USING MATHEMATICAL MODELS TO EVALUATE
FEEDLOT PERFORMANCE OF CATTLE FED DIFFERING
CORN:CORN SILAGE RATIOS DURING WINTER AND SUMMER

by

PHILIP DANA GEORGE

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This manuscript is dedicated to my parents, Mr. and Mrs. Philip W. George, brothers, Jay G. and Vern W., and sister, Frances. Thanks be to God for the deep roots in Animal Science and Christianity provided by such a family and necessary for my strength while working on my degree.

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INTRODUCTION

Biological systems are among the most complex studied by modern science. As knowledge of these systems becomes more detailed, it becomes increasingly difficult to organize this knowledge without the deductive methods of mathematics.

Mathematical procedures are useful snd sometimes necessary for the description and understanding of biological systems. Models may be used to aid in finding "nonmathematical answers" to "nonmathematical questions." Other models may become an integral part of the question and answer.

Several models are availsble which predict performance of beef cattle on growing and finishing rations. Most are based on literature reviews, or on feeding trials which provide only averages over the entire trial. They do not reflect performance changes relative to time or body weight. Additionally, most models are based on the California Net Energy System and thus do not account for associative effects between feedstuffs. Environment plays a major role in determining feed intake and growth rate. Few cattle feeding trials have determined absolute changes in feed intake or growth rate in response to hest or cold stress. Therefore, the objective of this study was to develope mathematical models which reflect instantaneous changes in performance of cattle fed varying roughage:concentrate ratios, as a function of

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time, body weight and effective environment, and to adapt these models

for practical economic analysis of cattle feeding.

REVIEW OF LITERATURE

Mathematical Models

Gold (1977) separated mathematical models into correlative and
explanatory models. A correlative model reflects an observed relation
between two or more variables. It describes, summarizes, and verifies
that relationship and then is used as a basis for prediction and con-
trol. An explanatory model reflects observed relationships between
variables and, in addition, the structure of the model reflects the
concept of a causal mechanism. Often, the complexity of biological
systems prevents direct measurement of the desired parameters. The
explanatory model allows relationships to be drawn between the desired
parameters and those which can be measured.

Models seldom mirror all properties of the system represented and
therefore are not substitutes for biological "intuition." However,
well developed models may replace actual experimentation although Rice
et al. (1974) emphasized the need to compare a developed model with
experimental data and modify it as required for behavior improvement
and literature update. Most models can serve to improve experimental
design for future data collection.

The simplest mathematical expression should be used that gives
sufficient agreement with the data. To assess "sufficient agreement,"
one needs estimates of the error associated with the data points and

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the ultimate desired accuracy. In addition, extrapolating mathematicsl expressions beyond the range of observations does not provide a basis for conclusions.

Mathematical models allow a great deal of flexibility in describing biological systems. Simulation analysis has allowed the incorporation of physical and biochemical parameters, thus extraction of more information from studies of metabolic regulation and the effects of physiological environment on cellular metabolic functions is possible than by routine observation (Gardinkel et al., 1974). Ramberg (1974) developed a kinetic model for the calcium system of a parturient cow. Rice et al. (1974) designed a dynamic model representing forage growth and senescence and its intake, assimilation, and utilization by grazing ruminants. Data from the literature were used by Song and Dinkel (1978) to develope prediction equations for physical and chemical composition of live weight using traits measurable prior to slaughter. Song and Dinkel (1978a) slso designed a mathematical model to estimate voluntary feed intake of cattle varying in age and breed and fed rations varying in energy density and/or crude fiber content.

Computers have increased the rate and effectiveness of designing mathematical models of biological systems. Because of the complexity and number of computations required, digital computers are essential. Thousands of data points can be collected within a few seconds or vast amounts of data may be gathered and integrated into useful models. Once the model is formulated, computers are essential to simulate performance through time. In addition, one model or response function is seldom useful. Resesrchers and managers demand computer programs

with the capability to integrate many biological, chemical, and/or economic response functions related to their problems.

Several researchers have formulated programs to aid in livestock management decisions. Smith and Ladue (1974) incorporated an animal production system with a counterpart economic system for a dairy farm business. Chestnut (1977) used mathematical models to describe average daily gain and feed intake changes during the feeding period in order to predict instantaneous cost of gain for steers fed differing corn:corn silage ratios. Fox et al. (1977) and Bergen et al. (1978) integrated net protein requirements based on protein turnover and protein deposition with feed net protein values. Fox and Black (1977) used the California Net Energy System with respective multipliers to provide a framework for adjusting feedlot performance for frame size, sex, breed, environment, growth stimulants, composition of gain, ration associative effects, digestive stimulants, and previous treatment.

Growth Models

Several mathematical models describing growth (which has been defined and measured in an infinite number of ways) have been developed. Brody (1945) modeled and defined growth as a relatively irreversible change in magnitude of the measured dimension or function with respect to time, and emphaaized the concept of irreversibility to exclude fluctuations in weight and dimension due to such effects as food supply, gestation, and lactation. Models developed by Laird et al. (1965) and Gall (1969) reasoned that growth is the net result of

catabolism and anabolism. For most animal production processes, growth is expressed as the increase in body weight and may be represented in four ways: (1) absolute gain per unit time; (2) relative rate (or percentage when multiplied by 100) gain per unit time; (3) cumulative weight (weight at a given time); and (4) current weight as a percent or proportion of mature weight. The former two measure growth rate and the latter two, which result in sigmoid-shaped curves, measure total growth.

Lawrie (1966) divides the sigmoidal growth curve, which starts with fertilization, into three phases. It begins with a short initial phase when live weight increases with increasing age, followed by a phase of very rapid growth; then, finally ending with a phase when the rate of growth is very low (Figure 1). Brody (1945) divides the age curve of growth into two principal segments (Figure 2). The first may be designated as the self-acceleration phase where rate of growth increases with time. The second may be designated as the self-inhibiting phase of growth where rate of growth slows with time.

Figure 1.   Age Growth Curve
            (Lawrie, 1966)

Phase #3

Phase #2

Phase #1

WEIGHT

TIME
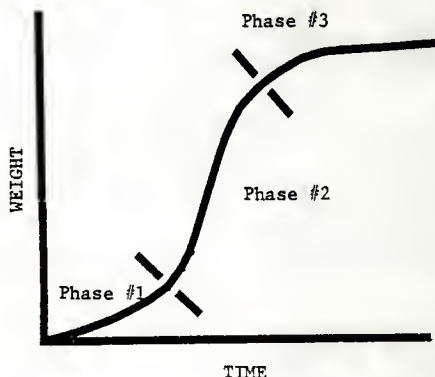
Figure 2.   Age Growth Curve
            (Brody, 1945)
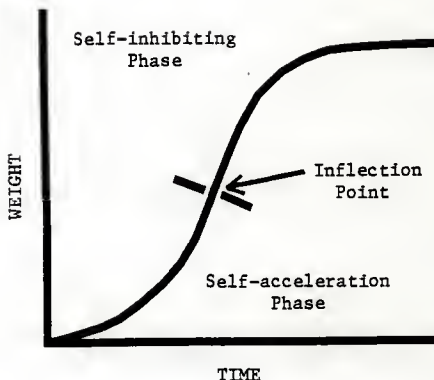
According to Brody, the general shape of the curve is determined
by two opposing forces: a growth-accelerating force and a growth-
retarding force. The former abides by the principal of mass action
which states that the reproduction rate tends to be directly propor-
tional to the number of reproducing units. Thus, when conditions are
favorable, one cell divides into 2, 2 to 4, 4 to 8, and so on at a
constant percentage growth rate. There comes a time, marked by the
inflection of the growth curve, in which growth rate becomes propor-
tional to the resources remaining for growth. Limits may include
space, food, or by-products of growth. Eventually, the growth-
accelerating forces and the growth-inhibiting forces reach a balance
at mature weight.

The inflection point represents the position at which increase
in growth velocity (self-accelerating phase) ceases and the decrease
in growth velocity (self-inhibiting phase) has not yet begun. Though

it is the time of maximum growth velocity, change in growth rate is zero. It marks the age of puberty and the age of lowest specific mortality (Brody, 1945) and hence, is a point of geometric and physiological age equivalence for all animals. Nevertheless, Laird et al. (1965) and Weymounth et al. (1931) agree that the inflection point has no biological significance.

