1976

Mathematical Models of Postweaning Growth, Feed Intake and Carcass Composition of Beef Cattle

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MATHEMATICAL MODELS OF POSTWEANING GROWTH, FEED INTAKE AND CARCASS COMPOSITION OF BEEF CATTLE

BY

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A thesis submitted
in partial fulfillment of the requirements for the
degree Doctor of Philosophy, Major in
Animal Science, South Dakota
State University

1976

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AND CARCASS COMPOSITION OF BEEF CATTLE

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Doctor of Philosophy, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser　　　　Date

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MATHEMATICAL MODELS OF POSTWEANING GROWTH, FEED INTAKE AND CARCASS COMPOSITION OF BEEF CATTLE

Abstract

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Under the supervision of Professor Christian A. Dinkel

A computer model was developed to evaluate the energetic efficiency of postweaning beef production of various biological types of cattle fed rations with different energy densities.

In Section I, a mathematical model was developed to estimate voluntary feed intake for growing cattle from weaning to slaughter. The mathematical model included effects of differences in energy density and crude fiber content of the ration and in breed and degree of maturity of cattle on feed intake. When gastrointestinal tract distension controlled feed consumption, the primary factors determining feed intake were (1) rate of excretion of digesta, (2) rate of digestion, (3) dry matter digestibility, (4) gut fill, (5) breed of cattle and (6) degree of maturity of cattle. When feed intake was controlled by chemostatic and/or thermostatic mechanisms, the dry matter consumption was determined by physiological demand for energy, which varied with age and breed of animal. Data from the literature and from Bond (personal communication) were utilized to develop necessary equations. A computer program is available which estimates voluntary feed intake for various breeds of cattle of different degrees of maturity fed various diets.

In Section II, the effect of protein level in the diet and degree of maturity of the cattle on the coefficient of metabolizable energy utilization for fattening (k_f) were evaluated. This coefficient indicates the percent of metabolizable energy retained as body tissue. Data from Peterson et al. (1973) were utilized to develop a multiple curvilinear regression equation for adjusting k_f values recommended by A.R.C. (1965). The results of this study indicate that both degree of maturity of the cattle and protein level in the diets influenced the k_f values. As cattle matured, k_f value decreased. Both percent protein and calorie-protein ratio had nonlinear effects on k_f values.

In Section III, mathematical equations for estimating physical and chemical composition of steers of different biological types fed various diets were developed. Thus, the calorific value of live weight gain was also measured. All dependent variables of the equations were traits measurable prior to slaughter. Physical composition of live weight was divided into empty body weight and gut fill. Empty body weight was further divided into eight subcomponents according to the similarity of chemical composition within each component. Regression analyses were used to estimate gut fill and eight subcomponents of empty body. Regression equations for estimating chemical composition of each subcomponent of empty body were developed utilizing data from the literature. A computer program is available which predicts the physical composition, chemical composition and calorific value of live weight gain of steers for different biological types of cattle fed on various diets.

In Section IV, a computer simulation was made (1) to estimate the energetic efficiency of postweaning beef production from four breed groups, (a) Jersey, (b) Hereford-Angus, (c) Dairy Shorthorn and (d) Holstein; (2) to evaluate the optimum time of slaughter for each breed type and (3) to evaluate the effect of slaughter at ages other than optimum time on energetic efficiency of beef production. The computer model included information from Sections I and II of this study and from N.R.C. (1976) and A.R.C. (1965) recommendations. Simulated results indicated larger breeds tended to reach the optimum time of slaughter at older ages and heavier weights than smaller breeds. Slaughtering cattle at ages other than optimum were evaluated in terms of energetic efficiency. Four ways of determining slaughter ages were used, (1) slaughter at simulated breed optimum age; (2) slaughter at various constant ages; (3) slaughter at a constant degree of maturity and (4) slaughter at a constant weight. Slaughter at a constant weight was least efficient and slaughter at a constant age was intermediate between slaughter at optimum age and slaughter at constant weight. Slaughter at a constant degree of maturity was second in efficiency only to slaughter at breed optimum age. For practical application it will be necessary to estimate mature weight of young cattle. Further study will be necessary to develop accurate predictions of mature weight from early performance of the animal and its pedigree.

ACKNOWLEDGMENTS

The author expresses sincere appreciation to Dr. C. A. Dinkel for his guidance, encouragement, patience and stimulation given throughout the graduate program and the development of this thesis. The author is also in great debt to Dr. C. A. Dinkel in organizing and editing the thesis.

The author wishes to express special thanks to Dr. W. J. Costello, Dr. L. B. Embry, Dr. W. R. Parker, Dr. W. W. Schneider, Dr. Harold J. Tuma and Dr. R. C. Wahlstrom for their contribution to this thesis through a number of discussions; to Dr. W. L. Tucker for his assistance in statistical data analyses and to Marjorie Thom for typing the thesis.

The author expresses special appreciation to Dr. Gerald M. Smith and Dr. James Bond for their cooperation by sending research data and offering criticisms for part of this thesis.

The patience and understanding of my wife, Eun-Hee, and the encouragement in my educational pursuit by my parents, Se-Keun and Sun-Ok Song, have been particularly appreciated.

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LIST OF ABBREVIATIONS

BD_{VFI_d}	....	Breed differences in voluntary feed intake controlled by distension of gastrointestinal tract
BD_{VFI_p}	....	Breed differences in voluntary feed intake controlled by physiological demand for energy
CF	....	Percent crude fiber in diets
DD	....	Percent dry matter digestibility of feeds
DM	....	Dry matter
DOM	....	Degree of maturity of animal
$Energy_{DM}$	....	Kcal metabolizable energy per g dry matter of feed
$Energy_{PD}$	....	Physiological demand for energy per kg $W^{.73}$
GF_{dry}	....	Gut fill in dry matter base per kg metabolic weight (g/kg $W^{.73}$)
GIT	....	Gastrointestinal tract
H_I	....	Number of hours from feeding to excreting 2% of digesta
H_X	....	Number of hours per coded X values in general cumulative excretion curve (GCEE)
ME	....	Metabolizable energy
MRT	....	Mean retention time of feeds
PMRT	....	Partial mean retention time
ROD	....	Rate of digestion and absorption of digesta
ROE	....	Rate of excretion of digesta

RT .... Retaining time of digesta since feeding:

$RT = DAY_i \times 24$ (hr)

VFI .... Voluntary feed intake at <u>ad libitum</u> feeding

VFI_d .... VFI regulated by GIT distension

VFI_p .... VFI regulated by physiological demand for energy (chemostatic and/or thermostatic mechanisms)

VFI_t .... True voluntary feed intake

PREFACE

Efficiency of beef production has been of interest to researchers and producers. It has been found that cow size has no significant effect on efficiency of production when the efficiency was expressed as TDN consumed by cow-calf unit per kg calf weight at weaning (Bennyshek and Marlowe, 1973; Brinks et al., 1962; Marshall, 1975; Urick et al., 1971). The concepts of efficiency of beef production have changed as the consumer demand for meat product has changed. The difference in price of lean and fat tissue has increased. This changing concept of efficiency requires an appropriate way of expressing efficiency. TDN per kg calf weight produced would provide an appropriate measure of efficiency of beef production if all calves had the same composition. However, the proportion of lean, fat and bone in the carcass varies depending on breed and age at slaughter (Smith et al., 1976). It is obvious that live weight of calf needs to be adjusted in market value according to carcass characteristics.

Another question which needs to be answered before the efficiency of beef production can be evaluated is what is the optimum age to slaughter a calf for meat? Comparing the efficiency of different cow-calf units would be most appropriate when all cow-calf units were at the optimum stage of yielding maximum efficiency. Theoretically, the optimum age to slaughter a calf is the age at which net return from the cow-calf pair will be maximum. However, under practical conditions it is difficult to estimate the optimum age to slaughter because (1) it is impossible to have more than one performance record in regard to

carcass characteristics since a calf can not be slaughtered more than once and (2) it is necessary to keep the record of feed consumed by cow and calf individually, which is a costly procedure. Therefore, it would be useful to have a computer program which can help to evaluate the optimum stage of slaughter both for producers and researchers.

The purpose of this study was to develop a computer program to estimate voluntary feed intake, postweaning growth, efficiency of feed conversion and carcass characteristics of calves and thus to assist in evaluating the total efficiency of beef production on a cow-calf unit.

Voluntary Feed Intake

Amount of feed and kinds of feed consumed are one of the important factors for animal growth. An understanding of how much feed the animal consumes is necessary to simulate growth of calf and efficiency of feed conversion. In Section I of this study, a mathematiocal model was developed to estimate ad libitum daily dry matter intake fed for growing cattle from weaning to slaughter. The mathematical model included effects of differences in energy density and crude fiber content in ration, in degree of maturity of cattle and in breed on feed intake.

The basic principles used in developing a mathematical model were (1) rate of excretion of digesta, (2) rate of digestion, (3) dry matter digestibility, (4) gut fill and (5) physiological demand for energy, with the first four items depending on the crude fiber content

of feed and age of animal and the physiological demand for energy varying with age and breed of animal.

Efficiency of Energy Conversion to Gain (k_f)

In Section II of this study, the effects of protein level in diets and age of cattle on the efficiency of energy conversion into gain (k_f) were studied. The values of k_f (efficiency of metabolizable energy utilization for fattening) from A.R.C. (1965) were varied depending on the metabolizable energy density of feed. However, there have been other factors affecting the efficiency of conversion of feed into weight gain such as age of animal (Ritzman and Colovos, 1943) and protein content in diet (Peterson *et al*., 1973).

A statistical model (Model I) was used to estimate a multiplicative factor to adjust k_f (A.R.C., 1965) according to age of animal and protein level of diets. The research data used for regression analysis were from the study by Peterson *et al*. (1973), where 16 different diets (four levels of energy x four levels of protein) were used and efficiency of gain was observed for three to four consecutive age groups per diet. The statistical model (Model I) was $Y_{ijkl} = a + b_1D_i + b_2D_i^2 + b_3P_j + b_4P_j^2 + b_5E_k + b_6E_k^2 + b_7DP_{ij} + b_8DE_{ik} + b_9DPE_{ijk} + b_{10}DPE_{ijk}^2 + b_{11}C_l + b_{12}C_l^2 + b_{13}DC_{il} + b_{14}DC_{il}^2$ where

Y_{ijkl} is the estimated multiplicative adjusting factor of k_f according to age of animal and protein level of diets

a is the intercept when all independent variables are zero

b_1D_i is the partial regression effect on the ith degree of maturity where degree of maturity is current weight divided by expected mature weight

$b_2D_i^2$ is the partial regression effect on the quadratic of the ith degree of maturity

b_3P_j is the partial regression effect on the jth percent protein of diet

$b_4P_j^2$ is the partial regression effect on the quadratic of the jth percent protein in diet

b_5E_k is the partial regression effect on the kth energy level of diet

$b_6E_k^2$ is the partial regression effect on the quadratic of the kth energy level of diet

b_7DP_{ij} is the partial regression effect on the interaction of the ith degree of maturity with the jth protein level

b_8DE_{ik} is the partial regression effect on the interaction of the ith degree of maturity with the kth energy level

b_9DPE_{ijk} is the partial regression effect on the three-way interaction of the ith degree of maturity with the jth protein level and with the kth energy level

$b_{10}DPE^2_{ijk}$ is the partial regression effect on the three-way interaction of the ith degree of maturity with the jth protein level and with the quadratic of the kth energy level

$b_{11}C_l$ is the partial regression effect on the lth calorie-protein ratio

$b_{12}C^2_l$ is the partial regression effect on the quadratic of the lth calorie-protein ratio

$b_{13}DC_{il}$ is the partial regression effect on the interaction of the ith degree of maturity with the lth calorie-protein ratio

$b_{14}DC^2_{il}$ is the partial regression effect on the interaction of the ith degree of maturity with the quadratic of the lth calorie-protein ratio.

Chemical and Physical Composition of Body Gain

A knowledge of chemical and physical composition of body is necessary to evaluate (1) efficiency of feed conversion into body gain, (2) optimum age of slaughter and (3) efficiency of beef production on cow-calf pair basis.

Even though there have been many studies of chemical and physical composition, there has been only limited study of estimation of physical and chemical composition of live animal and carcass of cattle from traits measurable prior to slaughter. In Section III of

this study, prediction of chemical and physical composition of body gain was investigated.

Physical Composition of Live Weight

Physical composition of live weight was divided into three components, (1) dressed hot carcass, (2) remainder and (3) gut fill. Dressed hot carcass was composed of four subcomponents, (1) water evaporated during chilling and dissecting carcass, (2) separable muscle, (3) separable fat and (4) separable bone. Dissected cold carcass referred to the sum of the last three subcomponents. Remainder was divided into five subcomponents according to the similarity of chemical composition within each component. These were hide and hair (% HIDE), blood and organs (% BO), offal fat (% OF), bone from head, legs and tail (% BONE) and scraped soft tissue from head, legs and tail (% SCRAPE).

Research data in regard to hot carcass, dissected cold carcass and three subcomponents of dissected cold carcass were available for several different breeds, different diets and different ages of cattle. Gut fill was not different from breed to breed (Callow, 1961). Therefore, the lack of data in representing several breeds was not considered to be a problem. However, remainder composed of hide, offal fat, blood, organs, head, legs and tail has been studied only for a few different breeds of cattle. For this reason, hot carcass, dissected cold carcass, the three subcomponents of dissected cold carcass and gut fill were first estimated and then the remainder was estimated by the difference between live weight and the sum of hot carcass and gut fill.

Hot Carcass and Subcomponents

In estimating physical composition of the dissected cold carcass, two methods were investigated. Research data included in the regression analyses were from studies by Bond et al. (1972), Hooven et al. (1972) and Smith et al. (1976).

The statistical model (Model II) used in Method I was derived from techniques presented by Draper and Smith (1968) as follows:

$$Y_{ijklm} = a + b_1L_i + b_2L_i^2 + b_3D_j + b_4D_j^2 + b_5LD_{ij} + b_6LD_{ij}^2 + b_7C_k + b_8LC_{ik} + b_9M_l + b_{10}LM_{il} + b_{11}B_m + b_{12}B_m^2 + b_{13}LB_{im} + b_{14}LB_{im}^2$$ where

Y_{ijklm} is the dependent variable

a is the intercept when all the independent variables are zero

b_1L_i is the partial regression effect on the ith live weight of cattle

$b_2L_i^2$ is the partial regression effect on the quadratic of the ith live weight of cattle

b_3D_j is the partial regression effect on the jth degree of maturity

$b_4D_j^2$ is the partial regression effect on the quadratic of the jth degree of maturity

b_5LD_{ij} is the partial regression effect on the interaction of the ith live weight with the jth degree of maturity

$b_6LD_{ij}^2$ is the partial regression effect on the interaction of the ith live weight with the jth quadratic of degree of maturity

b_7C_k is the partial regression effect on the kth percent crude fiber in diet

b_8LC_{ik} is the partial regression effect on the interaction of the ith live weight with the kth percent crude fiber in diet

b_9M_l is the partial regression effect on the lth mature weight of cattle

$b_{10}LM_{il}$ is the partial regression effect on the interaction of the ith live weight with the lth mature weight

$b_{11}B_m$ is the partial regression effect on the mth biological type-I

$b_{12}B_m^2$ is the partial regression effect on the mth quadratic of biological type-I

$b_{13}LB_{im}$ is the partial regression effect on the interaction of the ith live weight with the mth biological type-I

$b_{14}LB_m^2$ is the partial regression effect on the interaction of the ith live weight with the mth quadratic of biological type-I.

Model III in Method II was identical to Model II except that the former had four additional independent variables. These four variables were BT2 referring to biological type-II, $BT2^2$ referring to the quadratic of biological type-II, LW x BT2 referring to the interaction of live weight with biological type-II and LW x $BT2^2$ referring to the interaction of live weight with the quadratic of biological type-II.

Biological type-II refers to the physiological demand for energy. Montgomery and Baumgardt (1965) proposed that ruminants

consumed feed until the physiological demand for energy was satisfied. Feed intake data from 1120 steers of seven different breed groups (Smith et al., 1976) indicate that feed consumption (g/kg $W^{.73}$/day) was different from breed to breed (table 1). Also, data from a study by James Bond (personal communication) indicate differences in energy intake among breed groups (table 1).

These differences in feed intake capacity of breed groups listed in table 1 were interpreted as breed differences in physiological demand for energy. Feed intake data in table 1 could not be used as a measure of physiological demand for energy of breeds directly because the data came from two different studies. The feed intake data in table 1 were coded in order to make the two studies comparable. Since both studies had common breed groups, Hereford (H x H) and Angus (A x A), all feed intake data of other breeds were expressed as the ratio to the average feed intake of H x H and A x A groups within each study (table 1). These ratio values were referred to as BT2.

Model IV used to estimate the percent water loss in hot carcass was $Y_i = a + bP_i$ where

Y_i is the percent water loss in hot carcass

a is the intercept when the independent variable is zero

bP_i is the regression effect on the ith percent separable fat in the dissected cold carcass.

TABLE 1. FEED INTAKE (G/KG $W^{.73}$/DAY) OF DIFFERENT BREED GROUPS OF CATTLE AND CALCULATION OF BIOLOGICAL TYPE-II (BT2)

Breeds[a]	Feed intake (g/kg $W^{.73}$)		BT2[d]	
	Bond[b]	Smith[c]	Bond	Smith
H x H, A x A	110.4	110.86	1.000	1.000
H x A, A x H	--	113.98	--	1.028
C x H, C x A	--	111.20	--	1.003
J x H, J x A	--	112.50	--	1.015
SD x H, SD x A	--	115.10	--	1.038
Sm x H, Sm x A	--	116.10	--	1.047
L x H, L x A	--	109.60	--	.989
Ho x Ho	114.1	--	1.034	--
DS x DS	112.0	--	1.014	--
J x J	113.2	--	1.025	--

[a] H = Hereford, A = Angus, C = Charolais, J = Jersey, SD = South Devon, Sm = Simmental, L = Limousin, Ho = Holstein and DS = Dairy Shorthorn.

[b] James Bond (personal communication).

[c] Smith *et al*. (1976).

[d] Biological type-II expressing the physiological demand for energy of different breeds. The numeric number of BT2 for each breed group is the ratio of breed intake to the average of H x H and A x A intake within each study.

Gut Fill

Regression equation developed in Section I was used to estimate the gut fill of cattle.

Remainder

The remainder was indirectly estimated by subtracting hot carcass and gut fill from live weight. The percent subcomponents of remainder were estimated by using multiple curvilinear regression procedure presented by Draper and Smith (1968). The statistical model (Model V) was $Y_{ij} = a + b_1P_i + b_2P_i^2 + b_3D_j + b_4D_j^2 + b_5PD_{ij}$ where

Y_{ij} is the estimated % HIDE, % OF, % BO, % BONE and % SCRAPE

a is the intercept when all independent variables are zero

b_1P_i is the partial regression effect on the ith percent separable fat of dissected cold carcass

$b_2P_i^2$ is the partial regression effect on the quadratic of the ith percent separable fat

b_3D_j is the partial regression effect on the jth degree of maturity

$b_4D_j^2$ is the partial regression effect on the quadratic of the jth degree of maturity

b_5PD_{ij} is the partial regression effect on interaction of the ith percent separable fat with the jth degree of maturity.

