thus become a smaller percentage of total fecal excretion. This minimal dry matter fecal excretion is probably analogous to fecal metabolic nitrogen. A theoretical 100 per cent dry matter or gross energy digestibility may be possible but would not occur because of the existence of fecal metabolic energy.

In the case of milo which is poorly digestible compared to barley, a greater portion of the gut fill and final fecal excretion is probably represented by undigested residues than by true fecal metabolic energy. Thus as a steer on milo eats more to satisfy his energy needs the undigested fecal residue represents a greater portion of the fecal excretion.

Despite the opposing information given in the regression analyses, it would seem important to note that the magnitude of the slopes of the regression lines, equation [13], significant in opposite directions, preclude the use of wide ranges of weights of cattle in digestion trials. For example, using 2.5 per cent of weight as a level of intake and calculating back from the regression data presents some interesting information. At five kilograms and eight kilograms of intake, two 260 kilogram steers are involved. For the barley regression, dry matter and intake adjusted for actual weight, 73 and 77 per cent digestibility are achieved at the five and eight kilogram intake levels respectively. If the milo regression is compared, dry matter and intake adjusted for actual weight, 71 and 64 per cent digestibility are obtained, at five and eight kilograms intake respectively. While the barley results show an increase of four percentage points, the milo results show a decline of seven percentage points. Continuing the calculations, a mean digestibility of 71 per cent dry matter digestibility is obtained. This shows that the milo ration began at the mean digestibility and declined while the barley ration increased. There is an absolute difference between the two final dry matter digestion coefficients of 13 percentage points, undoubtedly large enough to be significantly different.

From the above sample calculations it can be deduced that there are enough varying factors to limit the range of weights of cattle employed in digestion trials.

The similarities existing between dry matter regressed on feed intake adjusted for actual weight and feed intake adjusted for actual weight and feed intake adjusted for metabolic body size are sufficient, in view of the small differences obtained in the actual calculations of these two terms, to conclude that either weight correction will suffice. The similarities are due to the compensating magnitudes of the regression coefficients ($b_{3.4}$) and ($b_{3.5}$) from equations [7] and [8] given earlier.

In the high concentrate rations studied here, the high level of correlations between dry matter digestibility and gross energy digestibility suggest that one (preferably dry matter digestibility) can be used to predict the other. It seems that gross energy digestibility either equals or is up to four percentage points smaller than dry matter digestibility, seldom does gross energy exceed dry matter digestibility. This is due, no doubt, to the excretion of minerals into the lumen of the large intestine and the mineral content of the ration and the feces.

The correlation of digestibility (dry matter or gross energy) with the weight terms is not exceedingly high, particularly on the milo ration, but in the barley ration is in the neighborhood of .45. The level resulting in the barley ration were similar to those which suggested the initial covariance adjustment of intake to a trial mean weight basis.

Apparently the use of a single mean digestion coefficient for dry matter and gross energy is not as accurate as it might be, and should be supplemented by linear regressions of dry matter and gross energy digestibility on intake. It is conceivable that other ration fractions should also be supplemented by regression analyses, but this is purely conjecture.

It is apparent that considerable work in the area of digestion coefficients and other variables is in order to provide a truly satisfactory method of determining the value of a feed source to animals.

SUMMARY

To study the influence of body weight and feed intake on dry matter and gross energy digestibility three different regression analyses were attempted, two exponential and one linear regression model. The results indicate that the rations studied provided sufficient energy to maintain the steers above the point of energy equilibrium.

Three different rations were studied after a model was established in preliminary studies on a fourth ration containing both of the grains studied.

Examination of dry matter and gross energy digestibilities of milo and alfalfa when regressed against intake adjusted for actual weight and metabolic body size seem to follow previously reported trends.

Barley, however, provided completely opposite information. The foregoing analyses indicate that as intake increases on a barley ration, both digestibilities studied increase similarly. The increase in digestibilities with increased intakes may be explained by a buildup in microbial tissue which may be regarded as a type of fecal metabolic energy. This probably could be observed only on highly digestible rations. The high digestibility of barley has been shown by Arizona workers.

Indications are that curvilinear regression, whether or not weight adjustments are employed, is not the most efficient method of analyzing such data. The use of orthogonal polynomials may alleviate the problem of correlations between independent variables, but complexities in producing orthogonal sets of coefficients for intake might prohibit their use.

The results herein point out the dangers of over-extending the length of digestion trials on the same set of livestock in that digestibility seems to be a function of both weight and feed intake (i.e., intake increases as weight increases) and rather serious deviations from a mean digestion coefficient may occur in a digestion trial of extended length.

APPENDIX

APPENDIX

EXPLANATION OF ABBREVIATIONS

X_1	D M Dig	= Dry matter digestibility %
X_2	G E Dig	= Gross energy digestibility %
X_3	Int	= Feed intake kg
X_4	Act Wt	= Actual weight kg
X_5	M B S	= Metabolic body size $(W_{kg})^{3/4}$
X_6	Int adj Act Wt	= Intake adjusted for actual weight
X_7	Int adj M B S	= Intake adjusted for metabolic body size
	$\bar{x}$	= arithmetic mean of x_i
	$\bar{y}$	= arithmetic mean of y_i
	D R	= dry rolled
	S P	= steam processed

APPENDIX

Table 9. Calculations of Adjustment of Correlations between Digestibility and Intake Adjusted for Weight. (Equation [6] - p. 17)

Dry matter digestibility and intake adjusted for actual weight

$$r_{y1\cdot 2} = \frac{-.2176 - (.5151)(.3327)}{\sqrt{\left[1 - (.5151)^2\right] \cdot \left[1 - (.3327)^2\right]}} = -.4812$$

Gross energy digestibility and intake adjusted for actual weight

$$r_{y1\cdot 2} = \frac{-.1926 - (.5840)(.3327)}{\sqrt{\left[1 - (.5840)^2\right] \cdot \left[1 - (.3327)^2\right]}} = -.5054$$

Dry matter digestibility and intake adjusted for metabolic body size

$$r_{y1\cdot 2} = \frac{-.2176 - (.5165)(.3344)}{\sqrt{\left[1 - (.5165)^2\right] \cdot \left[1 - (.3344)^2\right]}} = -.4796$$

Gross energy digestibility and intake adjusted for metabolic body size

$$r_{y1\cdot 2} = \frac{-.1926 - (.5869)(.3344)}{\sqrt{\left[1 - (.5869)^2\right] \cdot \left[1 - (.3344)^2\right]}} = -.5096$$

APPENDIX

Table 10. Sample Calculations of Feed Intake Adjusted for Actual Weight (Equation [7] - p. 19)

Fat-mineral study

$$X_{6i} = 5.72 - .008\ (285.7 - 359.4) = 6.31$$

Milo study

$$X_{6i} = 6.39 - .002\ (220.5 - 290.7) = 6.50$$

Barley study

$$X_{6i} = 7.08 - .033\ (325.7 - 304.1) = 6.36$$

Alfalfa study

$$X_{6i} = 6.42 - .015\ (242.6 - 239.9) = 6.38$$

Table 11. Sample Calculations of Feed Intake Adjusted for Metabolic Body Size (Equation [8] - p. 19)

Fat-mineral study

$$X_{7i} = 5.72 - .048\ (69.49 - 82.31) = 6.34$$

Milo study

$$X_{7i} = 6.39 - .009\ (57.22 - 70.20) = 6.51$$

Barley study

$$X_{7i} = 7.08 - .185\ (76.67 - 72.70) = 6.35$$

Alfalfa study

$$X_{7i} = 6.42 - .079\ (61.47 - 60.92) = 6.38$$

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