Growth rate is generally a more useful criteria for evaluating growth than total growth. Two concepts have been used to estimate growth rates. Either a curve is fit to the plot of x (weight) vs. y (time) and then differentiated or the increment method is used in which the velocity curve is fit to Δx (weight change) vs. y (time). The basic criteria for the type of curve to be fit include choosing a curve which provides a close fit to the data, has a simple functional expression, and has few biological parameters. The traditional method (plotting weight vs. time and differentiating) requires that the course of growth be studied over a time period long enough to allow accurate determinations of the upper and lower asymptotes. Van't Hof et al. (1976) developed an approach for studying growth velocities from data over short time periods. They point out that one of the drawbacks of the increment method is that successive increments are negatively correlated, since x_2 is involved in both Δx_1 ($=x_2-x_1$) and Δx_2 ($=x_3-x_2$). Thus, if x_2 is measured with error $\varepsilon > 0$, Δx_1 is too large and Δx_2 is too small or visa versa. Moreover, since two measurement errors are involved in computing any given increment, the standard error of the difference between successive observations is $\sqrt{2}$ times that of the

error of the individual measurements. In addition, an increase in sampling frequency is not accompanied by an increase in precision.

Since the measurement error of a given increment depends only on the errors of the individual measurements, increasing sampling frequency results in relatively lower accuracy of the calculated velocities (Van't Hof et al., 1976). When observations are made more frequently, the magnitudes of the associated changes are necessarily smaller and yet the magnitudes of the measurement errors remains unchanged. The latter may then comprise the major source of variation.

White and Ratti (1977) weighed birds quite accurately and suggested the observed variation was not due to sampling error but to the growth process. They included an error term in differential equations to allow the growth rate to fluctuate randomly. However, no differences were found in growth rate between the dark and light phases. Fill variation in larger animals, especially ruminants, would overshadow any random variation in the growth process, though it may occur.

Minot (Brody, 1945) represented relative growth rate (change in weight during the specified time period relative to the weight of the animal during the time period) as weight gain during a given time interval divided by the weight, W_1, at the beginning of the time interval:

$$\text{Average Relative Growth Rate} = \frac{W_2 - W_1}{W_1} \qquad \text{Eq. 1}$$

where W_2 is the weight at the end of the time interval. Brody (1945) suggested a more appropriate denominator of $\frac{1}{2}(W_2 + W_1)$. The equation then obtained was:

$$\text{Average Relative Growth Rate} = \frac{W_2 - W_1}{\frac{1}{2}(W_2 + W_1)} \qquad \text{Eq. 2}$$

Brody found both equations unsatisfactory, as time intervals change with equal weight increases and both assumed growth to occur in a linear manner. As an alternative, Brody (1945) derived instantaneous relative growth rate,

$$\frac{dW/dt}{W} \qquad \text{Eq. 3}$$

from the finite weight gain equation

$$\frac{W_2 - W_1}{t_2 - t_1} \qquad \text{Eq. 4}$$

where W_1 is weight at time t_1, W_2 is weight at time t_2, t_1 is time at the beginning of the growth period, and t_2 is time at the end of the same growth period.

In equation 2, dW/dt is the instantaneous absolute growth rate or the change in weight with respect to time at time t and W represents animal weight at the instant dW/dt is measured. However, weight gains cannot be measured in the infinite short periods of time dt, so Brody (1945) to describe the self-acceleration phase of growth derived:

$$\frac{dW}{dt} = kW \qquad \text{Eq. 5}$$

where k is a constant defined as the instantaneous relative growth
rate for a given unit of time. By integrating this equation, weight
at time t equals:

$$W = Ae^{kt}$$

Eq. 6

where e is the base of natural logarithms and A is the natural
logarithm of W when $t = 0$. Thus, true instantaneous growth rate
could be determined by fitting weights taken at various times during
the growing period to equation and differentiating.

Although the constant A in equation 6 has the value of W when
$t = 0$ (conception), Brody placed no biological significance on it and
considered it merely as a parameter of the equation.

Equation 5 supports the principle of mass action for describing
the kinetics of monomolecular change. In physical chemistry, the
speed of first order reactions when all other conditions are equal
is proportional to the number of available units entering the reaction
at a given instant. Brody (1945) analogized growth with the principle
of mass action and stated that cell reproduction rate in early growth
tends to be directly proportional to the number of reproducing units
(cells). In later growth phases, Brody (1945) applied the principle
of mass action and stated that growth rate, dW/dt, is proportional to
available land, food supply, or encroaching by-products. Thus, the
equation:

$$\frac{dW}{dt} = -k(A - W)$$

Eq. 7

describes true instantaneous growth rate during the self-inhibiting phase. A is the mature weight and A – W would be the amount of weight gain still possible at time t. Growth rate decreases as time increases and as weight, W, approaches its maximum, A.

By integrating equation 7, weight data can be fit to the equation:

$$W = A - Be^{-kt} \qquad \text{Eq. 8}$$

where B is an integration constant. The equation can then be differentiated to determine true instantaneous growth rate, dW/dt.

In summarizing Brody's work, prior to puberty, weight was represented by the equation $W = Ae^{kt}$ and growth rate, which tends to be proportional to the weight already attained was represented by dW/dt = kW. Following puberty, weight was represented by $W = A - Be^{-kt}$ and dW/dt = -k(A - W) represented growth rate, which tends to be proportional to the growth yet to be made. Note that k and A are not the same in the two equations.

Gompertz describes growth with the equation (Brody, 1945):

$$W = Ae^{-e^{-t}} \qquad \text{Eq. 9}$$

where W is weight at time t, A is mature weight, and e is the base of natural logarithms. It has an inflection point of .368 A and states that for a given growth cycle the log-logs of the percentage of growth increase directly with time. The first derivative of the Gompertz curve:

$$\frac{dW}{dt} = Ae^{-t}e^{-e^{-t}} \qquad \text{Eq. 10}$$

describes instantaneous growth rate.

Robertson (1923) inferred that growth is an autocatalytic process and that the velocity of growth may be limited by a monomolecular autocatalytic chemical reaction represented by the equation:

$$\frac{dW}{dt} = kW(A - W) \qquad \text{Eq. 11}$$

in which growth rate is a function of both growth already made and growth yet to be made. The autocatalytic function is sigmoid shape with an inflection point at 0.5 mature weight. But animals reach puberty and decline in growth rate earlier than this. For this reason an animal's total weight fits the Gompertz curve which has an inflection point at about 1/3 of mature weight, better. Marubini et al. (1972) found the take-off point or the initial data points serve as the initial estimate of the lower asymptote in fitting logistic (Eq. 11) and Gompertz (Eq. 9) curves, but estimates of constants must be based upon well defined upper asymptotes.

Bertalanffy (1960) derived the equation:

$$\frac{dW}{dt} = aW^m - bW^n \qquad \text{Eq. 12}$$

in which the rate of change in body weight (W) per unit time (t) is the difference between the rate of anabolism (a) times weight to the mth power and the rate of catabolism (b) times weight to the nth power. The equation is based on the concept that growth occurs when or to the

extent that anabolism exceeds catabolism, and that the anabolic factor acts in proportion (m) to surface area and the catabolic factor in proportion (n) to weight and is assumed as unity. Maturity or a steady state would be reached when both processes are equal. Anabolism is a function of metabolism, which Bertalanffy assumes related to body weight in the same manner as surface area is related to volume. Therefore, m receives the value of 2/3.

Thus, Eq. 12 is written:

$$\frac{dW}{dt} = aW^{2/3} - bW \qquad \text{Eq. 13}$$

which on integration becomes:

$$W = (\sqrt[3]{W^*} - (\sqrt[3]{W^*} - \sqrt[3]{W_o})e^{-kt})^3 \qquad \text{Eq. 14}$$

where W_o is weight at time $t = 0$, W^* is mature weight and k equals b/3. This is very similar to Brody's monomolecular equation (Eq. 7) as growth rate depends on both initial and mature (or ultimate) weights and the velocity of growth rate change is dependent on the difference between weight at time t and the final weight.

Because of the theoretical value of m, Richards (1959, 1969) altered Bertalanffy's equation to:

$$W = (A^{1-m} + B_e^{-kt}, 1/1-m \qquad \text{Eq. 15}$$

where A is mature size.

Apart from the degree of compression, the shapes of different growth curves are due solely to differences in m. This constant

determines the proportion of the final size at which the inflection point occurs. Thus, equation 15 is very flexible. It may include the monomolecular (Eq. 7), autocatalytic (Eq. 11), and the Gompertz (Eq. 9) functions.