Chemical Composition of Live Weight

The chemical composition refers to percent chemical water, percent chemical fat, percent chemical protein and percent chemical ash. Since live weight is composed of kg separable muscle (SM), separable bone (SB), separable fat (SF), hide and hair (HIDE), blood and organs (BO), offal fat (OF), bone from head and tail (BONE), scraped lean and fat from head, legs and tail (SCRAPE), water evaporated (WATER) and gut fill, a knowledge of chemical composition of each subcomponent will provide a means of estimating the chemical composition of whole body. Three statistical models were used to estimate the chemical composition of each body component except water evaporated and gut fill, which were not analyzed since the former was 100% chemical water and the latter was not a part of the body. Model VI was used to

estimate the chemical composition of separable muscle (SM) of dissected cold carcass, which was $Y_i = a + bP_i$ where

Y_i is the estimated chemical composition of separable muscle

a is the intercept when PSF_i is zero

bP_i is the regression effect on the ith percent separable fat in dissected cold carcass.

Model VII was used to estimate the chemical composition of separable fat (SF) of dissected cold carcass, which was $Y_i = a + b(\log_{10}P)$ where

Y_i is the predicted chemical composition of separable fat

a is the intercept when the independent variable is zero

$b(\log_{10}P)$ is the regression effect on the common logarithm of percent separable fat of dissected cold carcass.

Model V was used to estimate the chemical composition of HIDE, BO, OF and SCRAPE of remainder and that of bone from whole body. In physical study the bone (SB) in carcass and the bone (BONE) in remainder were classified as two different subcomponents of live weight. However, in estimating the chemical composition of bone, the total bone of live weight was not subdivided into SB in carcass and BONE in remainder. Data (Moulton et al., 1922b) used for regression analysis to estimate the chemical composition of bone included all the bone of body. Therefore, SB in dissected cold carcass and BONE in remainder were not differentiated in terms of the chemical composition.

Optimum Slaughter Age

A computer program was developed to simulate the efficiency of beef production from different breed types fed to various end points. The program estimates (1) voluntary feed intake of steers of different breeds during postweaning period fed on various diets, (2) physical and chemical composition of live weight, (3) calorific value of gain for different breed types of steers from weaning to slaughter, (4) the efficiency of feed conversion into body gain and (5) the optimum slaughter age of yielding maximum efficiency.

In Section IV of this study, optimum slaughter ages of Jersey, Angus-Hereford (equal number of Angus and Hereford mixture group), Dairy Shorthorn and Holstein breeds were estimated from computer program. The optimum slaughter age yielding maximum efficiency was determined as the age of calf when TDN required by the cow-calf pair to produce 1 kg of calf live weight was a minimum.

SECTION I

A MATHEMATICAL MODEL TO ESTIMATE VOLUNTARY FEED INTAKE FROM WEANING TO SLAUGHTER FOR CATTLE OF DIFFERENT BIOLOGICAL TYPE

Introduction

Voluntary feed intake is one of the important factors influencing efficiency of gain. Kleiber (1961) stated that total efficiency was higher with greater relative feed capacity within a given partial efficiency where the relative feed capacity was expressed as $I_{max}/W^{.75}$. I_{max} is maximum feed intake at ad libitum and $W^{.75}$ is metabolic weight.

Ad libitum voluntary feed intake varies with age of cattle (Holmes et al., 1961) and with energy density and/or crude fiber content of feed (Montgomery and Baumgardt, 1965; Nelson et al., 1968). Montgomery and Baumgardt (1965) proposed a graphical model illustrating the relationships between energy and feed intake and controlling mechanisms. However, no mathematical model has been reported in regard to voluntary feed intake of cattle of different breeds that vary in age and are fed different diets.

The purpose of this study was to develop a mathematical model to estimate voluntary feed intake from weaning to slaughter age for different types of cattle fed on various rations. The mathematical model included effects of difference in energy density and crude fiber content in ration, in degree of maturity of cattle and in biological types of cattle on feed intake.

Procedures and Source of Data

The graphical model proposed by Montgomery and Baumgardt (1965) illustrates the relationships between energy and feed intake and controlling mechanisms. To develop a series of mathematical equations estimating dry matter intake, feed intake regulated by chemostatic and/or thermostatic regulations was considered separately from feed intake regulated by distension of gastrointestinal tract (GIT). Voluntary feed intake was expressed as g dry matter per kg metabolic weight where metabolic weight was $W^{.73}$.

Feed Intake Regulated by Chemostatic and/or Thermostatic Mechanism

When dry matter intake is controlled by chemostatic and/or thermostatic regulations, the physiological demand for energy seems to be satisfied by voluntary feed intake. It has been found that ruminants have a capability of consuming enough feed to satisfy the physiological demand for energy even when the diets vary in caloric density (Baile and Pfander, 1967; Cowsert and Montgomery, 1969; Montgomery and Baumgardt, 1965; Nelson et al., 1968). Therefore, voluntary feed intake (VFI) was estimated from equation 1 as follows:

$$VFI_p = \frac{Energy_{PD}}{Energy_{DM}} \qquad (1)$$

where VFI_p is g of *ad libitum* dry matter intake per kg metabolic weight (g/kg $W^{.73}$) when feed intake is controlled by physiological demand for energy. $Energy_{PD}$ refers to physiological demand for energy per kg metabolic weight and $Energy_{DM}$ refers to kcal metabolizable energy per g dry matter of feed.

Since feed intake decreased with age of animals (Holmes _et al._, 1961), data from 1120 steers of 14 different biological types of cattle from Smith _et al._ (1976) were used in regression analysis to estimate the effect of degree of maturity on feed intake. The decrease in feed intake and/or energy intake with age was interpreted as the decrease in physiological demand for energy. Degree of maturity (DOM) is the term used by Brody (1945) and is calculated as follows:

$$DOM = \frac{\text{Current live weight}}{\text{Expected mature weight}} \qquad (2)$$

Physiological demand for energy referred to the maximum energy that the animal could consume from feed when the distension from GIT did not inhibit the maximum energy intake. Metabolizable energy per kg dry matter of feed was obtained from tables of N.R.C. (1970).

Feed Intake Regulated by Distension of GIT

Ruminants lose the capability of consuming enough feed to satisfy the maximum physiological demand for energy when the feed contains too much crude fiber. The voluntary intake of roughages and/or diets with high crude fiber depends on the rate of digestion, rate of excretion and dry matter digestibility (Elliott, 1963; Campling _et al._, 1961; Freer _et al._, 1962; Crampton, 1957; Blaxter _et al._, 1961; Freer and Campling, 1963).

When the distension of GIT controls feed intake, voluntary feed intake (VFI) would be equal to disappearing rate of ingesta. Thus, the disappearing rate is an estimate of VFI.

In order to derive a mathematical equation to estimate VFI, a series of logical steps were expressed as equations. First, if there were no digestion, no absorption and no excretion of feed after ruminants have consumed voluntarily an equal amount of feed per day (VFI) for several days (n), the relationship between gut fill of dry matter and VFI would be as follows:

$$GF_{dry} = n \times VFI \tag{3}$$

where GF_{dry} is gut fill in dry matter (g/kg $W^{.73}$). If we consider the rate of excretion of feed as a source of loss of digesta from GIT, gut fill will be less than that of equation 3 as follows:

$$GF_{dry} = \sum_{i=1}^{n} VFI \times (1 - ROE_i) \tag{4}$$

where ROE_i is the proportion of feed excreted at the ith day after consumption and $(1 - ROE_i)$ is the proportion of feed remaining in the gut. ROE_i will increase as i (number of days after feed intake) increases up to n. ROE_i can range from 0 to 1.0, where 0 is no excretion and 1.0 is complete excretion after ith day. If we consider the rate of disappearance of digesta due to digestion and absorption, then gut fill will be less than that of equation 4 as follows:

$$GF_{dry} = \sum_{i=1}^{n} VFI \times (1 = ROE_i) - \sum_{i=1}^{n} VFI \times (1 - ROE_i) \times ROD_i \times DD$$

$$= \sum_{i=1}^{n} VFI \times (1 - ROE_i) \times (1 - ROD_i \times DD) \tag{5}$$

where ROD_i is rate of digestion and DD is percent dry matter digestibility of feed. Since VFI is a constant representing average feed intake for a period of days, VFI can be located outside the Σ as follows:

$$GF_{dry} = VFI_d \times \sum_{i=1}^{n} (1 - ROE_i) \times (1 - ROD_i \times DD) \qquad (6)$$

$$VFI_d = \frac{GF_{dry}}{\sum_{i=1}^{n} (1 - ROE_i) \times (1 - ROD_i \times DD)} \qquad (7)$$

where VFI_d is the VFI regulated by GIT distension. Knowledge of rate of excretion at ith day (ROE_i), rate of disappearance due to digestion and absorption (ROD_i), percent dry matter digestibility (DD) of feed and gut fill in dry matter (GF_{dry}) is required to estimate VFI_d from equation 7.

Gut Fill

Gut fill data from the literature are listed in table 2. A multiple regression analysis was made to estimate wet gut fill (g/kg $W^{.73}$), where independent variables were percent crude fiber, degree of maturity and an interaction term between percent crude fiber and degree of maturity. The regression model was $Y = a + b_1C_i + b_2D_j + b_3CD_{ij}$ where

Y is the estimated wet gut fill (g/kg $W^{.73}$)

a is the intercept when all independent variables are zero

b_1C_i is the partial regression effect on the ith percent crude fiber in diet

TABLE 2. GUT FILL (G/KG $W^{.73}$) AFFECTED BY PERCENT CRUDE FIBER IN DIETS AND DEGREE OF MATURITY OF STEERS

Gut fill	Crude fiber in diet (CF)[a] (%)	Degree of maturity (DOM)	CF x DOM	Live weight (kg)	Age (month)	Reference
736	24.0	.275[b]	6.60	227.9		Haecker (1920)
907	23.9	.329[b]	7.86	272.8		
789	23.1	.343[b]	7.92	316.7		
782	21.6	.437[b]	9.44	363.0		
733	21.7	.493[b]	10.70	408.9		
659	22.4	.547[b]	12.25	453.9		
639	22.2	.601[b]	13.34	499.0		
521	21.5	.656[b]	14.10	544.3		
652	22.9	.710[b]	16.26	589.7		
718	23.0	.765[b]	17.60	635.0		
602	19.2	.820[b]	15.74	680.4		
659	13.8	.175[c]	2.42	204.9	5	Moulton *et al.* (1922a)
709	13.8	.282[c]	3.89	206.2	8	
522	13.8	.348[c]	4.80	323.8	10	
586	13.8	.367[c]	5.06	313.3	10.6	
607	13.8	.567[c]	7.82	517.1	17.7	
519	13.8	.637[c]	8.79	526.2	20.9	
573	13.8	.840[c]	11.59	743.4	33.6	
450	13.8	.876[c]	12.09	690.7	38.7	
415	13.8	.880[c]	12.14	842.8	39.5	
594	13.8	.909[c]	12.54	853.0	44.5	
485	13.8	.924[c]	12.75	883.5	47.0	

[a] Percent crude fiber in diet was estimated from tables of N.R.C. (1970).

[b] Degree of maturity was calculated by dividing live weight by estimated mature weight. Estimated mature weight was considered to be 830 kg, since each weight class included varying numbers of steers from Angus, Hereford and Shorthorn breeds.

[c] Degree of maturity was estimated from regression equation, DOM = $.007 + .3566 \times (\log_{10}\text{Age})^2$. This regression equation was developed using data reported by Brody (1945). Coefficient of determination associated with this prediction equation was .943.

b_2D_j is the partial regression effect on the jth degree of maturity of cattle

b_3CD_{ij} is the partial regression effect on the interaction term of the ith percent crude fiber with the jth degree of maturity.

To estimate GF_{dry} from wet gut fill, the percent dry matter in gut fill was required. Data (table 3) from Bines and Davey (1970) were used for a simple linear regression analysis to estimate percent dry matter of gut fill, where the independent variable was common logarithm of percent crude fiber of diet.

Dry Matter Digestibility

Data from several experiments (table 4) were used in simple linear regression analysis to estimate the percent dry matter digestibility (DD) of various feeds, where CF was an independent variable.

Rate of Excretion of Digesta as Feces

Review of literature concerning excretion rate of digesta (Balch, 1950; Blaxter *et al*., 1961; Campling and Freer, 1966; Campling *et al*., 1961; Castle, 1956) indicated that (1) the cumulative percent excretion of various feeds followed a sigmoid curve, (2) the excretion curves for various feeds were common in respect that the first 5% excretion occurred slowly, then from 5% to 80% the curves rose rapidly and thereafter the curves gradually flattened and (3) the rate of excretion became slower as the percent crude fiber of feed increased.

TABLE 3. PERCENT DRY MATTER OF GUT FILL AND PERCENT CRUDE FIBER IN DIET[a]

Percent dry matter			Crude fiber in diet	
Before meal	After meal	Mean	%	log (CF)
7.9	11.2	9.6	8.05	.905796
9.2	13.2	11.2	16.22	1.210051
10.3	14.9	12.6	25.24	1.402089
10.6	15.0	12.8	32.47	1.511482

[a] From Bines and Davey (1970).

TABLE 4. DRY MATTER DIGESTIBILITY (%) AND PERCENT CRUDE FIBER IN DIET

Crude fiber (%)	Dry matter digestibility (%)	Reference
3.6	80.0	Stobo et al. (1966)
24.3	57.6	
21.4	67.4	Campling and Freer (1966)
44.7	43.7	
5.3	88.0	Jahn et al. (1970)
10.5	78.0	
17.3	70.0	
22.4	64.0	
26.5	57.5	
31.5	61.8	
32.5	55.1	Bines and Davey (1970)
25.2	59.1	
16.2	69.1	
8.1	80.6	
40.9 urea[a]	47.3	Campling et al. (1962)
40.9	39.3	

[a] Urea was added through rumen fistula.

The procedure illustrated by Croxton et al. (1967) was used to express the cumulative percent excretion rate in the form of a Gompertz curve. The Gompertz curve formula was $Y = ka^{b^X}$ where

Y is the estimated (dependent variable) cumulative percent excretion

k is a constant representing the upper limit

a is a constant which permits Y to be any value from the upper limit of k to the lower limit of zero

b is a constant indicating the rate of increase with each coded X value

X is the independent variable coded from 0 to 14 in this study.

Data available in the literature for fitting the Gompertz curve were coded 0 to 14 by dividing the total time taken from 2% excretion to 100% excretion of digesta as feces into 14 equal intervals (table 5). The 15 mean cumulative excretion percentages and X values in table 5 were used to obtain the general cumulative excretion equation (GCEE) of digesta. The GCEE can be used for various feedstuffs if the time in hours per X (H_X) and the time in hours (H_I) taken from feeding to excreting initial 2% can be defined. Linear regression analysis of the data in table 6 was used to estimate H_X for various feeds, where the independent variable was percent crude fiber (CF) of feed. Data cited in table 7 were used to estimate H_I, where the independent variable was percent crude fiber of diet.

TABLE 5. CODED X VALUES FROM 0 TO 14 AND CUMULATIVE PERCENT EXCRETION FOR EACH X VALUE FOR TWO DIFFERENT FEEDS[a]

Coded X values	Cumulative percent excretion of digesta: Hay	Concentrate	Mean
0	2	2	2
1	13	7	10
2	31	15	23
3	54	35	44.5
4	65	48	56.5
5	75	61	68
6	85	76	79.5
7	87	86	86.5
8	91	90	90.5
9	94	94	94
10	96	96	96
11	98	97	97.5
12	99	98	98.5
13	99.5	99.5	99.5
14	100	100	100

[a] Data from Balch (1950).

TABLE 6. LENGTH OF TIME PER CODED X (H_X) AND PERCENT CRUDE FIBER OF DIET

Length of time per coded X (hours)	Crude fiber (%)	Reference
9.6	44.7	Campling and Freer (1966)
7.2	21.4	
3.8	5.6[a]	Balch (1950)
8.6	35.8[b]	

[a] Estimated percent crude fiber. Concentrate with 20% crude protein for lactating dairy cows assumed to be composed of 30% wheating, 20% decorticated cottonseed meal, 47.5% maize meal and 2.5% mineral and salt. These proportions of ingredients were estimated values.

[b] Orchard hay with full bloom was considered to be the meadow hay reported by Balch (1950).

TABLE 7. TIME IN HOURS (H_T) TAKEN FROM FEEDING TO THE TIME OF EXCRETING 2% AND 5% DIGESTA AND PERCENT CRUDE FIBER OF DIET

Feeds	Crude fiber (%)	Time taken for 2% excretion (hours)	Time taken for 5% excretion (hours)	Reference
Dried grass	21.4	19.6[a]	25	Campling and
Oat straw	44.7	28.3[a]	36	Freer (1966)
Hay	35.8[b]	20	26	Balch (1950)
Concentrate	5.6[c]	16	20	

[a] 2% excretion time was estimated by multiplying 5% excretion time by .785 (Balch, 1950).

[b] Estimated percent crude fiber as b in table 6.

[c] Estimated percent crude fiber as a in table 6.

Rate of Digestion

Bines and Davey (1970) and Topps *et al*. (1968) expressed rate of dry matter digestion as proportion digested of all digestible dry matter of feed at different locations of the digestive system. Topps *et al*. (1968) reported that 69 and 31% of total digestible dry matter of concentrate were digested in the forestomach and intestine, respectively, and 67 and 33% of total digestible dry matter of hay diet were digested in the forestomach and intestine, respectively. Bines and Davey (1970) found that average retention time of food in the rumen and hind gut were 76 and 24% of total retention time of the digestive system, respectively, and 71 and 29% of total dry matter digestion occurred in the rumen and hind gut, respectively. At the end of mean retention time, 100% of digestible dry matter was digested.

When it was assumed that feed particles fed at one feeding traveled together throughout the digestive system, the rate of dry matter digestion (ROD) could be expressed as follows:

$$ROD_i = a + b_1 \times (\frac{RT_i}{MRT} \times 100) + b_2 \times CF_j \qquad (8)$$

where ROD_i is estimated rate of digestion (dependent variable), varying from 0 to 1 with 0 indicating no dry matter digestion and 1 indicating 100% digestion of digestible dry matter; a is the intercept when independent variables are zero; b_1 is the partial linear regression of ROD on retention time (RT_i) expressed as a percent of mean retention time (MRT) and $b_2 \times CF_j$ is the partial linear regression effect of ROD on the jth percent crude fiber of diets.

An equation was obtained from a multiple regression analysis by using data in table 8. The dependent variable was percent digested of total digestible dry matter of feed and the independent variables were percent retention time divided by mean retention time of the feed and percent crude fiber of diet.