When $m = 0$ the equation yields a monomolecular curve, when $m = 2$ an autocatalytic curve and when $m = 1$ a Gompertz curve. Values of m between 0 and 1 give curve types grading from monomolecular to Gompertz and values of m from 1 to 2 produce curves ranging in type between Gompertz and autocatalytic. Curves also exist for values of m greater than 2.

All biological types are recognized, as the value of m may vary between extremes of 2/3 (for species obeying the surface rule of metabolism) and unity (where oxygen consumption is proportional to the animal's weight instead of its surface area).

Polynomial growth curves ($W = a + bt + ct^2 \ldots nt^n$, where W is weight and t is time) provide convenient mathematical properties, but biological interpretations of the results are difficult (Kowalski and Guire, 1974). Additionally, the coefficient of the powers of time are statistically dependent, which makes statistical analysis of the data difficult technically and interpretatively (Kowalski, 1972).

Van't Hof et al. (1976) described individual growth curves by a low degree polynomial over small time intervals. They then obtained the growth velocity curve by taking the derivative of the approximating polynomial. By dividing the observation period into subintervals, low degree polynomials fit the observations within the subintervals, providing the subintervals are sufficiently small. They concluded that

moving polynomials are an effective way to smooth errors inherent in the increment method without removing important biological variation among growth velocities.

Richards (1969) describes two general lines of reasoning for selecting the right growth function. One approach is to simply find the function with three or four terms having the best fit. The second approach describes the function by summing all terms representing any biological contribution to growth. Accounting for all physiological reactions may be desirable but requires a large number of terms. Each additional term adds another inflection point and too many inflection points become hopelessly confusing. Presently the first approach provides the only means of describing growth, but systematic deviations from simplified best fit curves may include biological parameters and hence compromise between the two approaches.

Van't Hof et al. (1976) compared the traditional method (plotting growth vs. time and differentiating) with the increment method (plotting growth rate vs. time) for estimating growth rate with respect to time. He clearly showed the increment method to have no statistical advantage and perhaps would involve more data collection and manipulation before curves could be fit.

In summary, several functions representing growth have been described. Depending on the type of growth and the growth phase, one of the functions or a slight deviation of one of the described curves should describe the data. Brody's equations describing the self-accelerating and the self-inhibiting phases are simple and biologically reasonable for describing their respective phases.

For data encompassing the entire growth curve, Richards' curve, although not the simplest, includes biologically significant parameters in the most flexible mathematical expression available.

Feed Energy

Various mechanisms for evaluating animals' energy intake are described by Kroman (1973), including the net energy, total digestible nutrients (TDN), and the starch equivalent (SE) systems. The net energy systems proposed by the California (Lofgreen and Garrett, 1968), British (Blaxter, 1962), and German (Nehring et al., 1969) workers provide important contributions. Based on the laws of thermodynamics, all the systems propose that an animal maintains a constant balance between energy input and output and that animals' productive processes transform input energy into growth, milk, eggs, wool, or muscular work.

Antoine Lavoisier (1965) and Mr. de la Place in the Memoirs of the Academy for 1780 described an apparatus for measuring the relative quantities of heat contained in bodies and named it a "calorimeter." The quantity of "caloric" disengaged during animal respiration was determined using guinea pigs. Brody (1945) drew analogies between the feed and nutritional categories and the thermodynamic categories using Gibb's free-energy equation, $\Delta F = \Delta H = T\Delta S$, where ΔF represents the change in intrinsic or internal energy, ΔH represents the change in heat content, T is the absolute temperature, and ΔS represents the change in entropy (energy unavailable for work). The energy equivalent of oxygen consumed by a working animal above that consumed at rest is

analogous to ΔH and the total energy associated with work and the maximum theoretically obtainable work by an animal is analogous with ΔF. ΔF would correspond to the net energy of feeds or the feed energy available for work, milk, eggs, meat, and maintenance. ΔH would be analogous with metabolizable energy (net energy plus heat increment). Heat increment is that portion of energy unavailable for work; $T\Delta S$. Gross energy is heat of combustion of the original feed, and digestible energy is gross energy less gaseous and fecal loss.

Under the conventional energy-distribution scheme (Figure 3), digestible energy is really apparent digestible energy, since feces contain endogenous indigestible material and secretions from the body into the digestive tract which do not arise directly from feed. Considerable CH_4 which has high caloric value is produced from rumen fermentation yet is considered as digestible energy, since it is not included in feces. Gaseous losses may be as high as 4000 Cal/day, to one third of the resting maintenance requirement of a 1200 pound cow. In addition, urinary energy (UE) under the conventional scheme is gross energy of the urine. Endogenous urinary energy losses are included in UE, but should be included in the maintenance requirement of the animal. Nitrogen retained or lost from the body must be accounted for in UE to correct metabolizable energy.

N.R.C. (1976) and Harris et al. (1972) described the True Energy-Distribution Scheme (Figure 4). Food-intake gross energy (GE_i) is the gross energy of the food consumed as determined by bomb calorimetry. True digestible energy (TDE) would be equivalent to GE_i less gaseous products of digestion, heat of fermentation, and metabolic fecal

FOOD INTAKE GROSS ENERGY

FECAL ENERGY (1) Food origin
              (2) Metabolic (body) origin

APPARENT DIGESTIBLE ENERGY

GASEOUS PRODUCTS OF DIGESTION

URINARY ENERGY (1) Food origin
                (2) Endogenous (body) origin
                (3) Nitrogen balance

METABOLIZABLE ENERGY (ΔH)

HEAT INCREMENT (wasted unless animal is below
($T\Delta S$)   the critical temperature)
                (1) Heat of fermentation
                (2) Heat of nutrient metabolism

NET ENERGY (ΔF)

PRODUCTION (NEp)   MAINTENANCE (NEm)
    (1) Energy storage   (1) Basal metabolism
        --fetus   (2) Voluntary activity
        --semen   (3) Heat to keep warm
        --growth   (4) Heat to keep cool
        --fat
        --milk
        --eggs
        --wool, fur, feathers
    (2) Work

Figure 3. Conventional Energy-Distribution Scheme

FOOD INTAKE GROSS ENERGY (GE_I)

→ FECAL ENERGY OF FOOD ORIGIN
    (fecal energy minus metabolic fecal energy)

→ GASEOUS PRODUCTS OF DIGESTION

→ HEAT OF FERMENTATION

TRUE DIGESTIBLE ENERGY (TDE)

→ URINARY ENERGY OF GOOD ORIGIN
    (urinary energy minus endogenous urinary
    energy)

TRUE METABOLIZABLE ENERGY (TME_n)

→ HEAT OF NUTRIENT METABOLISM

TRUE NET ENERGY (TNE)

PRODUCTION ENERGY (TNE_p)   → MAINTENANCE ENERGY (TNE_m)
    (1) Energy storage   (1) Basal metabolism
        —fetus   (2) Voluntary activity
        —semen   (3) Metabolic fecal energy (FE_m)
        —growth   (4) Endogenous urinary energy
        —fat   (UE_e)
        —milk   (5) Heat to keep warm
        —eggs   (6) Energy to keep cool
        —wool, fur, feathers
    (2) Work

Figure 4. True Energy-Distribution Scheme

energy (FE_m). FE_m includes energy from the intestinal mucosa, diges-
tive fluids, etc. that is not part of unabsorbed ration residues. True
metabolizable energy (TME) remains following correction of TDE for
endogenous urinary energy (UE_e), that energy in the urine not directly
of food origin. TME corrected for the energy lost or gained in
nitrogen balance is defined as TME_n. By removing heat of nutrient
metabolism from TME_n, true net energy (TNE) remains and is partitioned
into true net energy for maintenance (TNE_m) and true net energy for
production (TNE_p). TNE_m is the sum of the energy required for basal
metabolism, voluntary activity, metabolic fecal energy, endogenous
urinary energy and constant body temperature. Below the critical
temperature and above the point of hyperthermal rise, the heat to
keep the body warm or the energy to keep the body cool must be con-
sidered. In both schemes heat of fermentation and heat of metabolism
reduce the maintenance requirement when the environment is below the
critical temperature. Above the thermal neutral zone, heat of metab-
olism and heat of fermentation increases the maintenance requirement.
TNE_p would include energy stored in the body as placental contents,
semen, growth, fat, milk, eggs, wool, fur, and feathers and energy
used for work.

Factors Affecting TDE and Subsequent TME

Chemical composition. Ration chemical composition is the primary
factor in determining digestibility and subsequent digestible energy.
Usually, digestibility decreases as the percent of fiber in the diet
increases. Lignin, highly correlated with fiber content, prevents

microbial cellulase action reducing fiber digestibility (Church, 1969).
Furthermore, Hamilton (1942) and Swift and French (1954) concluded
that starch or soluble carbohydrates reduce fiber digestibility.
Silica contained in forages reduce cell-wall digestibility (Van Soest
and Jones, 1968). Cell-contents constituents increase digestibility
(Van Soest, 1970).

Species differences. Comparisons between European cattle breeds
and sheep are inconclusive. Cipalloni et al. (1951) found cattle
digested roughages to a greater extent than sheep, whereas sheep
digested concentrates more efficiently. In 1959 Swift and Bratzler
(Church, 1969) found no significant differences between the two species
in the digestibility of forage dry matter, crude protein, and digest-
ible energy. Alexander et al. (1962) reported comparative results.
Tyrrell and Moe (1975) emphasized the danger of extrapolating digestion
coefficients derived from sheep to feeding standards applied to other
ruminants based on work by Wilson et al. (1973). They found digesti-
bility of corn grain differed significantly between cattle and sheep.
Studies by Hungate et al. (1960) indicate that Zebu cattle have a more
rapid fermentation rate than European breeds. These results were con-
firmed by Phillips (1961) who found Zebus digested 3% more organic
matter of low quality hay than Hereford steers. Numerous studies
showing digestibility differences between other ruminant species are
reported by Church (1969).

Intake. As intake increases, digestibility of various nutrients and of the total ration decreases, due to faster passage through the digestive tract and decreased microbial degradation in the reticulo- rumen. Digestibility of all fractions of the diet is not depressed equally. At high intakes cellulose and hemicellulose digestibility is depressed 2 to 3 times the depression of soluble carbohydrate digestibility. Orskov et al. (1969) found that reduced ad libitum intake decreased the amount of starch escaping fermentation in the reticulorumen. Wagner and Loosli (1967) found that when digestibility was depressed by intake, it was more severely depressed by increased percentage of grain. Similar data were reported by Brown (1966), Tyrrell and Moe (1975), and Leaver et al. (1969). The latter workers found that as feed intake increased there was a curvilinear decline in organic matter digestibility with ruminants fed high concentrate diets. Tyrrell and Moe (1975) demonstrated a linear decline of 4.58% in digestibility for each multiple of maintenance increase.

Processing. Processing effects digestibility (Moore, 1964; Van Soest, 1971) and modifies associative effects. In general, grinding, rolling or flaking grain increases digestibility. Coefficients of corn fed to cattle improved from 61.6% for whole dried corn to 80.1% for ground high moisture corn (Wilson et al., 1973). Steaming or cooking usually improves the carbohydrate utilization in grains. Pelleting has little effect on grains but increases rate of passage and intake of roughages while reducing their digestibility. According to Meyer, Kroman, and Garrett (1965), pelleting per se generally

decreases fiber digestibility but may or may not decrease energy digestibility. Heating may improve some protein utilization, but too much heat easily reduces digestibility.

In summary, any factor affecting TDE will affect subsequent TME. Although increased intake and processing decreases the digestibility of most finishing rations, total energy intake increases (Donker and Naik, 1979). More feed is available for growth and fattening the higher the energy intake. Consequently, gains are more rapid and more economical.

Maintenance Energy

Living is an expensive process. Circulation, respiration, excretion, and muscle tension never cease while life remains, even under conditions of absolute rest. There are, moreover, energy wastes associated with activities of enzyme systems and there is also an energy cost for maintaining the thermodynamically unstable living state.

Most differences between net energy systems are in the way the net energy for maintenance (NE_m) requirements are determined or expressed. Lofgreen and Garrett (1968) defined NE_m as equivalent to the fasting heat production. They extrapolated the plot of daily metabolizable energy intake ($kcal/W^{.75}kg$) vs. daily heat production ($kcal/W^{.75}kg$) to zero intake and arrived at NE_m of 77 kcal ($W^{.75}$). Reid and Robb (1971) have questioned using the logarithm of heat production to obtain linearity. Forbes et al. (1928) demonstrated heat production was, in fact, a sigmoidal function of energy intake and fasting heat production and

equal to 87.7 kcal/kg$\cdot^{.75}$. Forbes et al. (1931) later estimated fasting heat production as 76.1 kcal/kg$\cdot^{.75}$ and showed that during feeding it approached a maximum asymptotic value. Kleiber (1961) found 70 W$\cdot^{.75}$kg represented the kcal per day expended as heat by a fasting animal in a thermal neutral environment. Furthermore, he stated and is supported by data of Ritzman and Benedict (1930, 1931, 1938) and Ritzman and Colovos (1943) that this per day expenditure is influenced by age. Tepperman (1962) points out that differences in muscle tone alone could account for the variations in energy needed by two individuals apparently similar in body build and activity pattern. Relaxation of muscles during restful sleep may reduce the basal metabolic rate by as much as 16%. Conceivably, the act of sitting quietly could require more energy for the "high tone" individual than for the "low tone" individual.

Energy required for activity and maintaining body temperature is part of maintenance requirement. Whenever ambient temperatures drop below the lower critical temperature, extra metabolic heat must be produced for the animal to maintain its body temperature. Above the critical temperature, body temperature and metabolic rate remain constant but increase when heat gain of an animal exceeds heat loss (Klieber, 1961). Thermal stress is a function of several environmental factors that in combination are termed effective temperature; the cooling or heating power of the environment in terms of dry bulb temperature (Ames, 1974). The two major variables which determine effective temperature during cold are dry bulb temperature and wind velocity. These in combination are referred to as the wind-chill

effect. Wind-chill indices for bare-skinned animals are based on
studies by Sipple and Passel (1945). Data by Barnes (1974) suggest
insulated animals respond to wind-chill differently than bare-skinned
animals if wind velocities are greater than 20 m.p.h. Temperature
was the most important factor in determining the rate of heat loss.
Increasing wind velocity negated external insulation and air inter-
face insulation in fleeces up to 6 cm long but not in fleeces longer
than 6 cm (Barnes, 1974). Webster et al. (1969 and 1970) showed that
sheep and cattle adapt to cold environments by changing their critical
temperature. Schake et al. (1971) have reported a seasonal variation
in cattle performance in Texas.

Data by Young and Christopherson (1974) illustrate that cold can
reduce digestion efficiency in ruminants though cold's major effect is
because animals must produce heat to maintain homeothermy during expo-
sure. Productivity is reduced in prolonged cold periods due to reduced
digestion efficiency and thus increased maintenance requirement.
Apparent dry matter digestibility of alfalfa declines .27 to .40% per
$1°C$ drop in sheep and .19 to .34% per $1°C$ drop in calves.

In summary, the animal's maintenance requirement is about 77
$kcal/kg^{.75}$. Although age and muscle tone may influence it, additional
energy required to maintain homeothermy increases maintenance most.
To reduce their maintenance load, animals' critical temperatures, hair
coats, and eating and exercise habits fluctuate seasonally.

Factors Affecting Growth

Genetics

Genetic influences on animal growth are detectable early in embryonic life. Gregory and Castle (1931) found differences in cell division rate between the embryos of large and small races of rabbits 48 hours after fertilization. Birth weight of cattle and sheep is influenced largely by the nature of the respective embryos. Heritability estimates are 41 and 32%, respectively. Recessive gene expression resulting in dwarfism or doppelender development markedly influence growth.

Mature Weight

Fitzhugh and Taylor (1971) found size differences at any age are highly genetically correlated with size at other ages, inferring that size differences between immature individuals of the same age are due to differences in environmental history and mature weight. M. E. Dikeman (personal communication) states that mature weight is genetically determined and defines it as the point on the growth curve when structural tissue (muscle, bone, vital organ, and connective tissue) has ceased. He excludes protein turn-over and excess fat deposition from mature weight. Forrest et al. (1975) suggest that seldom, if ever, do animals attain their full potential and that environment determines the extent to which an animal performs and achieves mature weight. However, Thonney (1976) altered mature size in cattle by altering endocrine balances and Preston (1978) claimed diethyl stilbestrol increased the mature size of Hereford, Angus, and Charolais

cross steers. As mature weight is determined genetically, Eckles and Swett (1918) permanently reduced mature size of dairy heifers by severely restricting energy. I contend the latter workers did not alter mature weight but altered the environment and thus the final animal weight more nearly approached mature weight.