Unfortunately, feed particles from one feeding travel throughout the GIT with different speeds, resulting in feed reaching different locations of the digestive system within a given length of time after feeding and excretion as feces over a period of several days. Therefore, the MRT developed by Castle (1956) does not accurately estimate the rate of digestion when excretion rate of feed particles of one feeding was differentiated with GCEE curve. Partial mean retention time (PMRT) was developed to be used in place of MRT of equation 8 and was defined as the mean retention time of feed particles of one feeding within certain intervals of time from feeding to excretion time. MRT developed by Castle (1956) referred to the average retention time of feed excreted from 0 to 100% of excretion curve as shown in diagram A

TABLE 8. PERCENT OF RETENTION TIME TO MEAN RETENTION TIME (% RT/MRT) AND PERCENT DIGESTED TO TOTAL DIGESTIBLE DRY MATTER OF FEEDS VARYING IN CRUDE FIBER CONTENTS[a]

Crude fiber (%)	RT/MRT (%)	Percent digested of total digestible dry matter
32.47	72.7	60.4
32.47	100.0	100.0
25.25	79.3	69.0
25.25	100.0	100.0
16.22	80.9	74.4
16.22	100.0	100.0
8.05	68.8	80.6
8.05	100.0	100.0

[a] Data from Bines and Davey (1970).

of figure 1. PMRT for one feeding can be expressed for different periods such as $PMRT_{0-100}$, $PMRT_{0-50}$ and $PMRT_{50-100}$. $PMRT_{0-100}$ is identical to MRT of Castle (1956) except for the differences in calculating methods as shown in diagrams A and B of figure 1. $PMRT_{0-50}$ referred to the mean retention time of feed particles excreted from 0 to 50% of excretion curve (diagram C of figure 1) and $PMRT_{50-100}$ referred to the mean retention time of feed particles excreted from 50 to 100% of excretion curve (diagram D of figure 1). Placing $PMRT_{i-j}$ in the position of MRT of equation 8 resulted in equation 9 as follows:

$$ROD_i = a + b_1 \times \frac{RT_i \times 100}{PMRT_{i-j}} + b_2 \times CF \qquad (9)$$

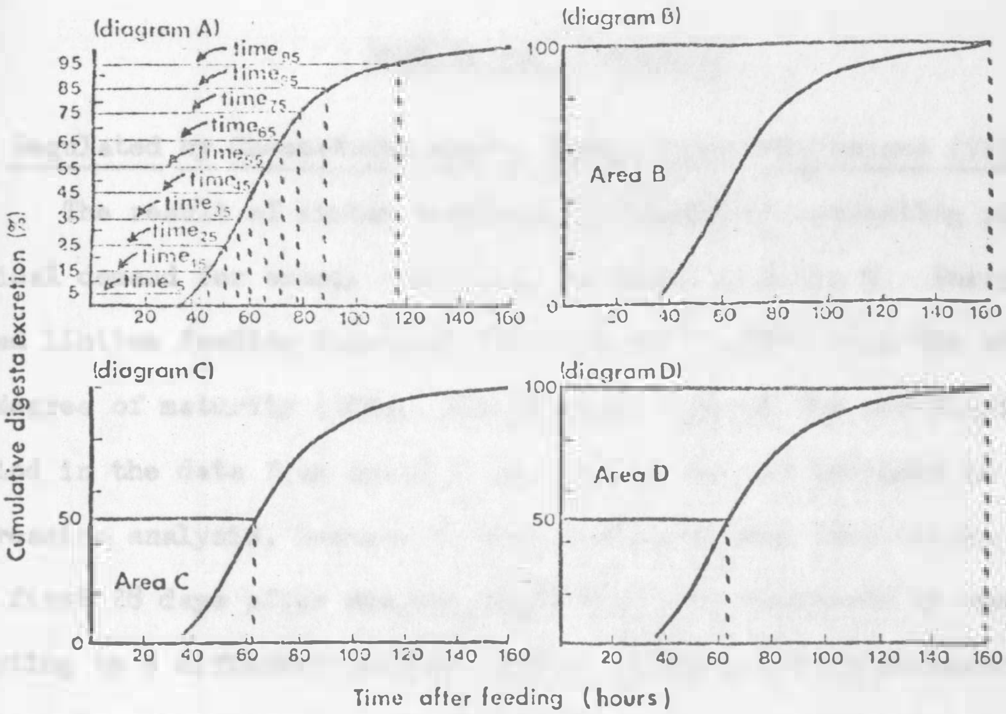

Diagram A. MRT was estimated from the 'R' value which was proportional to the area to the left of the curve, which was calculated by adding together the times of excretion from 5 to 95% at intervals of 10%, taken from the graph, and dividing the sum (R) by 10.

$$MRT = \frac{R}{10} = \frac{\text{time 5} + \text{time 15} + \text{time 25} + \ldots + \text{time 95}}{10}$$

(Castle, 1956)

Diagram B. $PMRT_{0-100}$ (partial mean retention time of feed particles excreted from 0 to 100% of excretion curve) was estimated by dividing Area B by the difference between 100 and 0% of cumulative percent excretion.

$$PMRT_{0-100} = \frac{\text{Area B}}{100-0} = \frac{\text{Area B}}{100}$$

Diagram C.

$$PMRT_{0-50} = \frac{\text{Area C}}{50-0} = \frac{\text{Area C}}{50}$$

Diagram D.

$$PMRT_{50-100} = \frac{\text{Area D}}{100-50} = \frac{\text{Area D}}{50}$$

Figure 1. Methods of estimating mean retention time (MRT) developed by Castle (1956) in diagram A and of estimating partial mean retention time (PMRT) in diagrams B, C and D.

Results and Discussion

VFI Regulated by Chemostatic and/or Thermostatic Mechanisms (VFI_p)

The result of linear regression analysis of estimating physiological demand for energy ($Energy_{PD}$) is shown in table 9. Energy intake at ad libitum feeding decreased linearly ($r^2 = .987$) with the advance in degree of maturity (DOM). The first 28 days of the postweaning period in the data from Smith et al. (1976) was not included in the regression analysis, because it was considered that feed intake during the first 28 days after weaning might have been depressed by reason of adapting to a different feeding system. Hodgson (1971) indicated that it took 3 weeks for calves to develop most changes in the relative weights of the alimentary tract and their contents after weaning. The regression equation (10) developed to estimate $Energy_{PD}$ is shown in table 9.

Equation 1 developed to estimate VFI when chemostatic and/or thermostatic mechanisms regulate was:

$$VFI_p = \frac{Energy_{PD}}{Energy_{DM}} \qquad (1)$$

Since $Energy_{PD} = 424.1 - 265.6 \times DOM$ (from table 9), VFI_p can be estimated from equation 11 as follows:

$$VFI_p = \frac{424.1 - 265.6 \times DOM}{Energy_{PD}} \qquad (11)$$

VFI Regulated by Distension of GIT (VFId)

Results of regression analyses of estimating gut fill (g/kg $W^{.73}$), dry matter digestibility of various feeds, percent dry matter in gut fill, H_X in GCEE, rate of digestion (ROD) and H_I are

TABLE 9. RESULTS OF REGRESSION ANALYSES OF ESTIMATING $ENERGY_{PD}$, GUT FILL (G/KG $W^{.73}$), PERCENT DRY MATTER (DM) IN GUT FILL, PERCENT DRY MATTER DIGESTIBILITY OF VARIOUS FEEDS (DD), H_X IN GCEE, RATE OF DIGESTION (ROD) AND TIME IN HOURS (H_I) TAKEN FROM FEEDING TO EXCRETING INITIAL 2% OF DIGESTA

Dependent variables	N[a]	r^2	Intercept	Regression coefficients: CF[b]	$Log_{10}CF$	DOM[c]	CF x DOM	RT/MRT[d]	Equation number
$Energy_{PD}$	7	.987	424.1	--	--	-265.6	--	--	10
Gut fill (g/kg $W^{.73}$)	22	.720[e]	359.9	23.4	--	--	-15.0	--	12
Percent dry matter in gut fill	4	.986	4.58	--	5.54	--	--	--	13
Percent DM digestibility (DD)	16	.934	88.0	-1.047	--	--	--	--	14
H_X of GCEE	4	.962	3.4	.145	--	--	--	--	15
ROD of digesta	8	.872[e]	.191	-.46	--	--	--	1.08	16
H_I for 2% excretion	4	.774	13.8	.267	--	--	--	--	17

[a] Number of observations.

[b] Percent crude fiber in diets.

[c] Degree of maturity.

[d] Percent of retention time (time in hours from the time of feeding to present time) to mean retention time of feeds.

[e] R^2.

shown in table 9. Wet gut fill increased linearly with percent crude fiber (CF) of feeds and decreased linearly with degree of maturity of steers (R^2 = .720), percent dry matter digestibility decreased linearly with the increase in crude fiber of feeds (r^2 = .934) and percent dry matter in gut fill increased linearly with common logarithm of percent crude fiber of feeds (r^2 = .986). H_X of GCEE and H_I of feed increased linearly with the increase in percent crude fiber, where r^2 values were .962 and .774, respectively. Rate of digestion increased linearly as RT/MRT approached 100 and decreased as CF of diet increased (R^2 = .872). The number of observations used in the regression analyses was small, especially for percent dry matter of gut fill, H_X of GCEE and H_I for 2% excretion shown in table 9.

GCEE fitted to the Gompertz curve was $ROE_i = 100 \times (.025)^{(.6334)^X}$ where X was the coded values from 0 to 14. GCEE was not developed to estimate cumulative percent excretion at X_i but to estimate the cumulative percent excretion at the end of ith day after feeding. Therefore, GCEE was expressed such that providing the number of days and CF in diet would result in the estimation of cumulative percent excretion as follows:

Since $X = \dfrac{DAY_i \times 24 - H_I}{H_X}$, $H_X = 3.4 + .145 \times CF$ and

$H_I = 13.8 + .267 \times CF$,

$$ROE_{ij} = 100 \times .025^{.6334^{\left(\frac{DAY_i \times 24 - 13.8 - .267 \times CF_j}{3.4 + .145 \times CF_j}\right)}} \qquad (18)$$

where DAY_i is the ith day after feeding, $DAY_i \times 24$ (hours) is the

number of hours from the time of feeding to the end of ith day and $DAY_i \times 24 - H_I$ is the number of hours from the time of 2% excretion to the end of ith day. Since excretion is considered to start at H_I, ROE_{ij} of equation 18 should be set to zero when $DAY_i \times 24 < H_I$. The estimated cumulative percent excretion of digesta for 7 1/2 days after feeding and for diets varying in crude fiber contents from 5 to 45% calculated from equation 18 are shown in figure 2.

The mathematical equation for estimating partial mean retention time (PMRT) is as follows (figure 3):

$$PMRT_{Y_i - Y_j} = \frac{\text{Area A} + \text{Area B}}{Y_j - Y_i}$$

$$= \frac{\text{Area A}}{Y_j - Y_i} + \frac{\text{Area B}}{Y_j - Y_i}$$

$$= H_I + \frac{\text{Area B}}{Y_j - Y_i}$$

where $Y_j > Y_i$ and Y_j and Y_i are the cumulative percent excretion at given X_j and X_i of GCEE, respectively. Coded X value, $\frac{\text{Area B}}{Y_j - Y_i}$, was multiplied by the number of hours in each unit of X (H_X) as follows:

$$PMRT_{Y_j - Y_i} = H_I + \frac{\text{Area B}}{Y_j - Y_i} \times H_X$$

$$PMRT_{Y_j - Y_i} = H_I + \text{Area B} \left(\frac{3.4 + .145 \times CF}{Y_j - Y_i}\right) \qquad (19)$$

Area B can be estimated as illustrated in figure 3 as follows:

$$\text{Area B} = Y_j \times X_j - Y_i \times X_i - \text{Area C}$$

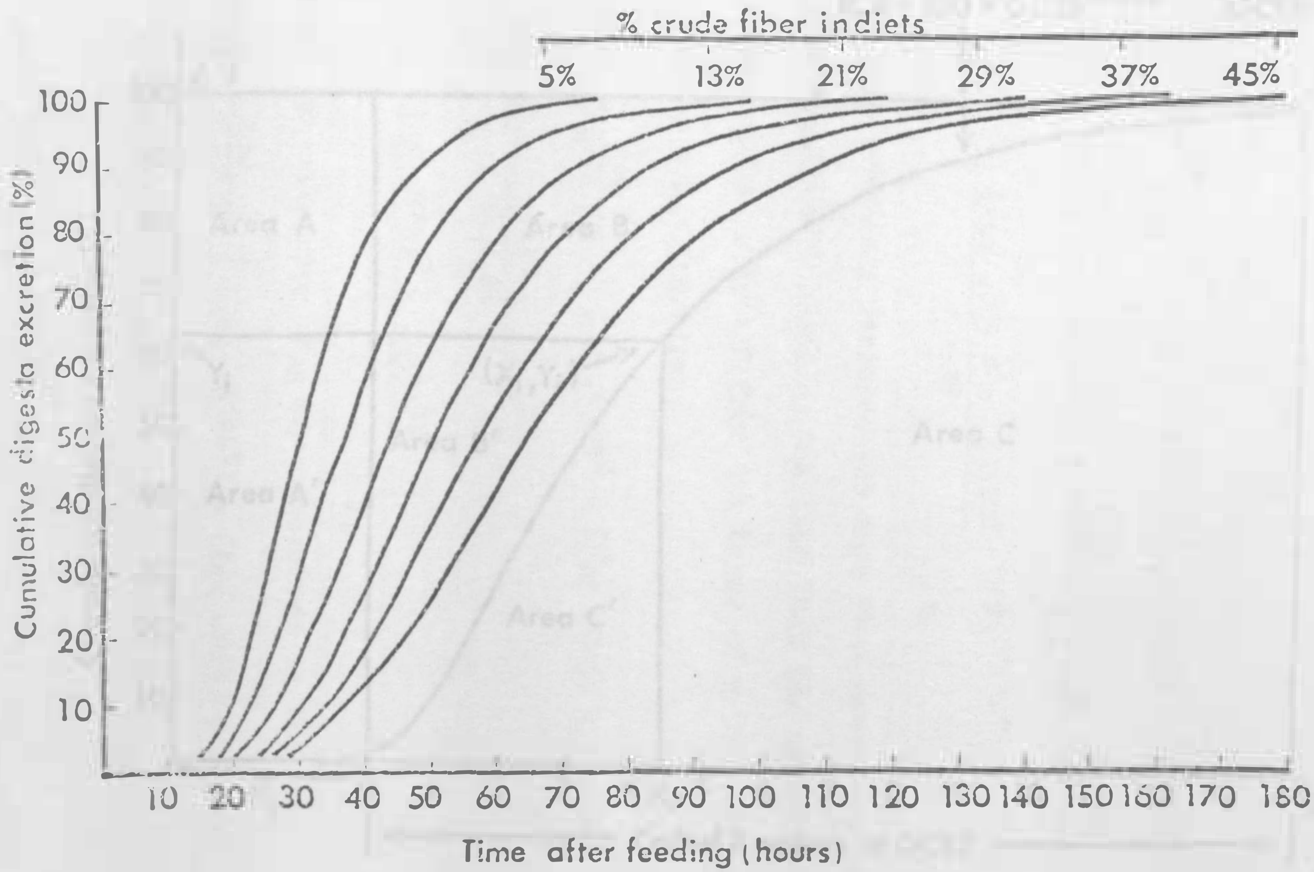

Figure 2. Estimated cumulative percentage excretion of digesta for various diets.

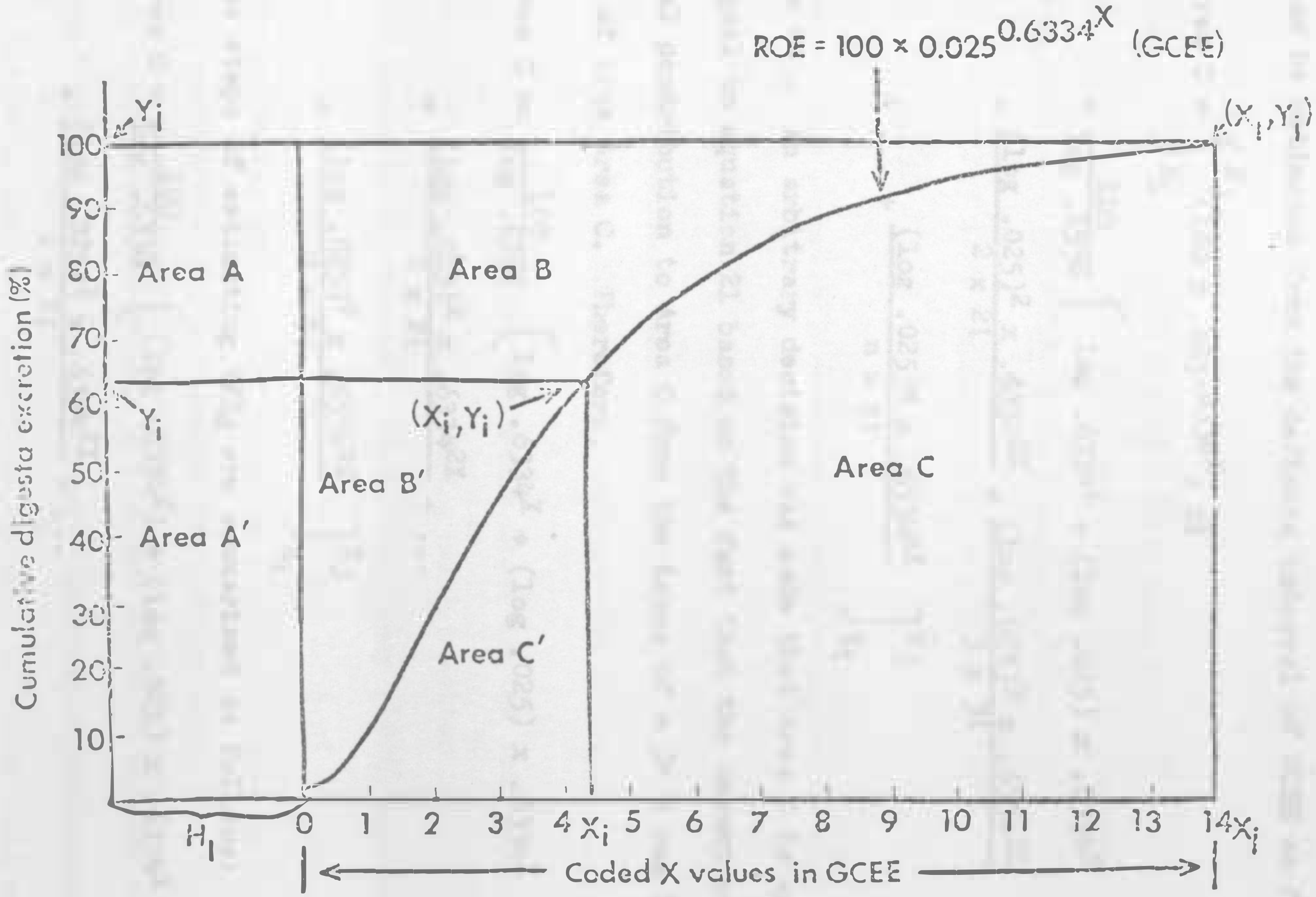

Figure 3. Illustration of excretion curve and the partial mean retention time (PMRT) of feed.