Calo et al. (1973) estimated mature weight of 1044 kg for Holstein-Friesian bulls 4½ to 6½ years old. Matsushima et al. (1971) fed two black-whiteface steers 436 days to a final weight of 1901 pounds.

Carcass Composition

Proportions of body bone, muscle, and fat change continuously during growth. Growth rates vary between tissue and between constituents in the same tissues. All three constituents increase from birth to maturity but bone grows at a steady, slow rate, muscle at a relatively rapid rate and fat at the most rapid rate. On an empty body basis during growth, the percentage of skeleton and lean tissue declines and that of fatty tissues increases. In their cattle, Forrest et al. (1975) found the percentage of bone declines faster than that of muscle, up to 10 months of age. After 10 months, the reverse occurred. Total protein, as a percent of empty body weight, declined about 7.5 percent from birth to maturity.

Adipose tissue contains approximately 2.5 times the energy per kg as protein and carbohydrates. Consequently, as animals grow and the percentage of fatty tissue increases in the empty body, the pounds of feed to pounds gain ratio increases. Thonney (1976) found cattle of large mature size grow more rapidly and more efficiently than cattle of smaller mature sizes when compared at the same weight as composition-

weight relationships are a function of genetically determined mature
weight. Thus, animals which differ genetically will contain different
amounts of fat and lean tissues at the same weight. Hence, they will
grow at different rates and efficiencies. As bulls tend to have greater
mature weights than heifers, they also tend to be leaner than heifers,
at the same weight.

Sex

Females usually mature earlier physiologically but males are
usually heavier and larger in the adult form. The difference in size
between sexes results in a difference in development of body proportions
since different parts of the body tissues grow at different rates.
Castration of either sex tends to reduce sex differences in growth
rate and body composition (Hammond, 1932).

Plane of Nutrition

Differences in the plane of nutrition at any age from late fetal
stage to maturity alter growth generally and affect the different body
regions, tissues and various organs differently (Lawrie, 1966). Animals
on different planes of nutrition, even if they are of the same breed and
weight, will differ greatly in form and composition (Hammond, 1932;
McMeekan, 1940, 1940a, 1941; Pomeroy, 1941; Wallace, 1948). Deficien-
cies in required nutrients or the inability of an animal to metabolize
a nutrient markedly affects growth.

Changes in nutritional plane play significant roles in body com-
positional changes during growth. Pigs started on a high level of
nutrition and switched to a low level produced carcasses with more

muscle and less fat than if the nutritional levels were reversed (low level to high level) (Forrest et al., 1975). To the contrary, Reid and Preston reviewed the literature and concluded that, except where energy level was severely restricted, level of energy intake has little influence on body composition of growing animals independent of weight (Thonney, 1976).

Compensatory Gain

An animal whose growth has been restricted exhibits, when restriction is removed, a rate of growth greater than that which is normal in animals of the same chronological age. Evidence of compensatory gain is well documented in the literature. Palsson (1955) found tissues and organs recuperate remarkably when growth restriction ceases. Waters (1908, 1909) found beef steers subjected to undernutrition could recover and reach normal mature size and height. Numerous experiments have shown negative correlations between winter and summer gains in cattle as cattle wintered on low planes of nutrition gain more rapidly on summer grass than those wintered on high nutritional planes (Black et al., 1940; Pearson-Hughs et al., 1955). Fox et al. (1971) and Dockerty et al. (1971) found beef animals subjected to energy restriction rapidly recovered when fed diets adequate in energy.

Ragsdale (1934) suggested that undernutrition disturbs the normal relationship between chronological and physiological age so that physiological age proceeds at a rate slower than normal when nutrition is restricted when normal nutrition is resumed, the animal tends to grow at a rate appropriate to its physiological age rather than its chronological age (Winchester and Ellis, 1957). Wilson and Osbourn (1960)

explain compensatory gain via a homeostatic mechanism which maintains a
constant relationship between body form and size. Thus, rapid growth
rates occur following restriction to re-establish the desired equilib-
rium between form and size. Pomeroy (1955) feels much of compensatory
gain is due to body metabolic efforts to replace adipose tissue stores
depleted by energy restriction.

Palsson (1955) found most organs and tissues will completely re-
cover from growth retardation if undernutrition is not too severe with
tissues retarded the most exhibiting the greatest recuperative capacity
once normal nutrition is resumed. He noted an increasing effect on
different organs and tissues in the direct order of their maturity. That
is, later maturing tissues were retarded more than early maturing tissues.

Dockerty et al. (1971) found energy restriction did not significant-
ly effect loin eye area or carcass grade if steers were fed to equivalent
slaughter weights on energy-rich diets as full-fed controls. Fox et al.
(1971) claimed that previous nutritional history effected protein utili-
zation as compensatory steers consistently utilized protein more effi-
ciently than full-fed controls. Carcasses of full-fed bull calves that
had previous fed energy-restricting diets contained less fat and a higher
proportion of saleable meat (Levy et al., 1971).

Maternal Environment

Favorable environmental conditions are necessary for the full
expression of an individual's genetic capacity. Irrespective of the
birth weight, the rate of weight increase in young pigs is largely
established by suckling order (Barber et al., 1955). In addition,
birth weights of the offspring from young mothers are lower than those

from mature females and birth weights of offspring from large individuals are greater than those from small females (Lawrie, 1966). Non-maternal environmental influences are generally assumed to affect animal growth via the maintenance requirement and consequently will be discussed in that section.

Endocrinology

Imbalances and over synthesis of growth hormone and thyroxine significantly effect growth. Baird et al. (1952) showed that the growth hormone content of the pituitary from rapidly growing pigs was significantly higher than that of slow growing pigs.

Feed Additives

Numerous compounds increase growth rate and feed efficiency through improving digestion efficiency by altering the acetate to propionate ratio or propionate in the rumen. Monensin increases gain of grazing cattle 10 to 15 percent. Avoparcin (60g/ton) improved average daily gain 4.3%, reduced intake 7%, and improved feed efficiency 11.4% in steers. Lasalocid sodium at a level of 10g/ton improved rate of gain by 9.2% and feed efficiency by 8.9%.

Some organophosphates and elfazepam improve growth rate and feed efficiency by increasing consumption. Amicloral improves animal performance by decreasing methane production. Naturally, methane inhibitors produce a more favorable response on high roughage diets. Young (1975) fed 4% 1,3-butanediol (BD) to growing cattle and showed slight improvements in rates of gain and feed efficiency. However, Yoshida et al. (1971) fed two calves diets containing 5.88% BD and showed no differences in performance.

Stress susceptibility interferes with growth and development as shown by Sherman et al. (1957, 1959) and Hansard et al. (1959) in which low doses of tranquilizers increased weight gain and feed efficiency in cattle and sheep.

Antibiotics have been shown to effect growth rates and feed efficiency in livestock, perhaps due to the control of subclinical infections. In ruminants, antibiotics improve feed utilization and starch digestion by depressing microbial activity responsible for producing waste gas (Preston, 1962).

Intake

Feed intake regulation includes both short term and long term components. Short term control starts and stops at a single meal, while long term control regulates a large number of single meals. Long-term energy intake must adapt to energy expenditure because animals, like humans, do not regulate exact caloric intake for a single meal. Long range results would be devastating if they consumed a few too many calories each meal.

Over a wide range of ration energy concentrations, animals (both ruminants and non-ruminants) adjust voluntarily feed intake so as to maintain equal caloric intakes. That is, they eat for calories unless physical fill interferes by limiting consumption (Baile and Forbes, 1974). Physical fill in ruminants occurs in low quality, high fiber diets or silage diets containing in excess of 80% water. However, Thomas et al. (1961) found water did not limit intake of silage fed to heifers.

Montgomery and Baumgardt (1965) proposed a model of feed intake control in which signals integrated by the feeding centers in the hypothalamus are triggered by distension or the physical filling of the digestive tract and by chemostatic signals related to metabolism. Rations low in nutritive value (due to either low digestibility or high bulkiness) are consumed poorly because the reticulo-rumen and not the intestines (Grovum and Phillips, 1978) becomes distended and dry matter intake is inhibited before the demand for energy is satisfied. As ration caloric density is increased, both feed and energy are set by the physiological demands of the animal. Further increases in the nutritive value of the ration are accompanied by decreased feed intake but constant energy intake (chemostatic control). Most non-ruminant rations and high concentrate ruminant rations are under chemostatic control.