Area C can be estimated from the definite integral of GCEE as follows:

$$\text{Area C} = \int_{X_i}^{X_j} (100 \times .025^{.6334^X})\, dX$$

$$= \frac{100}{\log .6334} \Big[\log .6334^X + (\log .025) \times .6334^X + \frac{(\log .025)^2 \times .6334^{2X}}{2 \times 2!} + \frac{(\log .025)^3 \times .6334^{3X}}{3 \times 3!} + \ldots + \frac{(\log .025)^n \times .6334^{nX}}{n \times n!} \Big]_{X_i}^{X_j} \quad (20)$$

where $n = \infty$. An arbitrary decision was made that Area C is approximately equal to equation 21 based on the fact that the amount of additional contribution to Area C from the terms of $n > 9$ was less than .5% of true Area C. Therefore,

$$\text{Area C} \approx \frac{100}{\log .6334} \Big[\log .6334^X + (\log .025) \times .6334^X + \frac{(\log .025)^2 \times .6334^{2X}}{2 \times 2!} + \ldots + \frac{(\log .025)^9 \times .6334^{9X}}{9 \times 9!} \Big]_{X_i}^{X_j} \quad (21)$$

The steps of estimating VFI_d are summarized as follows:

$$\text{Area C} = \frac{100}{\log .6334} \Big[(\log .6334^X) + (\log .025) \times .6334^X + \frac{(\log .025)^2 \times .6334^{2X}}{2 \times 2!} + \ldots + \frac{(\log .025)^9 \times .6334^{9X}}{9 \times 9!} \Big]_{X_i}^{X_j} \quad (21)$$

where $X_j = 14$ and $0 < X_i < 14$.

$$\text{Area B} = Y_j \times X_j - Y_i \times X_i - \text{Area C}$$

where $Y_j = 100$ and $Y_i = 100 \times .025^{.6334X_i}$.

$$PMRT_{Y_i - Y_j} = H_I + \frac{3.4 + .145 \times CF}{Y_j - Y_i} \times \text{Area B} \qquad (19)$$

$$ROD_{ik} = .191 - .46 \times CF_k + 1.08 \times \frac{DAY_i \times 24}{PMRT_{Y_i - Y_j}} \qquad (22)$$

$$GF_{dry} = (359.9 + 23.4 \times CF - 15 \times CF \times DOM) \times (4.58 + 5.54 \times \log_{10} CF)/100$$

$$ROE_{ik} = 100 \times .025^{.6334 \frac{(DAY_i \times 24 - 13.8 - .267 \times CF_k)}{3.4 + .145 \times CF_k}} \qquad (18)$$

$$DD = 88.0 - 1.047 \times CF$$

$$VFI_d = \frac{GF_{dry}}{\sum_{i=1}^{n} (1 - ROE_{ik}) \times (1 - ROD_{ik} \times DD)}$$

VFI_d estimated from the procedure above is the voluntary feed intake from feeding 5 hours a day. Kilogram dry matter intake per day varied with frequency of feeding. Bines and Davey (1970) observed that cattle fed for 24 hours a day consumed 148% and 105% of dry matter consumption by cattle fed 5 hours a day on a 100% concentrate diet and on a 50% concentrate diet, respectively, which indicates that the reduction in dry matter intake due to limited hours of feeding per day increased as the proportion of concentrate in diet increased. Regression analysis was used to develop equation 23 using data reported by Mohrman et al. (1959), Campbell and Merilan (1961) and Bines and Davey (1970). The dependent variable (Y) was dry matter consumption of cattle fed 24 hours a day expressed as percent of dry matter intake of cattle fed 5 to 8 hours a day, and the independent variable was the

common logarithm of percent crude fiber of diet. The resulting equation ($r^2 = .843$) was:

$$Y = 213.8 - 79.8 \times \log_{10} CF \qquad (23)$$

Therefore, VFI_d from feeding 24 hours a day was estimated by the converting factor (Y) from equation 23 times equation 7 as follows:

$$VFI_d = \frac{GF_{dry}}{\sum_{i=1}^{n} (1 - ROE_i) \times (1 - ROD_i \times DD)} \times \frac{Y}{100} \qquad (24)$$

Breed Differences in VFI

Karue et al. (1972) reported that Zebu type cattle had higher VFI than British breeds on roughage diets. On the contrary, on high concentrate diets British breeds had higher VFI than Brahman and Brahman-British crosses (Rogerson et al., 1968; Frisch and Vercoe, 1969; Ledger et al., 1970). It was interpreted that British breeds might have higher physiological demand for energy and lower capacity for roughage than Brahman and Brahman crosses. Because of this interaction of breeds with quality of feeds on VFI, breed differences in roughage intake were dealt with separately from the breed differences in intake of high concentrate diet.

Breed Differences in VFI_p (BD_{VFI_p}). Analysis of data from Smith et al. (1976) indicated that there were significant differences ($P < .05$) in feed intake among seven breed groups (table 10). The breed differences in VFI_p were expressed as the ratio of feed intake of each breed group to the mean feed intake of Angus and Hereford as shown in table 11.

TABLE 10. LEAST SQUARES ANALYSIS OF VARIANCE FOR THE EFFECTS OF YEAR, BREED AND DEGREE OF MATURITY ON FEED INTAKE

Source of variation	df	Mean square
Total	350	
Year	2	6374.679***
Breed	6	433.856*
Replicates	1	149.242[a]
Year x breed	12	190.756[a]
Year x replicates	2	125.796[a]
Breed x replicates	6	93.665[a]
DOM[b] (linear)	1	538.027*
DOM (quadratic)	1	595.452*
DOM (cubic)	1	538.947*
Remainder	317	102.494

* $P < .05$.
*** $P < .001$.
[a] Nonsignificant.
[b] DOM refers to degree of maturity of cattle.

TABLE 11. BREED DIFFERENCES IN FEED INTAKE ON HIGH CONCENTRATE DIETS[a]

Breeds[b]	Feed intake[c]	BD_{VFI_p}[d]
H x H, A x A	110.86	1.000
H x A, A x H	113.98	1.028
C x H, C x A	111.20	1.003
J x H, J x A	112.50	1.015
SD x H, SD x A	115.10	1.038
Sm x H, Sm x A	116.10	1.047
L x H, L x A	109.60	.989

[a] Data from Smith et al. (1976).
[b] H = Hereford, A = Angus, C = Charolais, J = Jersey, SD = South Devon, Sm = Simmental and L = Limousin.
[c] Grams dry matter per kg metabolic weight ($W^{.73}$).
[d] Breed difference in VFI_p, expressed as a ratio to the average of H x H and A x A.

Breed Differences in VFI_d (BD_{VFI_d}). Breed differences in feed intake when the distension of GIT regulates were observed in the study by James Bond (personal communication), where all roughage diets were fed to five breeds. Breed differences were expressed as the ratio of feed intake of each breed to the mean of four breeds as shown in table 12.

Considering the research results by Callow (1961) indicating no breed differences in gut fill (g/kg $W^{.73}$), the breed differences in roughage intake in table 12 might have been caused by breed differences in rate of digestion and rate of excretion of roughage.

Relationship Between VFI_p and VFI_d

Voluntary feed intake can be estimated by equations 11 and 24. When the estimated VFI_p and VFI_d are not equal, the smaller one was considered to be the true voluntary feed intake (VFI_t). VFI_t will be 100 g if VFI_d is 100 g/kg $W^{.73}$ and VFI_p is 120 g/kg $W^{.73}$ because the capacity of GIT to distend is lower than the physiological demand for energy. If satiety signal comes from GIT distension first before physiological demand for energy is satisfied, VFI_t will be equal to VFI_d, while, if inhibitory signal originated from chemostatic and/or thermostatic first, VFI_t will be the same as VFI_p. When VFI_d is equal to VFI_p, the dry matter intake will be the maximum.

Since the process of estimating VFI_t is rather tedious, especially in the estimation of VFI_d, a computer program was written to be used in estimating VFI_t for cattle varying in degree of maturity and breed type and fed on different diets. VFI_p, VFI_d, VFI_t and energy

TABLE 12. BREED DIFFERENCES IN FEED INTAKE ON ALL HAY DIETS[a]

Breeds	N[b]	Feed intake[c]	BD_{VFI_d}[d]
Angus	4[e]		
Hereford	8	100.6	.901
Dairy Shorthorn	16	111.8	1.002
Jersey	14	116.9	1.047
Holstein	20	116.1	1.040
Mean		111.6	1.000

[a] James Bond (personal communication).
[b] Number of steers.
[c] Grams dry matter per kg metabolic weight ($W^{.73}$).
[d] Breed difference in VFI_d, expressed as a ratio to the mean.
[e] Angus was not included in calculating mean feed intake because of small number of steers involved.

intake for steers of six different degrees of maturity fed on 10 different diets were estimated. In the computer estimation BD_{VFI_p} and BD_{VFI_d} were .980 and 1.000, respectively. The estimated VFI_p and VFI_d are shown in figure 4 and the estimated VFI and energy intake are shown in figure 5. Estimated VFI_p values from equation 11 increased curvilinearly as the energy density of diet decreased (figure 4). Estimated VFI_d values decreased curvilinearly as the crude fiber diets increased. These curvilinearities of VFI_p and VFI_d were not in agreement with the linearity suggested by Montgomery and Baumgardt (1965). The intersection of VFI_p and VFI_d as shown in figure 4 is the point at which feed intake is regulated both by GIT distension and chemostatic and/or thermostatic mechanisms at the same time, and at this point the maximum dry matter intake occurs.

Maximum dry matter intake occurred on diets with 2.81, 2.76, 2.73, 2.68, 2.58 and 2.54 kcal metabolizable energy (ME) per g dry

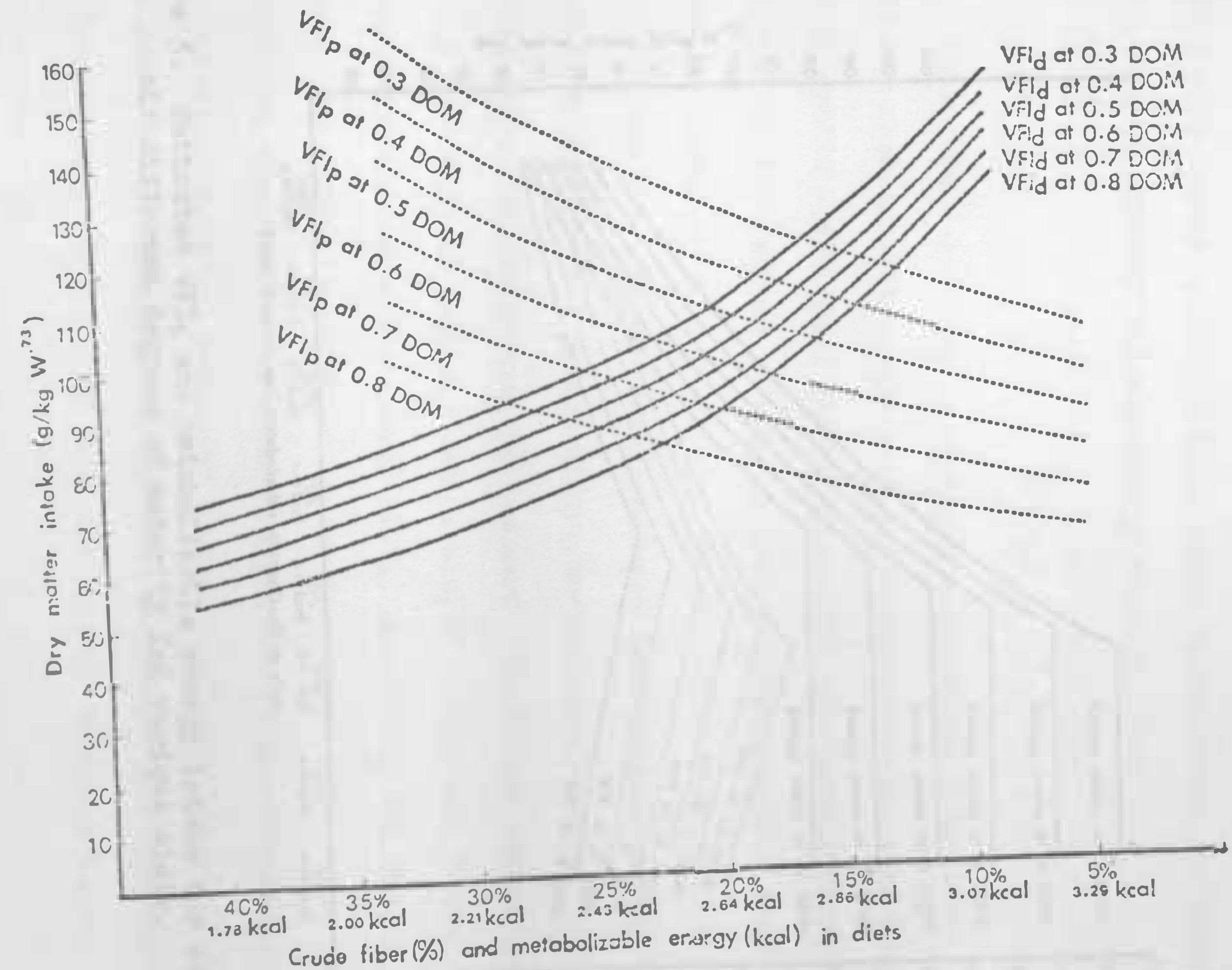

Figure 4. Estimated VFI_p and VFI_d for cattle of six different degrees of maturity fed various diets.

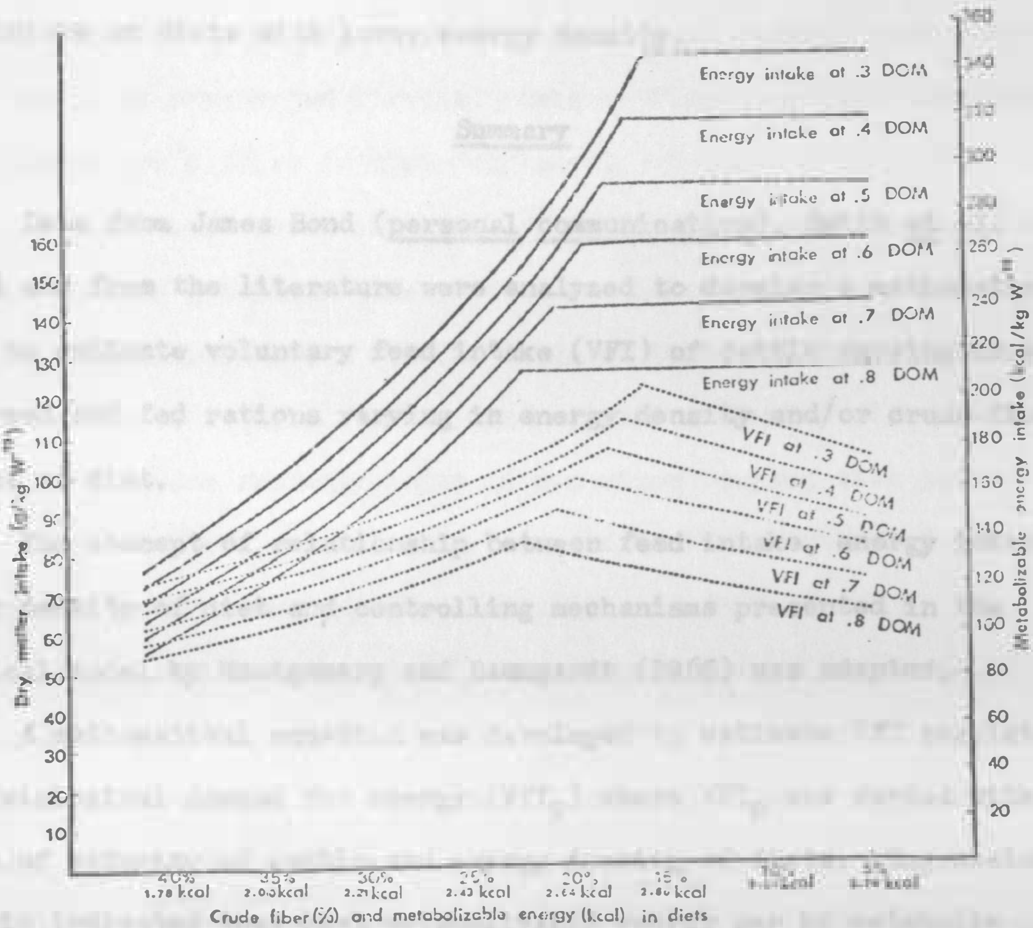

Figure 5. Estimated VFI_t and metabolizable energy intake for cattle of six different degrees of maturity fed various diets.

matter for cattle with .3, .4, .5, .6, .7 and .8 degree of maturity, respectively. McCullough (1969) has observed a similar result from an experiment in which younger cattle tended to achieve maximum feed intake on diets with higher energy density, while older cattle had maximum feed intake on diets with lower energy density.

Summary

Data from James Bond (personal communication), Smith et al. (1976) and from the literature were analyzed to develop a mathematical model to estimate voluntary feed intake (VFI) of cattle varying in age and breed and fed rations varying in energy density and/or crude fiber content of diet.

The concept of relationship between feed intake, energy intake, energy density of diet and controlling mechanisms presented in the graphical model by Montgomery and Baumgardt (1965) was adopted.

A mathematical equation was developed to estimate VFI regulated by physiological demand for energy (VFI_p) where VFI_p was varied with degree of maturity of cattle and energy density of diets. Regression analysis indicated that kcal metabolizable energy per kg metabolic weight (kcal ME/kg $W^{.73}$) decreased as degree of maturity of cattle increased. It was interpreted that the decrease in energy intake per kg metabolic weight was due to decrease in physiological demand for energy with aging.

Another mathematical equation was derived to estimate VFI controlled by gastrointestinal tract (GIT) distension (VFI_d) based on

the rate of disappearance of digesta from GIT. The rate of disappearance varied with rate of digestion, rate of excretion of undigested material, dry matter digestibility of feeds and gut fill in dry matter. Rate of digestion increased linearly with the increase of retention time of digesta in GIT expressed as a percent of partial mean retention time (PMRT) of unexcreted digesta. Rate of digestion also increased as the percent crude fiber in diet decreased.

Partial mean retention time (PMRT) developed in this study was defined as mean retention time of feed particles from one feeding excreted together within a certain range of time, while MRT developed by Castle (1956) referred to the mean retention time of all feed particles from one feeding. Rate of excretion varying with percent crude fiber of diets and retention time of food was estimated from an equation fitted to the Gompertz curve.

VFI_p was the estimated VFI when chemostatic and/or thermostatic mechanisms regulated the feed intake, and VFI_d was the estimated VFI when distension of GIT was the controlling mechanism of feed intake. The decision of which estimate is VFI_t was made by comparing the VFI_p with VFI_d. When VFI_p is less than VFI_d, VFI_p is the VFI_t and, when VFI_p is larger than VFI_d, VFI_d is the estimated VFI_t.

Because of the interaction between breeds and diets on feed intake, breed differences in feed intake were expressed in two separate ways as breed differences in VFI_p (BD_{VFI_p}) and breed differences in VFI_d (BD_{VFI_d}). BD_{VFI_p} was expressed as a ratio to the mean of Angus and Hereford breeds, and BD_{VFI_d} was expressed as a ratio to

the mean of several breeds involved in this study. These breed difference factors multiply either VFI_d or VFI_p in order to predict voluntary feed intake of a particular breed. Otherwise, the estimated VFI_p will be the average of Hereford and Angus breeds, and VFI_d will be the average of several breeds involved.

A computer program to estimate VFI_t for various breeds of cattle with different degrees of maturity fed varying diets is available.

SECTION II

EFFICIENCY OF METABOLIZABLE ENERGY CONVERSION TO BODY GAIN

Introduction

The coefficient of metabolizable energy utilization for fattening (k_f) recommended by A.R.C. (1965) varies with energy density of diet. However, there have been research reports suggesting that level of protein in diets (Peterson et al., 1973; Titus and Fritz, 1971) and age of animal (Ritzman and Colovos, 1943) affect the efficiency of energy utilization for fattening. Meanwhile, all the existing feeding systems supply only the information in regard to the optimum level of protein in diet.

The purposes of this study were to examine the effect of protein level in diet and degree of maturity on k_f values and to develop a multiplicative factor to adjust k_f values recommended by A.R.C. (1965).

Procedures and Source of Data

There have been no research data from which effect of protein and energy density of diet on k_f value can be examined at the same time. Research by Peterson et al. (1973) was performed with 160 Angus x Hereford steers fed 16 diets (four energy levels x four protein levels). However, the energy retention in empty body at the beginning and at the end of each experimental period was not measured. Thus, the estimation of calorific value of gain and/or the estimation of k_f were not possible.

By using equations recommended by A.R.C. (1965) in regard to the calorific value of gain and k_m, predicted k_f values for 16 groups of steers were estimated based on the feed intake and live weight changes in several periods. These estimated k_f values are listed in table 13. The estimated k_f values of diets were expressed as a ratio to the mean k_f of four iso-energetic diets with various protein levels and shown in table 14. In other words, the k_f values listed in table 14 are the k_f values expressed as ratio to the k_f of diets with 13.33% crude protein on a dry matter basis and with equal energy levels.