Dinius and Baumgardt (1970) found in sheep that dry matter intake (DM) per unit of metabolic weight ($MW = kg^{.75}$) increased as digestible energy (DE) increased (physical control) up to 2.47 kcal/gm (65% concentrate ration). Intake declined at higher DE concentrations (chemostatic control). Under physical control, DM/MW was 4.57 + 31.74 DE/gm and under chemostatic control, 147.50 - 26.13 DE/gm. Blaxter et al. (1961) found similar results. A 40 kg sheep ate less than 800 gm of a poor-quality roughage (40% digestible) and over 2000 gm of a high-quality herbage (85% digestible). Sheep ate 150 to 300 gm DM per day of 28% to 32% digestible roughage but 1300 to 1500 gm DM of 56% to 57% digestible roughage. DE/MW increased with increasing DE to 2.5 kcal/gm and was described by the equation DE/MW = 158 +

148 DE/gm. With higher DE energy intake remained constant, DE/MW = 241 - 12 DE/gm, though daily DM consumption decreased. The equations of Blaxter et al. (1961a) and Dinius and Baumgardt (1970) are comparable by a factor of ration energy density. Dinius and Baumgardt (1970) anticipated the threshold point between bulk density and energy regulation to be higher than 2.5 kcal DE/gm for rapidly growing or lactating animals having a higher energy requirement than animals nearing maturity. Conrad et al. (1964) found ad libitum daily feed intake was directly proportional to animal weight in feeds less than 66.7% digestible and proportional to the log of weight above 66.7%. The equation $0.54WD^{1.53}$ x 10^{-6} where W is body weight in pounds and D is the dry matter digestion coefficient described daily digested dry matter intake of dairy cows fed diets less than 66.7% digestible. $30W^{.62}E^{.27}_{m+p}D^{-1.19}$ where E_{m+p} is the adjustment for energy produced in the milk predicted daily digested dry matter intake for rations greater than 66.7% digestible.

Crampton (1957) concludes that recurring hunger in ruminants is primarily determined by reduced rumen load, which in turn depends on the rate of cellulose degradation and the hemicellulose content of the food. Adding yeast, protein, non-protein nitrogen or minerals to ruminant rations low in protein and minerals enhances the rate of microbial digestion and increases the rumen emptying rate. Blaxter (1961) states that foods of different qualities pass through the gut at rates which were proportional to their qualities. Particle size affects rate of passage and hence intake. When roughages are ground or pelleted, intake increases.

Major phases of the physiology of feed intake regulation remain hypothetical. There is a central regulatory mechanism for hunger and satiety, but the messages that activate the brain centers may be from osmoreceptors, a thermostat, a glucostat, or a lipostat, as well as amino acids, and/or hormones (Theologides, 1976). Brobeck and colleagues (1943), working with rate, showed that two centers in the hypothalamus are involved in the control of feeding and satiety. The ventromedial nuclei or satiety center relays information from the central nervous system and controls satiety. Destroying the center results in cumulative overeating and eventually obesity. Destroying the activity of the lateral hypothalamus results in animals refusing to eat. Electrical stimulation of the extreme parts of the lateral hypothalamic nuclei or the mammillo-thalamic tract in the medulla will produce immediate eating in goats.

Mayer and co-workers (1952) noted that in non-ruminants, blood glucose concentration and feed intake are closely related and suggested that appetite in man and simple-stomached animals responded to the arteriovenous difference in glucose, which is monitored in the hypo-thalamus as one component of chemostatic control. Glucoreceptors are contained in the hypothalamic satiety center and other central and peripheral centers. Panksepp (1974) states that a variety of glucose receptors exist within the hypothalamus. Those located in the medial area are insulin sensitive, are impaired by gold thioglucose and their impairment results in over-eating obesity. Those located in the lateral hypothalamus respond to hypoglycemia and when impaired, animals starve. Glucose levels controlled by pancreatic insulin

enhance blood sugar and result in increased feed intake (Bray, 1974). Glucagon, which produces hyperglycemia by glycogen break-down in the liver, inhibits feed intake.

Ruminants normally have low blood glucose concentrations and intravenous glucose in large amounts over long periods seems to have no effect on feed intake. Consequently, the blood glucose to feed intake interrelationship does not exist physiologically. Alternatively, the absolute concentration or arterio-venous difference in concentration of a metabolite other than glucose may be involved in chemostatic appetite regulation of ruminants.

Acetate, propionate, and butyrate are produced in large quantities by rumen microflora. Butyrate is largely metabolized in the rumen wall, but acetate and propionate are absorbed through the rumen wall and used as primary energy substrates in most ruminant tissues (Baile and Forbes, 1974). Acetate is produced and absorbed in the greatest quantities. Its intraruminal injection depresses intake in cattle, sheep, and goats much more than can be accounted for by the caloric value of the injection (Baile and Forbes, 1974). Additionally, intravenous infusions of ammonia or acetic acid will reduce food intake (Blaxter, 1962). Acetate receptors appear to be located in the rumen wall, and in highest concentration in the ventral rumen. Responses are transmitted neurally. On the other hand, intraruminal injections of propionate depress feed intake but not as dramatically as when propionate is given intravenously. Thus, propionate receptors may be located in the rumen vein walls and the luminal side of the rumen (Baile and Forbes, 1974).

Liebelt and co-workers (1963, 1965) found the total body fat mass of rats and mice to be regulated. Kennedy (1953) suggests that in the long run the hypothalamus modifies the general levels of feed intake and bodily activity in response to changes in body fat. This hypothesis accounts for the increased appetite and reduced activity in animals with hypothalamic lesions. In addition, the hypothesis suggests that animals attempt to maintain constant fat content of their bodies.

The amount of free fatty acids (FFA) mobilized each day is proportional to adipose tissue stores (Bates et al., 1955). Some correlate of FFA mobilization or utilization may be monitored by the central nervous system and provides an error signal for maintenance of stable body fat levels (Panksepp, 1974). Hervey (1969) proposed that feeding adjustments in response to body fat variations may be regulated by a tracer dilution involving steroid hormones. Baile et al. (1971) noted that prostalgandin production in adipose tissue is related to fat metabolism and thus may serve as a feedback signal which monitors adipose levels. Liebelt (1963) postulated that total body fat was regulated by a parameter other than adipose tissue. Faust et al. (1977) found fat stability to be achieved by adipocyte lipid content regulation and that such regulation controls food intake via neural and hormonal mediation.

Mellinkoff et al. (1956) reported an inverse relationship between amino acid levels and appetite in humans. Adair et al. (1968) observed marked food intake reductions in rats during chronic intravenous administration of amino acids. Additionally, rats compensate for selective dilution of a dietary protein source by increasing intake (Rozin, 1968)

but will eat little of imbalanced amino acid diets. Little is known
about the precise site of action of imbalanced diets but the response
is probably mediated directly by the brain (Leung and Rogers, 1971).
It is unlikely that amino acid levels or patterns play much of a role
in feed intake in ruminants, as absorption of amino acids occurs
several hours after ingestion in the small intestine and intravenous
injections of amino acid metabolites influence feed intake very little.

Brobeck (1948) proposed a thermostatic theory which states that
eating is a response to a fall in heat production and that animals
stop eating due to a rise in heat production. This theory states
that there are thermoreceptors in the hypothalamus but in areas
different from the lateral and ventro-medial nuclei. According to
the thermostatic hypothesis, in ruminants, continued heat exposure
depresses food intake and continued cold exposure increases food
intake. Appleman and DeLouche (1958) found that ruminants will not
eat at all above 40 C. Severe heat which limits or inhibits feeding
may be related to stress rather than to a normal signal for satiety
(Spector et al., 1968). Andersson and Larsson (1961) have shown with
goats that eating stops if the preoptic heat loss center of the hypo-
thalamus is warmed. When it is cool, eating is induced. Time rela-
tionships that exist between eating and peripheral vasodilation suggest
a correlation between thermoregulatory mechanisms and the hypothalamic
centers concerned with appetite regulation. However, body heat repre-
sents only a small part of the total body energy and is maintained
constant by a system that seems to act independently of the energy
balance regulating system (Baile and Forbes, 1974). Changes in

environment affecting the thermoregulatory system likely affect feed intake via changes in body fat or normal stress signals rather than directly via changes in body heat load.