The model of multiple regression analysis (Draper and Smith, 1968) was $Y_{ijkl} = a + b_1D_i + b_2D_i^2 + b_3P_j + b_4P_j^2 + b_5E_k + b_6E_k^2 + b_7DP_{ij} + b_8DE_{ik} + b_9DPE_{ijk} + b_{10}DPE_{ijk}^2 + b_{11}C_l + b_{12}C_l^2 + b_{13}DC_{il} + b_{14}DC_{il}^2$ where

Y_{ijkl} is the estimated multiplicative adjusting factor of k_f according to age of animal and protein level of diets

a is the intercept when all independent variables are zero

b_1D_i is the partial regression effect on the ith degree of maturity where degree of maturity is current weight divided by expected mature weight

$b_2D_i^2$ is the partial regression effect on the quadratic of the ith degree of maturity

b_3P_j is the partial regression effect on the jth percent protein of diet

TABLE 13. ESTIMATED k_f VALUES FOR STEERS FED 16 DIETS

Crude protein in diet[a] (%)	Energy[b] (kcal)	Days on feed after weaning 0-55	56-111	112-167	Until 475 kg final wt.	Mean
9	2.6	.7924	.6084	.5899	.4625	
11	2.6	.7806	.6078	.4624	.5023	
13	2.6	.6735	.6237	.5366	.4670	
15	2.6	.8032	.6297	.6081	.5317	.6050
9	2.8	.5673	.5687	.5072	.4546	
11	2.8	.6449	.5757	.4819	.4782	
13	2.8	.5920	.5630	.5253	.4604	
15	2.8	.6443	.5686	.4641	.5242	.5388
9	3.0	.5097	.5598	.5274	.4880	
11	3.0	.5639	.5585	.5073	.5276	
13	3.0	.6145	.6649	.5471	.5143	.5312
15	3.0	.6814	.6439	.5901	--	
9	3.2	.5752	.6534	.5887	.5858	
11	3.2	.6634	.6814	.6684	--	
13	3.2	.7417	.7470	.6935	--	
15	3.2	.7961	.6890	.6700	--	.6734

[a] 90% dry matter basis.
[b] Kcal metabolizable energy per g dry matter.

TABLE 14. k_f EXPRESSED AS RATIO TO THE MEAN OF FOUR ISO-ENERGETIC DIETS

Crude protein in diet[a] (%)	Energy[b] (kcal)	Days on feed after weaning 0-55	56-111	112-167	Until 475 kg final wt.
9	2.6	1.3097	1.0057	.9750	.7645
11	2.6	1.2902	1.0046	.7643	.8302
13	2.6	1.1132	1.0309	.8869	.7718
15	2.6	1.3276	1.0408	1.0051	.8789
9	2.8	1.0529	1.0555	.9414	.8438
11	2.8	1.1969	1.0684	.8943	.8875
13	2.8	1.0987	1.0450	.9749	.8545
15	2.8	1.1959	1.0554	.8613	.9729
9	3.0	.9595	1.0539	.9929	.9186
11	3.0	1.0615	1.0513	.9550	.9932
13	3.0	1.1568	1.2517	1.0309	.9683
15	3.0	1.2828	1.2121	1.1109	--
9	3.2	.8542	.9704	.8742	.8699
11	3.2	.9851	1.0119	.9926	--
13	3.2	1.1015	1.1093	1.0298	--
15	3.2	1.1822	1.0231	.9950	--

[a] 90% dry matter basis.
[b] Kcal metabolizable energy per g dry matter.

$b_4P_j^2$ is the partial regression effect on the quadratic of the jth percent protein in diet

b_5E_k is the partial regression effect on the kth energy level of diet

$b_6E_k^2$ is the partial regression effect on the quadratic of the kth energy level of diet

b_7DP_{ij} is the partial regression effect on the interaction of the ith degree of maturity with the jth protein level

b_8DE_{ik} is the partial regression effect on the interaction of the ith degree of maturity with the kth energy level

b_9DPE_{ijk} is the partial regression effect on the three-way interaction of the ith degree of maturity with the jth protein level and with the kth energy level

$b_{10}DPE_{ijk}^2$ is the partial regression effect on the three-way interaction of the ith degree of maturity with the jth protein level and with the quadratic of the kth energy level

$b_{11}C_l$ is the partial regression effect on the lth calorie-protein ratio, which is kcal ME per kg diet divided by percent protein

$b_{12}C_l^2$ is the partial regression effect on the quadratic of the lth calorie-protein ratio

$b_{13}DC_{il}$ is the partial regression effect on the interaction of the ith degree of maturity with the lth calorie-protein ratio

$b_{14}DC_{il}^2$ is the partial regression effect on the interaction of the ith degree of maturity with the quadratic of the lth calorie-protein ratio.

Results and Discussion

Results of stepwise multiple curvilinear regression analysis for the multiplicative k_f adjusting factor are shown in table 15. Although some independent variables were not significant, they were included in the equation when the quadratic of the corresponding variable was significant or its interaction term was significant. The k_f adjusting factors for cattle with varying degrees of maturity fed on different diets were estimated by the multiple regression equation obtained from the 10th step of regression analysis in table 15.

The estimated results in table 16 indicate that multiplicative adjusting factors become smaller with advance in degree of maturity and the decrease was greater in lower energy diets than in higher energy diets. This is in agreement with the results by Ritzman and Colovos (1943) in regard to the effect of maturity on efficiency of energy utilization.

Level of protein had a linear effect, while calorie-protein ratio had a curvilinear effect on k_f values (table 15). The effect of protein

TABLE 15. RESULTS OF MULTIPLE REGRESSION ANALYSIS OF ESTIMATING THE MULTIPLICATIVE ADJUSTING FACTOR FOR k_f VALUES ACCORDING TO THE DEGREE OF MATURITY OF CATTLE, PERCENT CRUDE PROTEIN AND ENERGY LEVEL OF DIET AND CALORIE-PROTEIN RATIO IN DIET

				Partial regression coefficients[a]								
Step	R^2	SE	Intercept	P	E	C^2	C	D x P	D x P x E	D x E	D x C^2	D
1	.100[b]	.128	.7929	.01693								
2	.107[b]	.130	.6408	.01732	.0511							
3	.116[b]	.132	.7543	-.00108	.1386	-.00000229						
4	.161[b]	.131	-2.2042	.12293	-.4018	-.00002729	.018642					
5	.618***	.090	-2.0310	.14686	-.3858	-.00002576	.017626	-.0715				
6	.721***	.078	3.1086	.03900	-.7245	.00000145	-.001030	-.4949	.14872			
7	.731*	.078	3.5454	.01379	-.6943	.00000371	-.002386	-.4899	.16383	-.2273		
8	.743*	.078	3.1486	.00587	-.5515	-.00000306	-.000428	-.4144	.15689	-.6716	.00001056	
9	.756*	.077	2.8858	-.02523	-.5484	-.00002246	.007148	-.0872	.10717	-.4579	.00003126	-4.183

[a] D = degree of maturity, P = percent crude protein, E = Mcal metabolizable energy per kg feed dry matter and C = calorie-protein ratio calculated by divided kcal metabolizable energy per kg feed dry matter by percent protein in diet.

[b] Statistically not significant. Some independent variables were included in the equation even with nonsignificant contribution to the sum of squares of regression because its interaction and/or quadratic terms were significant.

* $P < .05$.

*** $P < .001$.

TABLE 16. ESTIMATED k_f ADJUSTING FACTORS FROM DEVELOPED REGRESSION EQUATION[a]

Energy[b] (Mcal)	Protein (%)	Degree of maturity .3	.4	.5	.6	Mean
2.60	10	1.1440	1.0094	.8748	.7402	.9421
	12	1.1689	1.0080	.8471	.6862	.9276
	14	1.1750	1.0135	.8519	.6904	.9327
	16	1.1792	1.0307	.8822	.7337	.9565
	Mean	1.1668	1.0154	.8640	.7126	.9397
2.80	10	1.0729	.9843	.8957	.8071	.9400
	12	1.1299	1.0091	.8882	.7673	.9486
	14	1.1579	1.0344	.9110	.7875	.9727
	16	1.1792	1.0689	.9587	.8485	1.0138
	Mean	1.1350	1.0242	.9134	.8026	.9688
3.00	10	.9912	.9512	.9111	.8711	.9312
	12	1.0837	1.0046	.9254	.8463	.9650
	14	1.1355	1.0513	.9672	.8831	1.0093
	16	1.1749	1.1040	1.0331	.9622	1.0686
	Mean	1.0963	1.0278	.9592	.8907	.9935
3.20	10	.8991	.9101	.9211	.9321	.9156
	12	1.0302	.9945	.9589	.9232	.9767
	14	1.1077	1.0642	1.0207	.9772	1.0425
	16	1.1666	1.1360	1.1054	1.0748	1.1207
	Mean	1.0509	1.0262	1.0015	.9768	1.0139

[a] Developed equation may not be applicable beyond the ranges as follows: energy level between 2.6 and 3.2 Megacalories per kg feed dry matter, percent protein between 10.0 and 16.6 and degree of maturity of growing cattle between .25 and .60.

[b] Megacalorie of metabolizable energy per kg dry matter of diet.

level on k_f values was greater in diets with high energy density than in diets with low energy density (table 16).

Summary

Data published by Peterson et al. (1973) were used to develop an adjustment for the k_f value recommended by A.R.C. (1965) according to the degree of maturity of cattle and the protein level of the diet. The protein level of diet was expressed in two ways, percent and calorie-protein ratio.

As cattle grow toward maturity, k_f value decreased in all diets. However, the decrease was greater in lower energy density diet. Percent protein had a linear effect on k_f values and calorie-protein ratio had a curvilinear effect on k_f values. It was also observed that the effect of protein level in diets on k_f values was dependent on the energy density of diets.

SECTION III

COMPUTER ESTIMATION OF CHEMICAL AND PHYSICAL COMPOSITION OF GAIN FOR VARIOUS BIOLOGICAL TYPES OF CATTLE FED DIETS OF DIFFERENT ENERGY DENSITY TO DIFFERENT DEGREES OF MATURITY

Introduction

Breed differences in efficiency of conversion of feed to body gain have been demonstrated by Bond et al. (1972), Cundiff (1974) and Kidwell and McCormick (1956), whereas Roubicek et al. (1956) did not find this difference. Bond et al. (1972) suggested that these differences among studies might be due to length of period, weight, way of expressing efficiency, age, stage of maturity and degree of finish. Calorific value per kg live weight gain was used in A.R.C. (1965) to estimate expected gain in body weight. A.R.C. (1965) supplies information of calorific value for different live weights of animal and level of energy retained daily. However, both breed and level of nutrition significantly affect the calorific value of live weight gain (Callow, 1961).

Methods of estimating the chemical composition of dressed carcasses have been evaluated (Crouse and Dikeman, 1974; Hankins and Howe, 1946; Hooper, 1944; Powell and Huffman, 1973; Vance et al., 1971). While some of these methods have been shown to be accurate in estimating the chemical composition of carcass (R^2 or r^2 ranges from .71 to .93), none of these can be utilized to estimate the calorific value of gains of live weight since (1) the calorific value of live weight

gain is more than a calorific value of carcass weight gain and (2) while all of these methods require slaughtering animals to evaluate predictors, the main interest of this study was to study a possible way of estimating calorific value of gain prior to slaughter.

The purpose of this study was to develop mathematical equations to predict the chemical and physical composition of gain and thus to predict the calorific value of gain of steers from traits measurable prior to slaughter.

Procedures and Source of Data

Knowledge of chemical composition of live weight would make it possible to evaluate calorific value of live weight gain. Since various tissues in the body have distinctively different chemical composition, live weight of animal was divided into smaller quantitative components according to the similarity of chemical composition within each component.

Physical Composition of Live Weight

Live weight (LW) of slaughter animal was divided quantitatively into three components, (1) hot carcass (HC), (2) gut fill (GF) and (3) remainder (RMD). HC and RMD were further divided into subcomponents. HC was composed of kg water evaporated, separable muscle (SM), separable fat (SF) and separable bone (SB), and dissected cold carcass (CC) was composed of the last three subcomponents. RMD was divided into five subcomponents, (1) percent hide and hair (% HIDE), (2) percent blood and organs (% BO), (3) percent offal fat (% OF), (4) percent bone from head,

legs and tail (% BONE) and (5) percent soft tissue from head, legs and tail (% SCRAPE).

Multiple curvilinear regression analyses (Draper and Smith, 1968) were used to develop regression equations predicting physical composition of live weight.

Model II was used to estimate kg of SM, SF and SB where live weight (LW), quadratic of live weight (LW^2), mature weight (MW), interaction of live weight with mature weight (LW x MW), degree of maturity (DOM), quadratic of degree of maturity (DOM^2), interaction of live weight with degree of maturity (LW x DOM), interaction of live weight with the quadratic of degree of maturity (LW x DOM^2), crude fiber content (%) of diets (CF), interaction of live weight with crude fiber (LW x CF), biological type-I (BT1), the quadratic of biological type-I ($BT1^2$), interaction of live weight with biological type-I (LW x BT1) and interaction of live weight with the quadratic of biological type-I (LW x $BT1^2$) were independent variables. Biological type-I referred to the energy in therms produced from the average annual milk production of a breed. To estimate kg SM, SF and SB of dissected cold carcass, data from three studies (Bond et al., 1972; Hooven et al., 1972; Smith et al., 1976) were used.

In Model III, kg SM, SF and SB were dependent variables similar to Model II. The same 14 independent variables in Model II plus four additional independent variables; biological type-II (BT2), the quadratic of biological type-II ($BT2^2$), interaction of live weight with biological type-II (LW x BT2) and interaction of live weight with

the quadratic of biological type-II (LW x $BT2^2$); were included in Model III. Biological type-II referred to the breed differences in physiological demand for energy expressed as a ratio of each breed to the average of the Hereford and Angus breeds (table 17). Data used in regression analyses were the same as in Model II.

Since hot carcass is the sum of dissected cold carcass and water evaporated during chilling in the cooler and dissecting the carcass, it was necessary to know the amount of water evaporated. A linear regression equation was developed to estimate water evaporation in the hot carcass. The dependent variable was percent water loss in hot carcass due to evaporation and the independent variable was percent separable fat in the dissected cold carcass.

Remainder (RMD) was indirectly estimated by subtracting hot carcass and gut fill from live weight. Gut fill was estimated from the regression equation developed in Section I. Subcomponents of remainder were estimated from Model V, where dependent variables were % HIDE, % BO, % OF, % BONE and % SCRAPE. The independent variables were percent separable fat of dissected cold carcass (PSF), the quadratic of percent separable fat of dissected cold carcass (PSF^2), degree of maturity (DOM) of cattle, quadratic of degree of maturity (DOM^2) and interaction of percent fatty tissue of dissected cold carcass with degree of maturity (PSF x DOM). Data used for regression analyses were from the study by Moulton <u>et</u> <u>al</u>. (1922a).

TABLE 17. FEED INTAKE (G/KG W·73) OF DIFFERENT BREED GROUPS OF CATTLE AND CALCULATION OF BIOLOGICAL TYPE-II (BT2) EXPRESSED AS RATIO TO AVERAGE FEED INTAKE OF HEREFORD AND ANGUS BREEDS

	Feed intake (g/kg W·73)			BT2[e]		
Breeds[a]	Bond[b]	Smith *et al.*[c]	Cundiff[d]	Bond	Smith *et al.*	Cundiff
HH, AA	110.4	110.86	96.37	1.000	1.000	1.000
HoHo	114.1	--	--	1.034	--	--
DsDs	112.0	--	--	1.014	--	--
JJ	113.2	--	--	1.025	--	--
HA, AH	--	113.86	101.12	--	1.028	1.049
CH, CA	--	111.20	--	--	1.003	--
JH, JA	--	112.50	--	--	1.015	--
SdH, SdA	--	115.10	--	--	1.038	--
SmH, SmA	--	116.10	--	--	1.047	--
LH, LA	--	109.60	--	--	.989	--
BsH, BsA	--	--	102.28	--	--	1.061
MaH, MaA	--	--	98.60	--	--	1.023
CiH, CiA	--	--	100.13	--	--	1.039

[a] HH = Hereford x Hereford, AA = Angus x Angus, HoHo = Holstein x Holstein, DsDs = Dairy Shorthorn x Dairy Shorthorn, JJ = Jersey x Jersey, HA = Hereford x Angus, AH = Angus x Hereford, CH = Charolais x Hereford, CA = Charolais x Angus, JH = Jersey x Hereford, JA = Jersey x Angus, SdH = South Devon x Hereford, SdA = South Devon x Angus, SmH = Simmental x Hereford, SmA = Simmental x Angus, LH = Limousin x Hereford, LA = Limousin x Angus, BsH = Brown Swiss x Hereford, BsA = Brown Swiss x Angus, MaH = Maine-Anjou x Hereford, MaA = Maine-Anjou x Angus, CiH = Chianina x Hereford and CiA = Chianina x Angus.

[b] James Bond (personal communication).

[c] Smith *et al.* (1976).

[d] Cundiff (1974).

[e] Biological type-II, expressing the physiological demand for energy of different breeds. The numeric number of BT2 for each breed group is the ratio of breed intake to the average of HH and AA intake within each study.

Chemical Composition of Live Weight

The chemical composition refers to percent chemical water, fat, protein and ash. Since live weight is composed of kg separable muscle (SM), separable bone (SB) and separable fat (SF) in the dissected cold carcass and hide and hair (HIDE), blood and organs (BO), offal fat (OF), bone from head, legs and tail (BONE), scraped lean and fat from head, legs and tail (SCRAPE), water evaporated (WATER) and gut fill (GT), a knowledge of chemical composition of each subcomponent will provide a means of estimating chemical composition of the whole body.

Simple linear regression analyses (Model VI) were made to estimate chemical fat and chemical water of SM where percent separable fat (PSF) of dissected cold carcass was an independent variable using data from Callow (1948). Chemical protein and chemical ash in percent were assumed to be 90 and 10%, respectively, of nonfat dry matter according to the report by Callow (1948).

Model VII was used to estimate the chemical fat of separable fatty tissue (SF) of dissected cold carcass where independent variables were common logarithm of percent separable fat in dissected cold carcass ($\log_{10}$PF). Data from Callow (1948) were used for regression analysis. Chemical water, chemical protein and chemical ash of SF were 77%, 20.7% and 2.3%, respectively, of nonfat residue (Callow, 1948).

In the physical study, bone (SB) in the carcass and bone (BONE) in the remainder were classified as two different subcomponents of live weight. However, in estimating chemical composition, the bone of live weight was not divided into SB in carcass and BONE in remainder.

Model VIII was used to estimate chemical composition of bone (SB + BONE), HIDE, OF, BO and SCRAPE. Data used for these regression analyses were from Moulton *et al*. (1922b).

Results and Discussion

Physical Composition of Live Weight

Model II results of stepwise multiple curvilinear regression analyses for separable muscle, separable fat and separable bone in dissected cold carcass are presented in table 18. Independent variables were entered at the $P < .05$ level in stepwise fashion in order of importance of their contribution to the sum of squares for regression. Even though some independent variables were not significant, they were forced in when the quadratic of the corresponding variable or its interaction term were significant.

The regression equation predicting each dependent variable was chosen from the stage of stepwise analysis at which the last significant ($P < .05$) independent variable entered. The prediction equations (25, 26 and 27) for estimating separable muscle, separable fat and separable bone in dissected cold carcass are presented in table 18. Means and standard deviations for dependent variables and R^2, standard error of estimates, intercept and partial regression coefficients for each equation are given.

Increases in percent crude fiber in the ration decreased the weight of separable muscle and separable fat proportionally for a given live weight but did not affect the weight of separable bone.

TABLE 18. MEANS AND STANDARD DEVIATIONS (SD) FOR DEPENDENT VARIABLES AND R^2, INTERCEPT, STANDARD ERROR OF ESTIMATE (SE) AND PARTIAL REGRESSION COEFFICIENTS FROM MULTIPLE CURVILINEAR REGRESSION ANALYSES TO ESTIMATE THE WEIGHTS (KG) OF SEPARABLE MUSCLE (SM), SEPARABLE FAT (SF) AND SEPARABLE BONE (SB) IN DISSECTED COLD CARCASS FROM MODEL II

Dependent variable						Partial regression coefficient for independent variables															
Name	Mean	SD	SE	R^2	Intercept	LW	LW^2	MW	LW x MW	DOM	DOM^2	LW x DOM	LW x DOM^2	CF	LW x CF	BT1	$BT1^2$	LW x BT1	LW x $BT1^2$	Equation number
SM	137.84	46.9	4.70	.971	21.99	-.1395	--	-.025942	.0002369	-27.41	221.30	--	-.36463	-.30034	--	-.6941	--	-.005026	--	25
SF	71.45	32.7	5.75	.973	45.0	1.2179	--	-.047175	-.0005277	-614.86	242.05	--	--	-.62825	--	-.2422	.8056	--	-.0031227	26
SB	40.06	11.7	1.58	.987	-5.23	-.2025	--	.009762	.0001519	149.30	-68.68	--	.06055	-.17123	.0003489	1.5764	-.30957	--	.00040356	27

Callow (1948) explained that bulkiness of roughage increased gut fill, thus decreasing empty body weight and dressing percentage for a given live weight. Dairy breeds which have a higher biological type-I value tended to have more separable bone and less separable fat for a given live weight than lower milk producing breeds. Biological type-I had no effect on separable muscle weight. Degree of maturity affected all dependent variables. As cattle grew toward full maturity, separable muscle and separable bone decreased proportionally, while separable fat weight increased.

Table 19 shows the results of stepwise multiple curvilinear regression analyses from Model III for separable muscle, separable fat and separable bone in dissected cold carcass. Variables were entered stepwise at the $P<.05$ probability level to the equation. Some variables were forced in when the quadratic of the corresponding variable or its interaction term were significant.

Prediction equations (28, 29 and 30) for separable muscle, separable fat and separable bone are presented in table 19. These equations are from the final step where the last significant ($P<.05$) variable entered. Means and standard deviations of each dependent variable and R^2, standard error of estimate, intercept and partial regression coefficients for each equation are given.

Increases in crude fiber of diets decreased weight of separable muscle and separable fat and had no effect on the weight of separable bone in the dissected cold carcass. Dairy types (high BT1 values) tended to have less separable muscle and less separable fat but more

TABLE 19. MEANS AND STANDARD DEVIATIONS (SD) FOR DEPENDENT VARIABLES AND R^2, INTERCEPT, STANDARD ERROR OF ESTIMATE (SE) AND PARTIAL REGRESSION COEFFICIENTS FROM MULTIPLE CURVILINEAR REGRESSION ANALYSES TO ESTIMATE THE WEIGHTS (KG) OF SEPARABLE MUSCLE (SM), SEPARABLE FAT (SF) AND SEPARABLE BONE (SB) IN DISSECTED COLD CARCASS FROM MODEL III

Dependent variable						Partial regression coefficient for independent variables																		
Name	Mean	SD	SE	R^2	Intercept	LW	LW^2	MW	LW x MW	DCM	DCM^2	LW x DCM	LW x DCM^2	CF	LW x CF	BT1	$BT1^2$	LW x BT1	LW x $BT1^2$	BT2	$BT2^2$	LW x BT2	LW x $BT2^2$	Equation number
SM	137.84	46.9	4.12	.994	-290.39	4.626	-.00011292	-.026329	.0002653	49.94	85.53	—	-.18508	.31466	-.0012926	2.236	—	-.008963	—	907.35	-617.01	-9.222	4.756	28
SF	71.49	32.7	4.54	.983	877.47	-4.2486	-.000225	-.030128	-.0003632	-526.66	148.63	.48092	-.11749	-.9229	.0004685	8.9489	-1.5255	-.02583	.0025073	-1641.92	1001.24	10.154	-5.006	29
SB	40.06	11.7	2.32	.989	-12.87	-.2835	-.00002436	.005776	.0001357	146.90	-90.57	—	.07948	—	—	1.1288	.02053	—	—	155.93	-150.19	—	.1285	30

separable bone for a given live weight than lower milk producing cattle. Effect of degree of maturity was similar to Model II. Biological type-II, referring to breed differences in physiological demand for energy, contributed ($P<.05$) to the sum of squares for regression in estimating all dependent variables. Breeds with high BT2 value tended to increase separable fat and tended to decrease separable muscle and separable bone weight.

The Model IV regression equation estimating percent water loss (PWL) in hot carcass due to chilling and dissecting carcass ($r^2 = .457$) was as follows:

$$PWL = 13.6 - .359 \times PSF \qquad (31)$$

where the range of PSF in dissected cold carcass (CC) would be $3 < PSF < 35$. Therefore, hot carcass was obtained as follows:

$$HC = \text{kg water} + CC$$

$$HC = HC \times \frac{PWL}{100} + CC$$

$$HC - HC \times \frac{PWL}{100} = CC$$

$$HC \times (1 - \frac{PWL}{100}) = CC$$

$$HC = \frac{CC}{(1 - \frac{PWL}{100})}$$

The regression equation developed in Section I was used to predict wet gut fill ($g/kg\ W^{.73}$) as follows:

$$\text{Gut fill} = 359.9 + 23.4 \times CF - 15 \times CF \times DOM$$

where CF is percent crude fiber of diet and DOM is degree of maturity.

According to Callow (1961) there were no differences among breeds of cattle in percent gut fill.

Remainder (RMD) was estimated indirectly by subtracting HC and gut fill from live weight (LW) as follows:

$$RMD = LW - HC - \text{Gut fill}$$

Percent of subcomponents (% HIDE, % OF, % BO, % BONE and % SCRAPE) in remainder were estimated from equations developed from multiple curvilinear regression analyses of Model V given in table 20. Estimated subcomponents of remainder for steers with varying degree of maturity (DOM) and percent separable fat in dissected cold carcass are listed in table 21.

Chemical Composition of Each Subcomponent

Predicting equations for percent chemical fat (PCF in SM) and chemical water (PCW in SM) of separable muscle were developed from Model VI (table 22). Callow (1948) observed that percent chemical protein and percent chemical ash were 90% and 10%, respectively, of nonfat dry matter. Therefore, the mathematical equations estimating chemical protein and chemical ash were expressed as follows:

$$\text{PCP in SM} = (100 - \text{PCW in SM} - \text{PCF in SM}) \times .9 \qquad (39)$$

$$\text{PCA in SM} = (100 - \text{PCW in SM} - \text{PCF in SM}) \times .1 \qquad (40)$$

Estimated chemical composition of SM is shown in figure 6.

Chemical fat of separable fat (PCF in SF) in dissected cold carcass was estimated by regression equation 41 developed from statistical Model VII (table 22). Callow (1948) observed that the percent chemical water (PCW in SF), chemical protein (PCP in SF) and

TABLE 20. MULTIPLE CURVILINEAR REGRESSION ANALYSES TO ESTIMATE PERCENT OF HIDE AND HAIR (% HIDE), OFFAL FAT (% OF), BLOOD AND ORGANS (% BO), SCRAPED LEAN AND FAT (% SCRAPE) FROM HEAD, TAIL AND LEGS AND BONE FROM HEAD, TAIL AND LEGS (% BONE)

Dependent variable						Partial regression coefficients[a]					
Name	Mean	SD	R^2	SE	Intercept	PSF	PSF^2	DOM	DOM^2	PSF x DOM	Equation number
% HIDE	27.0	2.24	.512	1.692	27.07	-.534	.009	28.26	25.9	--	32
% OF	9.6	6.43	.920	1.964	-2.04	.9722	-.0138	-10.657[b]	20.3	--	33
% BO	45.0	3.28	.804	1.476	49.50	--	--	-10.90	--	--	34
% SCRAPE	6.6	.79	.111	.763	7.0	-.022	--	--	--	--	35
% BONE	12.0	2.73	.850	1.124	18.40	-.22	--	-15.10	15.2	--	36

[a] PSF refers to percent separable fat in cold carcass, DOM refers to degree of maturity of cattle and PSF x DOM refers to the interaction term of percent separable fat with degree of maturity.

[b] Not significant but forced in because the quadratic term (DOM^2) was significant.

TABLE 21. PERCENT OF OFFAL FAT (% OF), BLOOD AND ORGANS (% BO), BONE FROM HEAD, LEGS AND TAIL (% BONE), SCRAPED LEAN AND FAT (% SCRAPE), HIDE AND HAIR (% HIDE) IN REMAINDER ESTIMATED BY EQUATIONS 32, 33, 34, 35 AND 36 AND ADJUSTED TO TOTAL 100%

Independent variables		Estimated percentage						Estimated percentage after adjustment				
DOM[a]	PSF[b]	OF	BO	BONE	SCRAPE	HIDE	Total	OF	BO	BONE	SCRAPE	HIDE
.3	10	4.93	46.23	13.04	6.78	28.78	99.76	4.95	46.34	13.07	6.80	28.85
	12	6.27	46.23	12.60	6.74	28.10	99.94	6.27	46.26	12.61	6.74	28.12
	14	7.50	46.23	12.16	6.69	27.50	100.08	7.49	46.19	12.15	6.69	27.48
	16	8.61	46.23	11.72	6.65	26.98	100.19	8.60	46.14	11.70	6.64	26.93
	18	9.62	46.23	11.28	6.60	26.52	100.25	9.60	46.11	11.25	6.59	26.45
	20	10.52	46.23	10.84	6.56	26.14	100.28	10.49	46.10	10.81	6.54	26.06
.4	15	8.43	45.14	11.49	6.67	28.24	99.97	8.43	45.15	11.50	6.67	28.25
	17	9.49	45.14	11.05	6.63	27.75	100.06	9.48	45.11	11.05	6.62	27.74
	19	10.44	45.14	10.61	6.58	27.33	100.10	10.43	45.09	10.60	6.58	27.30
	21	11.28	45.14	10.17	6.54	26.98	100.11	11.27	45.09	10.16	6.53	26.95
	23	12.01	45.14	9.73	6.49	26.71	100.08	12.00	45.10	9.72	6.49	26.69
	25	12.63	45.14	9.29	6.45	26.50	100.01	12.63	45.13	9.29	6.45	26.50
.5	20	11.63	44.05	10.25	6.56	27.64	100.14	11.62	43.99	10.24	6.55	27.61
	22	12.42	44.05	9.81	6.52	27.33	100.13	12.40	43.99	9.80	6.51	27.30
	24	13.09	44.05	9.37	6.47	27.09	100.08	13.08	44.02	9.36	6.47	27.07
	26	13.66	44.05	8.93	6.43	26.92	99.99	13.66	44.05	8.93	6.43	26.93
	28	14.11	44.05	8.49	6.38	26.83	99.87	14.13	44.11	8.50	6.39	26.87
	30	14.46	44.05	8.05	6.34	26.80	99.70	14.50	44.18	8.07	6.36	26.89

TABLE 21 CONTINUED

Independent variables		Estimated percentage						Estimated percentage after adjustment				
DOM[a]	PSF[b]	OF	BO	BONE	SCRAPE	HIDE	Total	OF	BO	BONE	SCRAPE	HIDE
.6	25	14.56	42.96	9.31	6.45	26.98	100.26	14.52	42.85	9.29	6.43	26.91
	27	15.07	42.96	8.87	6.41	26.84	100.15	15.04	42.90	8.86	6.40	26.80
	29	15.47	42.96	8.43	6.36	26.78	100.00	15.47	42.96	8.43	6.36	26.78
	31	15.75	42.96	7.99	6.32	26.80	99.82	15.78	43.04	8.01	6.33	26.84
	33	15.93	42.96	7.55	6.27	26.88	99.60	16.00	43.13	7.58	6.30	26.99
	35	16.00	42.96	7.11	6.23	27.04	99.34	16.11	43.25	7.16	6.27	27.22
.7	30	17.20	41.87	8.68	6.34	26.24	100.33	17.14	41.73	8.65	6.32	26.16
	32	17.43	41.87	8.24	6.30	26.29	100.12	17.41	41.82	8.23	6.29	26.26
	34	17.55	41.87	7.80	6.25	26.41	99.88	17.57	41.92	7.81	6.26	26.44
	36	17.57	41.87	7.36	6.21	26.60	99.60	17.64	42.04	7.39	6.23	26.71
	38	17.47	41.87	6.92	6.16	26.86	99.29	17.59	42.17	6.97	6.21	27.06
	40	17.26	41.87	6.48	6.12	27.20	98.93	17.45	42.32	6.55	6.19	27.50

[a] Degree of maturity.

[b] Percent separable fat.

TABLE 22. RESULTS OF REGRESSION ANALYSES ESTIMATING PERCENT CHEMICAL WATER (PCW IN SM) AND PERCENT CHEMICAL FAT (PCF IN SM) IN SEPARABLE MUSCLE AND PERCENT CHEMICAL FAT (PCF IN SF) IN SEPARABLE FAT

Dependent variable						Regression coefficient		Equation
Name	Mean	SD[a]	r^2	SE[b]	Intercept	PSF	Log10PSF	number
PCW in SM	73.7	2.17	.814	.93	78.6	-.204	--	37
PCF in SM	4.9	2.06	.836	.82	.2	.197	--	38
PCF in SF	69.5	18.3	.895	5.5	-46.7	--	86.27	41

[a] Standard deviation.
[b] Standard error of estimate.

chemical ash (PCA in SF) in separable fat were 77, 20.7 and 2.3%, respectively, on a fat-free basis. Chemical water, chemical protein and chemical ash in separable fat were expressed as follows:

$$\text{PCW in SF} = (100 - \text{PCF in SF}) \times .77 \quad (42)$$

$$\text{PCP in SF} = (100 - \text{PCF in SF}) \times .207 \quad (43)$$

$$\text{PCA in SF} = (100 - \text{PCF in SF}) \times .023 \quad (44)$$

Figure 7 shows the estimated percent chemical fat, chemical water, chemical protein and chemical ash in separable fat varying with percent fat tissue in dissected cold carcass (PSF).

Results of regression analyses of Model V estimating chemical composition of bone (SB in carcass plus BONE in remainder), offal fat (OF), hide and hair (HIDE), blood and organs (BO) and scraped soft tissue (SCRAPE) from head, tail and legs are shown in table 23. Means and standard deviations of each dependent variable and R^2, standard error of estimate (SE), intercept and partial regression coefficients for each equation are given.

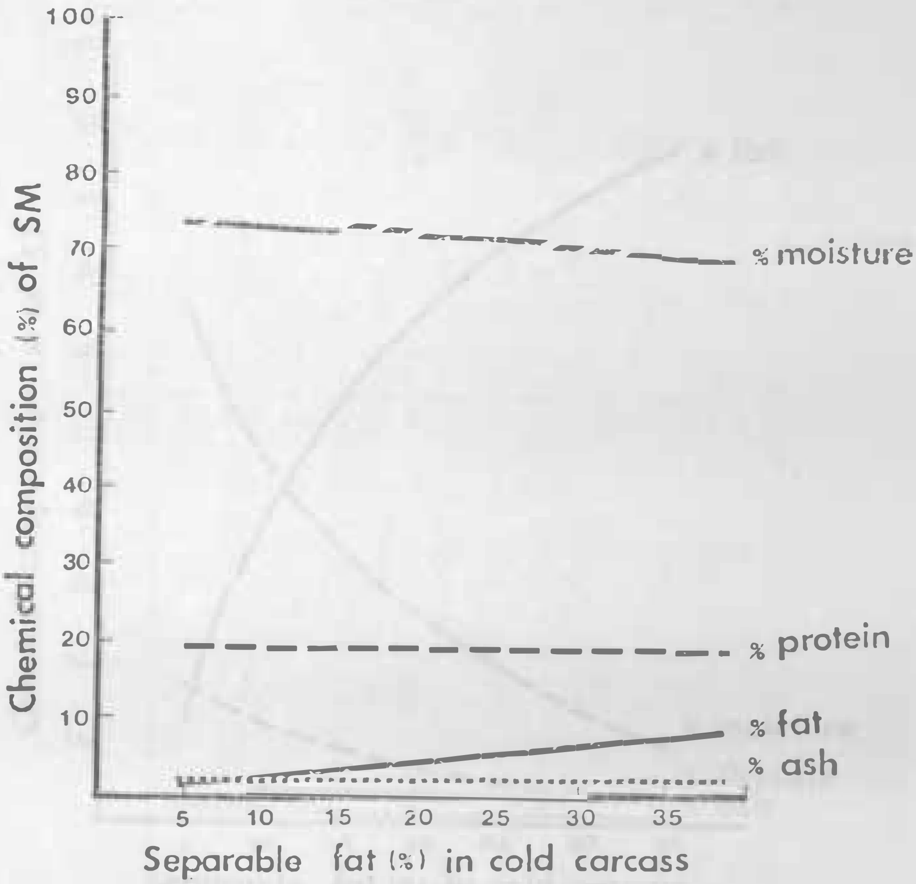

Figure 6. Changes in chemical composition of separable muscle (SM) with varying percent separable fat (PSF) in carcass.

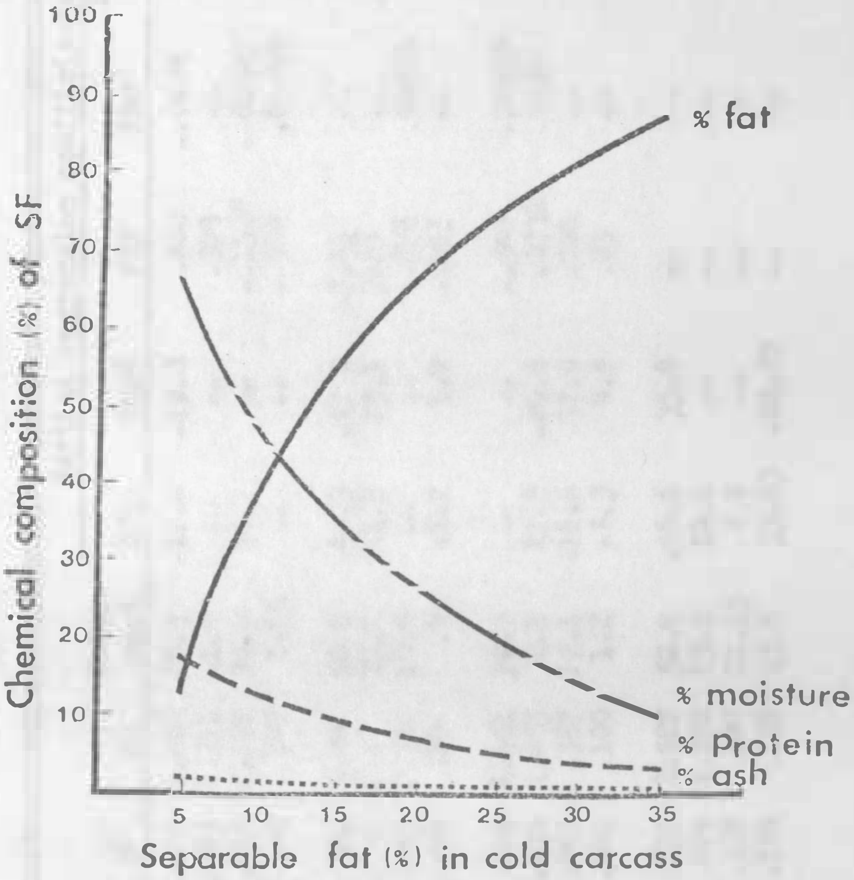

Figure 7. Effects of percent separable fat (PSF) in carcass on chemical composition of separable fat (SF) in carcass.