Interneural transmission of sensory information and feeding behavior is via synapses. Therefore, putative transmitters serve as a critical link in the control of feeding. Histamine and 5-hydroxytryptamine in the hypothalamus trigger feeding (Baile, 1974). Cyclic AMP monitors feeding but seems to play the much broader role of intracellular mediation of neural transmitters. Adrenoceptor and cholinergic systems monitor feeding behavior as receptor neurons in the brain activated by decreased availability of utilizable fuels have been whown to trigger catecholamine discharge from the adrenal medulla (Strickler et al., 1977). Drugs affecting these systems may also initiate or inhibit feeding.

Parksepp (1974) hypothesizes that the control of feeding in ruminants is due to two integrated mechanisms; a set point which regulates body weight and an error signal which detects any deviations from this set point and regulates feed accordingly. The set point would determine an animal's long term energy balance as body fat stores and any deviations in energy balance in turn would be reflected in daily intake. Various types of information collected via neural transmission, hormones, and other blood metabolites are scanned and evaluated within the CNS. The hypothalamus integrates the various inputs and initiates or inhibits feeding within the limits of physical fill. Hence, feeding behavior reflects all sensory and metabolic pool information affecting energy balance.

Perhaps this hypothesis provides the most logical approach as it includes the observed interrelationship between feed intake and energy balance yet allows stimulation or termination of feeding via negative feedback signals from various sources.

EXPERIMENTAL PROCEDURE

Mathematical models were developed independently by trial to describe accumulative weight, average daily gain, and daily dry matter consumption as a function of days on feed and body weight from data of Trial I (Chestnut, 1977) and Trial II. In each trial, ten rations differing in corn silage:corn ratios were fed ad libitum to 20 individually fed Hereford steers, two steers per ration. Major ration ingredients were whole plant corn silage, cracked No. 2 yellow dent corn, and 44% protein soybean meal. Corn silage dry matter in Trial I ranged between 33 and 40% and in Trial II between 37.5 and 43.6%. Ration 1 (all roughage) and ration 10 (all concentrate) were formulated and balanced for protein and minerals using a soybean meal supplement. Digestible protein (DP) requirements were calculated from Preston's equation, $DP = 2.79 \ W^{.75} \ (1 + 1.905G)$, where DP is grams of digestible protein per day, $W^{.75}$ is metabolic weight in kg, and G is body weight gain in kg/day (Preston, 1966). Feed intake required for a three pound gain for each ration was derived using Lofgreen's equation (Lofgreen and Garrett, 1968) and NE_m and NE_p values from NRC (1976). Rations 1 and 10 had 1.0078 and 1.4362 Mcal/kg NE_p respectively in Trial I and 1.0106 and 1.4376 Mcal/kg NE_p respectively in Trial II. Rations 2 through 9 were formulated to have equal increment increases in NE_p. In order to assure protein was not limiting, five soybean

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meal supplements (Tables 1 and 2) were formulated to bring the total ration DP to 108% of the requirement. Ration composition, NE_p, NE_m, and DP are shown in Tables 3 and 4.

Steers in Trial I, beginning March 10, 1976, (Chestnut, 1977) averaged 283.1 kg and ranged from 248.6 to 332.0 kg. In Trial II, beginning October 26, 1977, steers averaged 339.7 kg and ranged from 331.1 to 349.3 kg. In both trials, the ten heaviest steers were randomly allotted to rations and then the ten lightest. Twenty-one and 7 day periods were allowed for animals to adjust to their rations in Trial I and II, respectively. Steers were individually weighed each Wednesday prior to their morning feeding. At this same time all feed remaining in the individual bunks was weighed back and samples taken for dry matter determination. Animals were fed twice daily and portions were adjusted to insure ad libitum intake without excessive waste. Silage samples were checked periodically for dry matter and adjustments made to maintain the proper corn silage:corn ratios on a DM (dry matter) basis. Animals in Trial I were slaughtered at an efficiency end point (Chestnut, 1977) of 7.0 Mcal NE_p/kg gain. Steers in Trial II were slaughtered at 544.3 kg. Quality and yield grade data were taken for both trials.

All environmental data were as reported to the National Weather Service in Local Climatological Data (1976, 1977, 1978). Daily maximum and minimum temperatures came from the Kansas State Department of Physics in Manhattan. Mean daily wind velocity was estimated by averaging data from National Weather Service Stations at Topeka and Concordia. Effective temperatures (C) were estimated from wind-chill

TABLE 1.   COMPOSITION OF SBM SUPPLEMENT IN TRIAL I
(DRY MATTER BASIS)

Ration	1-2	3-4	5-6	7-8	9-10
SBM %	88.22	87.94	87.42	86.81	86.24
Dicalcium Phosphate %	2.22	0.60	0.00	0.00	0.00
Limestone %	2.33	4.50	5.86	6.70	7.46
Trace Mineral Salt %	4.79	4.53	4.28	4.06	3.85
Molasses %	2.50	2.50	2.50	2.50	2.50
Vit. A (thousands I.U./kg)	50	50	50	50	50

TABLE 2.   COMPOSITION OF SBM SUPPLEMENT IN TRIAL II
(DRY MATTER BASIS)

Ration	1-2	3-4	5-6	7-8	9-10
SBM %	88.22	87.95	87.58	87.07	86.68
Dicalcium Phosphate %	2.21	0.55	0.00	0.00	0.00
Limestone %	2.40	4.68	5.97	6.82	7.53
Salt %	4.79	4.56	4.30	4.08	3.87
Trace Mineral %	0.48	0.46	0.43	0.41	0.39
Animal Fat %	1.92	1.82	1.73	1.63	1.55

TABLE 3. COMPOSITION OF RATIONS IN TRIAL I (DRY MATTER BASIS)

Ration	1	2	3	4	5	6	7	8	9	10
Corn %	0.00	9.64	19.30	28.94	38.64	48.34	58.05	67.75	77.47	87.16
Corn Silage %	89.95	80.01	70.07	60.13	50.13	40.10	30.08	20.05	10.13	0.00
SBM Supp. %[a]	10.05	10.35	10.63	10.93	11.23	11.55	11.87	12.20	12.50	12.84
Dig. Protein %	8.21	8.58	8.94	9.31	9.67	10.04	10.40	10.77	11.13	11.50
NE_m Mcal/kg	1.5788	1.6484	1.7182	1.7879	1.8576	1.9273	1.9970	2.0666	2.1363	2.2060
NE_p Mcal/kg	1.0078	1.0554	1.1030	1.1506	1.1982	1.2458	1.2934	1.3410	1.3886	1.4362
ME Mcal/kg	2.5420	2.6151	2.6882	2.7613	2.8344	2.9075	2.9806	3.0538	3.1268	3.1999

[a]Composition listed in Table 1.

TABLE 4. COMPOSITION OF RATIONS IN TRIAL II (DRY MATTER BASIS)

Ration	1	2	3	4	5	6	7	8	9	10
Corn %	0.00	10.72	20.90	29.96	39.64	49.29	58.99	68.64	78.33	86.86
Corn Silage %	89.67	78.72	68.30	58.89	49.91	38.92	28.92	18.93	8.93	0.00
SBM Supp. %[a]	10.33	10.56	10.80	11.15	11.45	11.79	12.09	12.43	12.74	13.14
Dig. Protein %	8.21	8.58	8.94	9.31	9.67	10.04	10.40	10.77	11.13	11.50
NE_m Mcal/kg	1.5843	1.6611	1.7344	1.8001	1.8697	1.9391	2.0086	2.0780	2.1476	2.2093
NE_p Mcal/kg	1.0106	1.0632	1.1132	1.1581	1.2056	1.2530	1.3005	1.3479	1.3954	1.4376
ME Mcal/kg	2.5452	2.6180	2.6908	2.7636	2.8364	2.9093	2.9821	3.0549	3.1277	3.2005

[a]Composition listed in Table 2.

factors for sheep with a 1 to 6 cm fleece (Ames, 1974). Critical
temperatures used for calculating heat or cold stress were 2 C for
December through March, 15 C for April and May and September through
November, and 25 C for June through August.

The variables examined in each model were ration concentration
(Mcal ME/kg), weekly mean temperature (C), weekly mean effective
temperature (C), weekly mean temperature variance, weekly mean
effective temperature variance, and hot or cold stress (C). Weekly
mean daily dry matter intake and daily dry matter intake averaged
throughout the trial were tried as variables in the accumulative
weight and growth rate models. Unknown parameters were estimated
using the nonlinear procedure of Statistical Analysis System (SAS)
(Barr et al., 1976) which produces least-squares estimates of coeffi-
cients for a non-linear model. Selected models contained those
combinations of variables which produced the smallest mean square
error and whose variables possessed the narrowest 95% confidence
intervals which did not include zero. Continuity between and within
trials and range of predicted values in selection of number and type
of variables was considered important. Coefficients were reported
to 8 significant figures.