TABLE 23. MEANS AND STANDARD DEVIATIONS (SD) FOR DEPENDENT VARIABLES AND R^2, STANDARD ERROR OF ESTIMATE (SE), INTERCEPT AND PARTIAL REGRESSION COEFFICIENTS FROM MULTIPLE CURVILINEAR REGRESSION ANALYSES FOR CHEMICAL COMPOSITION OF HIDE AND HAIR (HIDE), OFFAL FAT (OF), BLOOD AND ORGANS (BO), BONE AND SCRAPED SOFT TISSUE FROM HEAD, LEGS AND TAIL (SCRAPE)

Dependent variables						Partial regression coefficients					
Name	Mean	SD	R^2	SE	Intercept	DOM	DOM^2	PSF	PSF^2	DOM x PSF	Equation number
PCW in HIDE	61.5	4.27	.883	1.604	68.3	-26.4	-19.8	.202	-.0238	1.58	45
PCF in HIDE	4.0	3.75	.899	1.211	-1.4	--	--	.303	--	--	46
PCP in HIDE	33.1	2.92	.522	2.132	30.9	16.7	--	-.152[a]	-.00427	--	47
PCA in HIDE	1.3	.37	.169	.347	1.66	--	--	-.044	.00098	--	48
PCW in OF	20.3	13.96	.841	6.00	60.0	-45.3	-47.9	-2.45	--	3.39	49
PCF in OF	75.7	16.32	.836	7.12	29.2	41.8	75.1	3.09	--	-4.36	50
PCP in OF	3.7	2.37	.683	1.38	10.0	--	--	-.576	.00888	--	51
PCA in OF[b]	.3	.21	.796	.10	.9	-1.7	1.7	-.015	--	--	52
PCW in BO	75.2	1.94	.666	1.161	79.3	--	--	-.343	.00434	--	53
PCF in BO	7.4	2.29	.636	1.485	2.2	21.8	-29.6	.0232	.0064	--	54
PCP in BO	16.4	.77	.493	.587	17.1	-16.6	37.0	.229	--	.672	55
PCA in BO	1.1	.12	.441	.100	1.2	-2.3	4.5	.03	--	-.083	56
PCW in BONE	38.2	6.46	.857	2.527	52.9	-56.6	35.8	--	--	--	57
PCF in BONE	17.5	3.04	.479	2.272	13.2	14.1	--	--	--	-.154	58
PCP in BONE	22.07	1.05	.328	.875	21.15	2.2	--	--	--	--	59
PCA in BONE	27.23	.36	.824	.157	13.8	33.83	-22.87	--	--	--	60

TABLE 23 CONTINUED

Dependent variables						Partial regression coefficients					
Name	Mean	SD	R^2	SE	Intercept	DOM	DOM^2	PSF	PSF^2	DOM x PSF	Equation number
PCW in SCRAPE	68.2	4.79	.974	.863	78.0	--	--	-.59	--	--	61
PCF in SCRAPE	12.2	5.27	.996	.304	1.75	--	--	.615	--	--	62
PCP in SCRAPE	18.8	.75	--	--	--	--	--	--	--	--	63
PCA in SCRAPE	1.05	.05	.486	.044	1.13	--	--	-.00476	--	--	64

[a] Not significant but forced in because the quadratic term (PSF^2) was significant.

[b] Prediction from equation 52 resulted in a negative value when PSF and DOM were high. In view of this, it was suggested that equation PCA in OF = .075 x (100 - PCW in OF - PCF in OF) be used in place of equation 52. PCA in OF was 7.5% of nonfat dry matter of OF.

Accuracy of Estimation From Prediction Methods I and II

Prediction Method I. Equations 25, 26 and 27 predicting physical composition of carcass which were developed in Model II (table 18) and equations predicting chemical composition of carcass (38, 39, 40, 42, 43, 44, 57, 58 and 59) were used to estimate percent chemical water, chemical fat and chemical protein of dissected cold carcass.

Prediction Method II. Prediction Method II refers to estimation of chemical composition of dissected cold carcass using equations 28, 29, 30, 38, 39, 40, 42, 43, 44, 57, 58 and 59.

Research data (Adams et al., 1973) which were not used in developing equations above were used to verify the prediction accuracy of the two methods. Estimates of percent chemical water, chemical fat and chemical protein of dissected cold carcass by each method and the values for six breeds reported by Adams et al. (1973) are shown in table 24.

The accuracy of estimation by the two methods was measured by the coefficient of determination (r^2), where the actual chemical composition of six breeds was the independent variable and the estimated chemical composition from each prediction method was the dependent variable. Prediction Method II was considered to be more accurate than Method I in predicting the chemical composition of dissected cold carcass as shown in table 25.

Calorific Value of Live Weight

A computer program was written using all the developed equations to estimate the calorific value of live weight for different biological

TABLE 24. ACTUAL AND ESTIMATED CHEMICAL COMPOSITION OF DISSECTED COLD CARCASS FOR SIX BREEDS OF CATTLE REPORTED BY ADAMS *ET AL*. (1973)

Chemical composition	Breed[a]	Actual	Estimated composition	
			Method I	Method II
		(%)	(%)	(%)
Percent chemical water	HH	48.4	48.2	48.9
	AH	47.0	48.0	46.5
	CH	52.9	52.4	52.8
	SmH	51.0	50.4	49.7
	LmH	52.4	50.9	52.4
	MaH	52.5	53.8	53.2
Percent chemical fat	HH	33.4	32.0	31.0
	AH	35.2	32.3	34.2
	CH	27.0	26.5	26.0
	SmH	29.8	28.8	29.7
	LmH	27.8	28.5	26.6
	MaH	27.5	24.5	25.4
Percent chemical protein	HH	14.3	14.8	15.0
	AH	13.9	14.8	14.4
	CH	15.8	15.9	16.0
	SmH	15.1	15.5	15.3
	LmH	15.6	15.5	15.9
	MaH	15.7	16.3	16.1

[a] HH = Hereford x Hereford, AH = Angus x Hereford, CH = Charolais x Hereford, SmH = Simmental x Hereford, LmH = Limousin x Hereford and MaH = Maine-Anjou x Hereford.

TABLE 25. COEFFICIENT OF DETERMINATION (r^2) IN REGRESSION ANALYSES WHERE ACTUAL CHEMICAL COMPOSITION WAS THE INDEPENDENT VARIABLE AND ESTIMATED CHEMICAL COMPOSITION FROM PREDICTION METHODS I AND II, RESPECTIVELY, WAS THE DEPENDENT VARIABLE

	Dependent variable					
	Estimated chemical composition from Method I			Estimated chemical composition from Method II		
Independent variable	Chemical water	Chemical fat	Chemical protein	Chemical water	Chemical fat	Chemical protein
Actual chemical water	.816			.928		
Actual chemical fat		.827			.942	
Actual chemical protein			.824			.959

types of cattle prior to slaughter. Breed groups involved were (1) Angus and Hereford (A, H), (2) Jersey, (3) Holstein, (4) Dairy Shorthorn, (5) Angus-Hereford cross, (6) Jersey x A, H cross, (7) South Devon x A, H cross, (8) Simmental x A, H cross, (9) Charolais x A, H cross and (10) Limousin x A, H cross. While the carcass data were available in the range of degree of maturity from .1 to .63 for the first four breed groups of steers, data for the last six breed groups were available only in a short range of degree of maturity from .45 to .674. Extrapolation beyond this range for the last six breed groups resulted in unsatisfactory estimates. Table 26 shows the estimated calorific value of live weight of 10 breed groups fed on two different diets within the range of degree of maturity present in the data. Characteristic information of 10 breed groups are shown in table 27.

Calorific value of gain in kcal per kg live weight gain (CVG) was calculated from calorific value of live weight (CVLW) in table 26 as follows:

$$CVG_{j-i} = \frac{CVLW_i \times LW_i - CVLW_j \times LW_j}{LW_i - LW_j} \text{ where}$$

CVG_{j-i} refers to the calorific value of live weight gain between the period from j to i

$CVLW_i$ refers to the calorific value of live weight at the ith time

LW_i refers to the kg live weight of steers at the ith time

$CVLW_j$ refers to the calorific value of live weight at the jth time ($j < i$)

LW_j refers to the kg live weight of steers at the jth time.

TABLE 26. ESTIMATED CALORIFIC VALUE OF LIVE WEIGHT (KCAL/KG) OF STEERS FROM 10 BREED GROUPS FED ON TWO DIFFERENT DIETS

Breed[a]	Degree of maturity					
	.2	.3	.4	.5	.6	.7
			15% Crude Fiber Diet			
H, A	1863	2216	2594	2987	3392	3786
Jersey	1753	1933	2235	2594	2988	3402
Dairy Shorthorn	1933	2228	2579	2958	3355	3748
Holstein	1786	1998	2304	2658	3040	3440
H x A, A x H	--	--	--	--	3508[b]	--
J x H, J x A	--	--	--	--	3355[b]	--
SD x H, SD x A	--	--	--	3105[b]	--	--
L x H, L x A	--	--	--	2914[b]	--	--
Sm x H, Sm x A	--	--	--	3038[b]	--	--
C x H, C x A	--	--	--	2925[b]	--	--
			25% Crude Fiber Diet			
H, A	1315	1819	2287	2743	3195	3633
Jersey	1196	1459	1859	2290	2739	3199
Dairy Shorthorn	1414	1858	2294	2732	3172	3607
Holstein	1367	1699	2071	2471	2889	3318
H x A, A x H	--	--	--	--	3314[b]	--
J x H, J x A	--	--	--	--	3144[b]	--
SD x H, SD x A	--	--	--	2891[b]	--	--
L x H, L x A	--	--	--	2699[b]	--	--
Sm x H, Sm x A	--	--	--	2832[b]	--	--
C x H, C x A	--	--	--	2721[b]	--	--

[a] H = Hereford, A = Angus, J = Jersey, SD = South Devon, L = Limousin, Sm = Simmental and C = Charolais.

[b] Estimation of calorific value of live weight of these breed groups was restricted to only one point of degree of maturity because the actual data were available in narrow range of degree of maturity.

TABLE 27. CHARACTERISTIC INFORMATION OF BREED GROUPS

Breed[a]	Bull mature weight (kg)	Biological type-I[b]	Biological type-II[c]
H, A	825	1.00	1.000
Jersey	650	3.39	1.025
Dairy Shorthorn	900	3.00	1.014
Holstein	1100	3.84	1.034
H x A	842	1.04	1.028
Jersey x H, A	768	2.20	1.015
SD x H, A	955	1.50	1.038
Sm x H, A	998	2.06	1.047
C x H, A	998	1.30	1.003
L x H, A	944	1.04	.989

[a] H = Hereford, A = Angus, J = Jersey, SD = South Devon, L = Limousin, Sm = Simmental and C = Charolais.

[b] Therm of energy in the average annual milk production of breed.

[c] The energy intake capacity of a breed expressed as a ratio relative to the average energy intake capacity of Hereford and Angus breeds.

Calorific value of gain was estimated for four breed groups of steers, (1) Hereford and Angus, (2) Jersey, (3) Dairy Shorthorn and (4) Holstein (table 28). The accuracy of estimating calorific gain of live weight was not verified because there were no experimental data available. Calorific value of live weight (table 26) increased as percent crude fiber content decreased. However, calorific value of live weight gain was not affected by percent crude fiber of diet (table 28). Steers fed on a low energy density diet tended to require more calories per unit of gain than steers on a high energy density diet especially at older slaughter ages.

TABLE 28. ESTIMATED CALORIFIC VALUE OF LIVE WEIGHT GAIN (KCAL/KG) OF STEERS FROM FOUR BREED GROUPS FED ON TWO DIFFERENT DIETS

Breed	Period in degree of maturity				
	.2-.3	.3-.4	.4-.5	.5-.6	.6-.7
	15% Crude Fiber Diet				
Hereford, Angus	2922	3728	4559	5417	6150
Jersey	2293	3141	4030	4958	5886
Dairy Shorthorn	2818	3632	4474	5340	6106
Holstein	2422	3222	4074	4950	5840
	25% Crude Fiber Diet				
Hereford, Angus	2827	3691	4567	5455	6261
Jersey	1985	3059	4014	4984	5959
Dairy Shorthorn	2746	3602	4484	5372	6217
Holstein	2363	3187	4071	4979	5892

Summary

Data from the literature were utilized to develop prediction equations for physical and chemical composition of live weight of cattle from traits measurable prior to slaughter.

Two methods of predicting chemical composition of the dissected cold carcass were evaluated in comparison to the actual chemical composition of six breeds reported by Adams et al. (1973).

From equations developed, estimation of the physical and chemical composition of live weight of steers of several breeds varying in degree of maturity fed on different diets was possible. A computer program is available which predicts the physical composition, chemical composition and calorific value of live weight gain of steers for different biological types of cattle fed on various diets. Because of the lack of experimental data, the accuracy of the prediction was not verified.

SECTION IV

CALORIFIC EFFICIENCY OF BEEF PRODUCTION AND OPTIMUM TIME OF SLAUGHTER FOR STEERS FROM DIFFERENT BREEDS

Introduction

Beef producers and researchers have been interested in comparing feedlot performance of different breeds of cattle. Smith (1976) reported that breed differences in feed efficiency were significant on age-constant, weight-constant and grade-constant bases. Feed efficiency of postweaning gain of calf and total TDN consumed by cow are necessary to evaluate the optimum slaughter ages of steers yielding maximum energetic efficiency of beef production. Even though there are many studies concerning feed efficiency of postweaning gain of cattle, few studies report total TDN required by the cow for maintenance, pregnancy and lactation.

The question of optimum slaughter age is difficult to answer because (1) it is necessary to measure not only the cost of producing slaughter animals but also the total cost of maintaining breeding stock and (2) it is impossible to kill the same cattle more than once to measure the carcass traits that vary with different end points.

An attempt was made to combine available knowledge concerning energetic efficiency of beef production into a computer program to be used in simulating the postweaning efficiency of beef production of different breed types fed to different end points. The proposed functions of this computer program were (1) to estimate the postweaning

voluntary feed intake of different rations for steers of different breeds, (2) to estimate calorific value of gain for different breed types of steers from weaning to slaughter, (3) to estimate the efficiency of feed conversion into body gain, (4) to estimate physical and chemical composition of live weight and (5) to predict the slaughter time which yields maximum efficiency.

The purposes of this study were to evaluate the differences between Jersey, Angus-Hereford (equal number of Angus and Hereford), Dairy Shorthorn and Holstein breeds in optimum time of slaughter and to evaluate the effect of slaughter at ages other than optimum time of slaughter on energetic efficiency of beef production.

Procedures and Source of Data

Optimum time of slaughter depends on several factors including (1) rate of maturity, (2) reproductive rate of breeding stock, (3) mature size of calves (capacity to grow), (4) maintenance cost of breeding stock (mature size and milk production of cows), (5) efficiency of body gain of slaughter animals and (6) quantity and quality of meat produced.

To simplify the problem, only TDN consumed by cow-calf pair was included and the calculation of optimum time of slaughter was based on mature cows with steer calves. Annual TDN requirements for mature cows of four breed groups (table 29) for maintenance, pregnancy and lactation were estimated based on weight and milk producing level according to N.R.C. (1976). Coefficients of energy utilization for fattening (k_f)

TABLE 29. INPUT INFORMATION FOR COMPUTER SIMULATION

Breed	Mature weight[a]		Weaning weight of calf[b]	Annual milk production[a]			Breed difference		TDN consumed by cow for a year of maintenance, pregnancy and lactation[e]
	Cow (kg)	Bull (kg)	(kg)	Dairy condition (kg)	Beef condition (kg)	Milk fat (%)	Roughage intake[c]	Energy intake[d]	(kg)
Jersey	417	653	183	3175	1633[b]	4.7	1.000	1.025	1701
Hereford, Angus	494	825	201	1361[b]	998[b]	3.0	1.000	1.000	1684
Dairy Shorthorn	522	900	215	3402	1724[b]	3.5	1.000	1.014	1943
Holstein	590	1043	236	4536	2041[b]	3.4	1.000	1.034	2171

[a] From reports by Briggs and Briggs (1969), French *et al.* (1966) and Rouse (1970).
[b] Estimated values from personal knowledge of breed performance.
[c] Expressed as a ratio to the average of several breeds involved in the study of Section I.
[d] Expressed as a ratio to the average of Hereford and Angus breeds.
[e] Estimated according to N.R.C. (1976) recommendation.

and coefficient of energy utilization for maintenance (k_m) were from A.R.C. (1965). Energy requirement for maintenance of growing steers was determined according to A.R.C. (1965) recommendation shown in table 30. Since A.R.C. (1965) recommendation of energy requirement for maintenance is based on age of cattle, the following equation was used to convert A.R.C. (1965) recommendation of energy requirement for maintenance to degree of maturity basis:

$$Y = .007 + .3566 \times (\log_{10}X)^2$$

where Y is the estimated degree of maturity and X is age of cattle in months.

Results and Discussion

Table 29 contains the characteristic information of four breed types used in computer simulation. The ration used in simulation had 15% crude fiber, 2.87 kcal metabolizable energy per g and 79% TDN on a dry matter basis. The program estimated average daily feed intake on a dry matter basis from weaning to slaughter age for the four breed types (table 31). Estimated average daily gain and live weight change from weaning to slaughter age (table 32) utilized the estimated feed intake (table 31) and the estimated calorific value of live weight gain in Section III (table 28). Energetic efficiency of calf live weight gain was calculated for the cow-calf pair and for the calf (table 33).

As shown in figures 8 and 9, steers from four breed groups reached the most efficient production at different ages and at different weights. Maximum efficiency occurred at 401, 429, 443 and

TABLE 30. FASTING HEAT PRODUCTION OF CATTLE

Fasting metabolism (kcal/kg $W^{.73}$)	Age of animal (months)	Degree of maturity[a]
140	1	.0070
135	3	.0882
125	6	.2230
110	12	.4223
100	18	.5689
95	24	.6863
90	36	.8707
85	48	1.0000
80	>48	1.0000

[a] Degree of maturity was estimated from equation $Y = .007 + .3566 \times (\log_{10} X)^2$, where Y is estimated degree of maturity and X is age of animal in months.

TABLE 31. DAILY AND ACCUMULATED TDN INTAKE BY STEERS AND TDN CONSUMED BY COW-CALF PAIR

Days from weaning (days)	Jersey: Daily TDN intake by calf (kg)	Jersey: Cumulated TDN intake: Calf (kg)	Jersey: Cumulated TDN intake: Cow-calf (kg)	Hereford-Angus: Daily TDN intake by calf (kg)	Hereford-Angus: Cumulated TDN intake: Calf (kg)	Hereford-Angus: Cumulated TDN intake: Cow-calf (kg)	Dairy Shorthorn: Daily TDN intake by calf (kg)	Dairy Shorthorn: Cumulated TDN intake: Calf (kg)	Dairy Shorthorn: Cumulated TDN intake: Cow-calf (kg)	Holstein: Daily TDN intake by calf (kg)	Holstein: Cumulated TDN intake: Calf (kg)	Holstein: Cumulated TDN intake: Cow-calf (kg)
14	2.68	38	1739	2.90	40	1724	3.08	43	1986	3.36	47	2218
28	3.67	89	1790	3.95	96	1780	4.26	103	2046	4.67	113	2284
42	4.81	157	1858	5.13	167	1851	5.58	181	2123	6.21	199	2370
56	5.03	227	1928	5.35	242	1926	5.85	262	2205	6.58	291	2462
70	5.22	300	2001	5.58	320	2004	6.08	348	2290	6.85	387	2559
84	5.35	375	2076	5.76	401	2084	6.30	436	2378	7.12	487	2658
98	5.49	451	2152	5.90	484	2167	6.49	526	2469	7.35	591	2762
112	5.58	529	2230	6.03	568	2252	6.62	619	2562	7.76	805	2976
126	5.57	608	2309	6.17	655	2338	6.76	714	2657	7.89	915	3087
140	5.72	688	2389	6.30	743	2426	6.89	811	2754	8.03	1027	3199
154	5.76	769	2470	6.40	832	2516	6.99	909	2852	8.12	1141	3313
168	5.81	851	2552	6.49	922	2606	7.08	1008	2951	8.21	1256	3427
182	5.85	933	2634	6.53	1014	2698	7.17	1108	3051	8.26	1372	3543
196	5.90	1015	2716	6.62	1107	2791	7.21	1209	3152	8.30	1488	3660
210	5.90	1097	2798	6.67	1200	2884	7.26	1311	3254	8.35	1605	3777
224	5.90	1180	2881	6.71	1294	2978	7.30	1414	3357	8.39	1723	3894
238	5.94	1263	2964	6.76	1389	3072	7.35	1517	3460	8.39	1840	4011
252	5.94	1346	3047	6.80	1484	3168	7.39	1620	3563	8.39	1958	4129
266	5.94	1429	3130	6.80	1579	3263	7.39	1724	3667	8.39	2076	4247
280	5.90	1512	3213	6.85	1675	3359	7.39	1827	3770	--	--	--
294	--	--	--	6.85	1770	3454	7.39	1931	3874	--	--	--
308	--	--	--	6.85	1867	3550	7.39	2034	3977	--	--	--
322	--	--	--	6.85	1973	3647	--	--	--	--	--	--
336	--	--	--	6.85	2058	3742	--	--	--	--	--	--
350	--	--	--	6.85	2154	3838	--	--	--	--	--	--

TABLE 32. ESTIMATED AVERAGE DAILY LIVE WEIGHT GAIN (ADG) AND LIVE WEIGHT CHANGES OF STEERS

Days from weaning	Jersey		Hereford-Angus		Dairy Shorthorn		Holstein	
	ADG	Live weight	ADG	Live weight	ADG	Live weight	ADG	Live weight
(days)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
0	--	183	--	201	--	215	--	236
14	.24	186	.30	205	.49	222	.64	245
28	1.13	202	.93	219	1.21	239	1.53	266
42	1.65	225	1.50	239	1.86	265	2.35	299
56	1.50	246	1.45	260	1.79	290	2.28	331
70	1.39	266	1.41	279	1.73	314	2.21	362
84	1.29	284	1.37	298	1.67	338	2.15	392
98	1.22	301	1.33	318	1.61	361	2.08	421
112	1.15	317	1.30	336	1.56	382	2.02	450
126	1.09	332	1.27	353	1.52	404	1.96	477
140	1.03	347	1.24	370	1.47	424	1.91	503
154	.99	361	1.21	387	1.42	444	1.85	529
168	.94	374	1.18	404	1.38	463	1.80	555
182	.91	386	1.15	420	1.34	482	1.74	579
196	.87	399	1.12	436	1.31	500	1.70	603
210	.83	411	1.10	451	1.27	518	1.65	626
224	.80	421	1.08	466	1.23	535	1.60	648
238	.78	432	1.05	481	1.20	552	1.56	670
252	.75	443	1.03	495	1.17	568	1.51	692
266	.72	453	1.02	509	1.13	584	1.47	712
280	.70	463	.99	523	1.11	600	1.43	732
294	--	--	.84	535	1.11	616	--	--
308	--	--	.85	547	1.08	630	--	--
322	--	--	.98	561	--	--	--	--
336	--	--	.95	574	--	--	--	--
350	--	--	.93	587	--	--	--	--

TABLE 33. ESTIMATED EFFICIENCY OF THE CALF AND COW-CALF PAIR BY PERIODS

Days from weaning	Calf efficiency (kg TDN/kg calf weight)				Cow-calf efficiency (kg TDN/kg calf weight)			
(days)	(Jersey)	(Angus-Hereford)	(Dairy Shorthorn)	(Holstein)	(Jersey)	(Angus-Hereford)	(Dairy Shorthorn)	(Holstein)
14	11.86	9.89	6.33	5.20	9.32	8.39	8.93	9.06
28	4.67	5.55	4.37	3.70	8.85	8.14	8.55	8.58
42	3.71	4.39	3.62	3.16	8.24	7.73	8.01	7.92
56	3.60	4.14	3.50	3.06	7.83	7.41	7.60	7.44
70	3.63	4.10	3.51	3.06	7.53	7.17	7.28	7.07
84	3.72	4.13	3.56	3.12	7.31	6.98	7.04	6.78
98	3.83	4.16	3.63	3.18	7.15	6.83	6.85	6.55
112	3.96	4.23	3.71	3.26	7.04	6.71	6.70	6.38
126	4.09	4.31	3.79	3.33	6.95	6.62	6.58	6.24
140	4.21	4.39	3.88	3.42	6.89	6.55	6.49	6.13
154	4.34	4.47	3.97	3.50	6.85	6.49	6.42	6.04
168	4.46	4.56	4.07	3.58	6.83	6.45	6.37	5.97
182	4.59	4.64	4.15	3.66	6.82	6.42	6.33	5.92
196	4.71	4.71	4.25	3.74	6.82	6.40	6.30	5.88
210	4.83	4.80	4.33	3.82	6.82	6.39	6.28	5.85
224	4.96	4.89	4.42	3.89	6.84	6.39	6.27	5.82
238	5.07	4.97	4.51	3.97	6.86	6.39	6.26	5.81
252	5.19	5.05	4.59	4.04	6.88	6.40	6.27	5.80
266	5.29	5.13	4.67	4.12	6.91	6.40	6.27	5.80
280	5.41	5.20	4.75	4.19	6.95	6.42	6.28	5.80
294	--	5.31	4.83	--	--	6.45	6.29	--
308	--	5.40	4.90	--	--	6.49	6.31	--
322	--	5.46	--	--	--	6.50	--	--
336	--	5.52	--	--	--	6.52	--	--
350	--	5.58	--	--	--	6.54	--	--

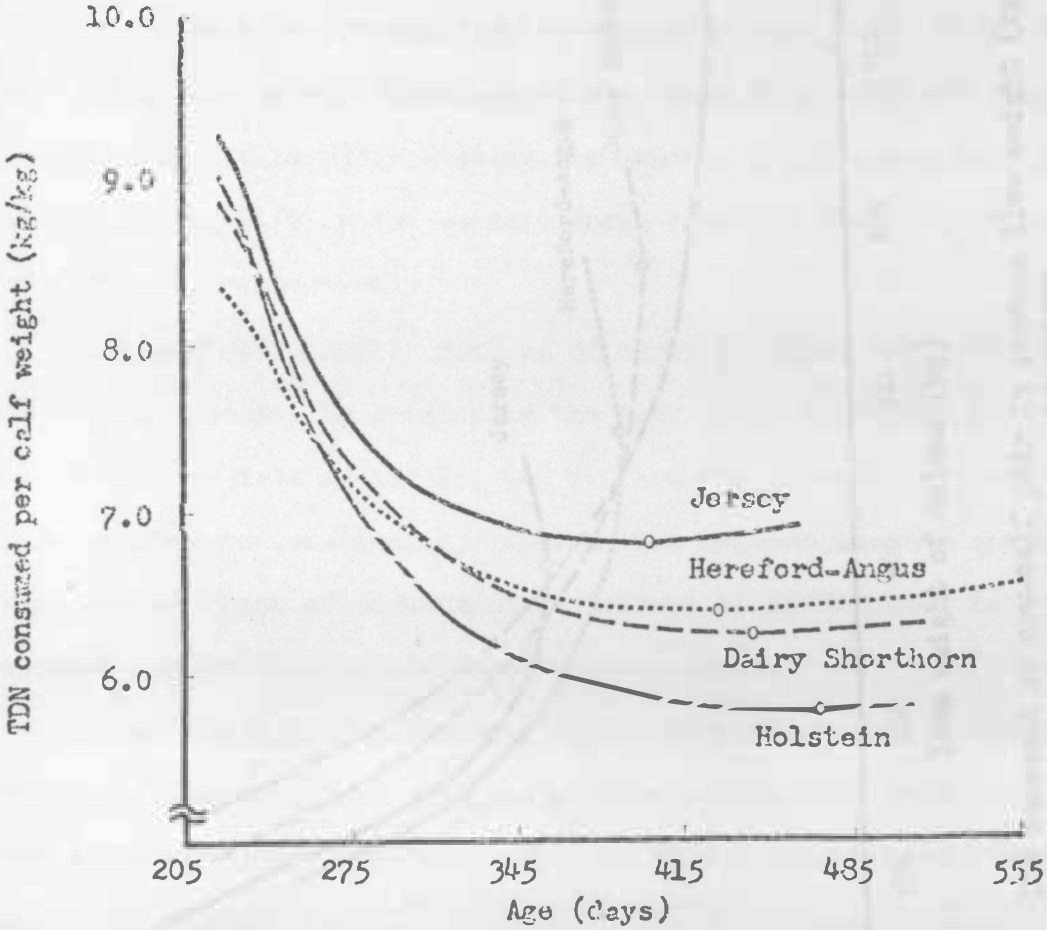

Figure 8. TDN consumed by cow-calf pair to produce live weight (kg) of calf with increase in age.

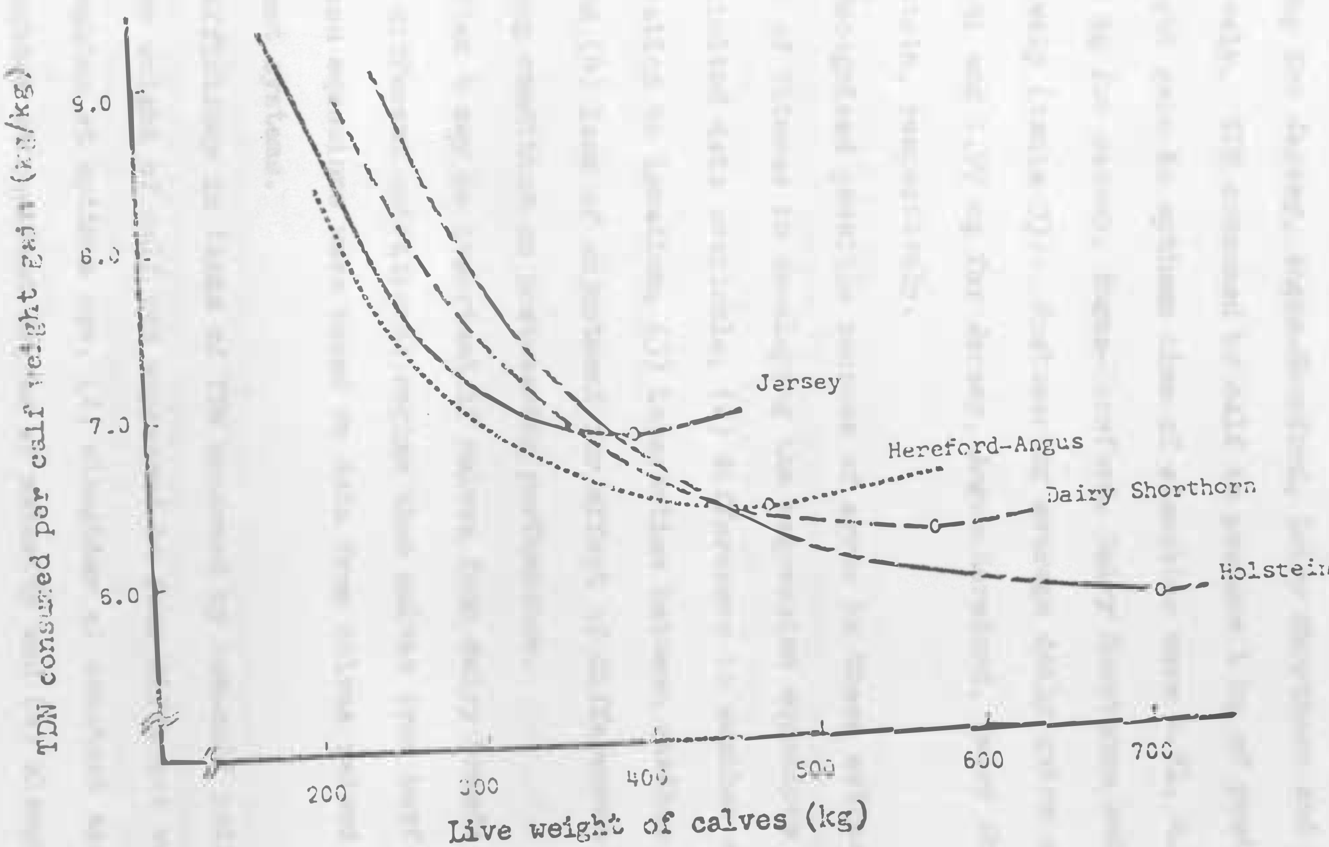

Figure 9. TDN consumed by cow-calf pair to produce live weight (kg) of calves with increase in weight.

471 days for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively. Live weights at corresponding ages were 399, 466, 552 and 712 kg for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively. TDN consumed by calf to produce 1 kg of postweaning live weight gain to optimum time of slaughter were 4.71, 4.89, 4.51 and 4.12 kg for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively (table 33). Postweaning average daily gains were 1.10, 1.18, 1.41 and 1.79 kg for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively.

Recognized possible sources of error in these estimates are (1) lack of fitness in developing the regression equations primarily due to limited data available, (2) differences in weather conditions from location to location, (3) interaction between weather and breed types and (4) lack of adjustment for effect of differences in preweaning condition on postweaning performance.

Item 4 may be important if calves from dairy breeds are managed under a different nutritional regime than calves from beef dams. The regression equations were based on data from calves raised under beef management systems.

Efficiency in terms of TDN consumed by cow-calf pair to produce 1 kg live weight of calf was expressed in four different ways, (1) slaughter at optimum age, (2) slaughter at constant age, (3) slaughter at constant degree of maturity and (4) slaughter at constant weight.

Slaughter at Optimum Age

Slaughter of steers from Jersey, Angus-Hereford, Dairy Shorthorn and Holstein groups was simulated at the optimum ages of 401, 429, 443 and 471 days, respectively. TDN consumed by cow-calf pair to produce 1 kg calf live weight at the corresponding optimum ages were 6.82, 6.39, 6.26 and 5.80 kg for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively (table 33). The average of the four breed groups is 6.318 kilograms.

Slaughter at Constant Age

Slaughter of steers from all breed types was simulated at four different constant ages, 401, 429, 443 and 471 days.

Slaughter at 401 Days of Age. When all steers from four breed groups were slaughtered at 401 days of age, TDN required by cow-calf pair to produce 1 kg calf live weight were 6.82, 6.40, 6.30 and 5.88 kg for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively. The average TDN required per kg calf live weight gain was 6.350 kilograms.

Slaughter at 429 Days of Age. TDN requirements were 6.84, 6.39 6.27 and 5.82 kg for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively. Estimated mean TDN requirement of four breed groups was 6.330 kilograms.

Slaughter at 443 Days of Age. Estimated TDN requirements to produce 1 kg calf live weight were 6.86, 6.39, 6.26 and 5.81 kg for

Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively, and thus the average of four breeds in TDN requirement was 6.330 kilograms.

Slaughter at 471 Days of Age. Estimated TDN consumed by cow-calf pair to produce 1 kg live weight of calf were 6.91, 6.64, 6.27 and 5.80 kg for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively. The average TDN consumption of four breed groups to produce 1 kg calf live weight was 6.345 kilograms.

Although there were some decreases in efficiency by slaughtering steers of different genetic groups of cattle at various constant ages, by choosing the constant age near the middle of the range in optimum age of different types of cattle the decrease in efficiency becomes small.

Slaughter at Constant Degree of Maturity

Degree of maturity refers to the ratio of live weight to expected mature weight (Brody, 1945). Slaughter of steers from each breed group was simulated when they reached .62 degree of maturity. The efficiency (kg TDN/kg calf weight) at .62 degree of maturity was 6.82, 6.40, 6.26 and 5.82 for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively. The average efficiency of four breed groups was 6.325.

Slaughter at Constant Weight

Slaughter weights selected were 450, 480, 500 and 530 kg for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively.

The estimated efficiencies (kg TDN/kg calf weight) were 6.91, 6.36, 6.30 and 6.04 for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively. The average efficiency of four breed groups was 6.410.

Efficiencies of postweaning beef production varying with different end points are summarized in table 34. Slaughter at the constant weights selected for study was the least efficient method in terms of energy required to produce growth. Slaughter at a constant age was next in inefficiency. However, the decrease in efficiency by slaughtering steers of different genetic groups at a constant age could be minimized by choosing the constant age near the average optimum age of all types of cattle. Slaughter at a constant degree of maturity was second in efficiency only to slaughter at the breed optimum age.

It was concluded that steers from large mature breeds tend to reach the optimum end point not only at heavier weights but also at older ages than steers from small breeds. Slaughtering steers of different mature size at constant weight resulted in slaughtering fast growing steers earlier and slow growing steers later than their optimum slaughter age. Slaughter at constant age resulted in the intermediate between slaughter at optimum age and slaughter at constant weight.

Even though slaughter at constant degree of maturity resulted in more efficiency than the other two methods, the former required an estimate of mature weight. For practical application further study will be necessary to accurately predict mature weight from early performance of the animal and from its pedigree.

TABLE 34. ENERGETIC EFFICIENCY AT VARIOUS END POINTS

End points	Breed groups: Jersey	Angus-Hereford	Dairy Shorthorn	Holstein	Mean efficiency	Ratio[a]
At optimum age	6.82	6.39	6.26	5.80	6.318	100.0
At constant ages						
401 days	6.82	6.40	6.30	5.88	6.350	100.5
429 days	6.84	6.39	6.27	5.82	6.330	100.2
443 days	6.86	6.39	6.26	5.81	6.330	100.2
471 days	6.91	6.40	6.27	5.80	6.345	100.4
At constant weight						
450, 480, 500 and 530 kg	6.91	6.39	6.30	6.04	6.410	101.5
At constant degree of maturity	6.82	6.40	6.26	5.82	6.325	100.1

[a] Mean efficiency expressed as a ratio to that at optimum age.

Summary

A model was developed to combine available information from several experiments concerning the calorific efficiency of beef production. In the model energy requirement for mature cow per year of lactation, pregnancy and maintenance was determined by N.R.C. (1976) recommendation. Metabolizable energy required for maintenance was according to A.R.C. (1965) recommendations.

The simulated optimum slaughter ages of steers from Jersey, Angus-Hereford, Dairy Shorthorn and Holstein were 196, 224, 238 and 266 days of postweaning feeding when the ration had 15% crude fiber and 79% TDN on a dry matter base. The weights of steers at corresponding optimum ages were 399, 466, 552 and 712 kg for Jersey, Angus-Hereford, Dairy Shorthorn and Holstein, respectively. The computation was performed based on mature cows with steer calves.

Four ways of determining slaughter ages were used; (1) slaughter at simulated optimum ages, (2) slaughter at various constant ages, (3) slaughter at the constant degree of maturity and (4) slaughter at constant weight. Slaughter at constant weight was least efficient and slaughter at constant age was next inefficient. Slaughter at constant degree of maturity and at simulated optimum time of slaughter were more efficient than others. However, both methods are dependent on estimated mature weight which can not be measured at young ages.

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