RESULTS AND DISCUSSION

Selected Weight and Growth Rate models for Trials I and II were:

Predicted Accumulative Weight (PWT)

Eq. 16 = $A*(1-Be^{-KT})$

Predicted Average Daily Gain as a function of Days on Feed (PADGT)

Eq. 17 = $A*B*Ke^{-KT}$, where

A = Mature weight in kg

B = Integration constant

e = Base of natural log

K = Relative growth rate

$= K_0 + K_1*ME + K_2*DDMT + K_3*TP$

T = Days on feed

ME = Mcal ME/kg dry ration

TP = Effective temperature (C)

$DDMT$ = Daily dry matter with respect to time

Predicted Average Daily Gain as a function of Body Weight (PADGW)

Eq. 18 = $-K*(A-WT)$, where

K = Relative growth rate

$= K_0 + K_1*ME + K_2*DDMW + K_3*TP$

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WT = Body weight in kg

DDMW = Daily dry matter with respect to weight

Selected Dry Matter Intake models for Trial I were:

Predicted Accumulative Dry Matter Intake as a function of Days on Feed (PDMT)

Eq. 19 Cubic Regression Model:

$$= X_0 + X_1*ME + X_2*ME^2 + X_3*ME^3 + X_4*T + X_5*T^2 +$$
$$X_6*T^3 + X_7*TP + X_8*TP^3 + X_9*ME*T + X_{10}*ME*TP$$

Eq. 20 Quadratic Regression Model:

$$= X_0 + X_1*ME + X_2*ME^2 + X_3*T + X_4*TP + X_5*ME*T +$$
$$X_6*T*TP + X_7*ME*TP$$

Predicted Accumulative Dry Matter Intake as a function of Body Weight (PDMW)

Eq. 21 Cubic Regression Model:

$$= X_0 + X_1*ME^2 + X_2*ME^3 + X_3*TP + X_4*WT + X_5*WT^2 +$$
$$X_6*WT^3 + X_7*ME*WT + X_8*TP*WT$$

Eq. 22 Quadratic Regression Model:

$$= X_0 + X_1*ME^2 + X_2*WT + X_3*WT^2 + X_4*ME*TP +$$
$$X_5*ME*WT + X_6*WT*TP$$

Predicted Daily Dry Matter Intake as a function of Days on Feed (PDDMT)

Eq. 23 $= Y_0 + Y_1*ME + Y_2*ME^2 + Y_3*T + Y_4*T^2 + Y_5*ME*T +$
$$Y_6*TP^2 + Y_7*ME*TP + Y_8*T*TP$$

Predicted Daily Dry Matter Intake as a function of Body Weight (PDDMW)

Eq. 24   Non-linear Model:

$$= Y_0 * (1 - e^{-Z*WT}) + Y_1 * ME + Y_2 * TP + Y_3 * TP^3$$

Eq. 25   Cubic Regression Model:

$$= Y_0 + Y_1 * ME + Y_2 * ME^2 + Y_3 * TP^2 + Y_4 * ME * WT +$$
$$Y_5 * ME * WT^2 + Y_6 * ME * WT^3 + Y_7 * ME * TP^2$$

Eq. 26   Quadratic Regression Model:

$$= Y_0 + Y_1 * ME + Y_2 * ME^2 + Y_3 * TP + Y_4 * TP^2 + Y_5 * WT +$$
$$Y_6 * WT^2 + Y_7 * TP * WT + Y_8 * ME * WT^2 + Y_9 * TP^2 * WT + Y_{10} * TP * WT^2$$

Selected Dry Matter Intake models for Trial II were:

Predicted Accumulative Dry Matter Intake as a function of Days on Feed (PDMT)

Eq. 27   Cubic Regression Model:

$$= X_0 + X_1 * ME + X_2 * ME^2 + X_3 * ME^3 + X_4 * T + X_5 * T^2 +$$
$$X_6 * T^3 + X_7 * TP + X_8 * TP^3 + X_9 * ME * T + X_{10} * ME * TP$$

Eq. 28   Quadratic Regression Model:

$$= X_0 + X_1 * ME + X_2 * ME^2 + X_3 * T + X_4 * TP + X_5 * ME * T +$$
$$X_6 * T * TP + X_7 * ME * TP$$

Predicted Accumulative Dry Matter Intake as a function of Body Weight (PDMW)

Eq. 29 Cubic Regression Model:

$$= X_0 + X_1*ME + X_2*ME^2 + X_3*ME^3 + X_4*TP + X_5*TP^2 +$$
$$X_6*TP^3 + X_7*WT + X_8*WT^2 + X_9*WT^3 + X_{10}*ME*WT +$$
$$X_{11}*TP*WT + X_{12}*ME*TP$$

Eq. 30 Quadratic Regression Model:

$$= X_0 + X_1*ME + X_2*ME^2 + X_3*TP^2 + X_4*WT + X_5*WT^2 +$$
$$X_6*ME*TP + X_7*ME*WT + X_8*TP*WT$$

Predicted Daily Dry Matter Intake as a function of Days on Feed (PDDMT)

Eq. 31 $= Y_0 + Y_1*ME + Y_2*ME^2 + Y_3*T + Y_4*T^2 + Y_5*ME*T +$
$$Y_6*TP^2 + Y_7*ME*TP + Y_8*T*TP$$

Predicted Daily Dry Matter Intake as a function of Body Weight (PDDMW)

Eq. 32 Non-linear Model:

$$= Y_0*(1-e^{-Z*WT}) + Y_1*ME + Y_2*TP + Y_3*TP^2$$

Eq. 33 Cubic Regression Model:

$$= Y_0 + Y_1*ME + Y_2*ME^2 + Y_3*TP + Y_4*ME*TP +$$
$$Y_5*WT^2 + Y_6*ME*WT^2 + Y_7*WT^3 + Y_8*ME*WT^3 +$$
$$Y_9*ME^2*TP + Y_{10}*ME*TP^3$$

Eq. 34 Quadratic Regression Model:

$$= Y_0 + Y_1*ME + Y_2*ME^2 + Y_3*TP + Y_4*TP^2 + Y_5*WT^2 +$$
$$Y_6*ME*WT + Y_7*TP*WT + Y_8*ME^2*WT + Y_9*ME*WT^2 +$$
$$Y_{10}*TP^2*WT + Y_{11}*TP*WT^2$$

Selected Feed Efficiency models for both trials were:

Predicted Instantaneous Feed Efficiency as a function of Days on Feed (PFET)

Eq. 35 = PDDMT/PADGT

Predicted Instantaneous Feed Efficiency as a function of Body Weight (PFEW)

Eq. 36 = PDDMW/PADGW

3-Dimensional Graphics

Three dimensional perspective plots of predicted average daily gain, predicted daily dry matter intake, and predicted feed efficiency as function of days on feed and body weight were constructed using a line plotter and the ITEL AS/5 processor using the Surface II Graphics System program (Sampson, 1975). Developed by the Kansas Geological Survey to map surfaces using least squares polynomial regression equations, Surface II is easily adapted to most data where two independent variables are related to one dependent variable.

The two independent variables X and Y are horizontal axes while the dependent variable Z is the vertical axis. X represents days on feed or body weight and Y the energy concentration of the ration, where ration 1 has the lowest concentration and 10 the highest. Predicted daily dry matter intake replaced observed values in average daily gain prediction equations. The flexibility of the size, transect, eleva-tion, and azimuth commands allowed the diagram to be illustrated in the fashion which depicts the modeled information most effectively.

All graphs in Figures 1-18 are viewed from an elevation of 30° above the horizontal X·Y plane and at an azimuth of either 65° or 115° to the right or -115° to the left of the Y·Z plane.

Equivalent base lines of the 3-D plots allowed differences to be shown between three independent variables and one dependent variable. Graphs on the same page illustrate differences in temperature effects within models within trials or temperature effects within models between trials.

Accumulative Weight

Selected Accumulative Weight Models (PWT) for Trials I and II, respectively, were:

Eq. 37 $PWT = (790.56265270)(1-Be^{-KT})$

$B = .63595042$

$K = -.00919977 + .00307900*ME + .00043685*DDMI -$
$.00001165*TP$

and

Eq. 38 $PWT = (601.26380120)(1-Be^{-KT})$

$B = .38005912$

$K = -.01791095 + .00564404*ME + .00092741*DDMI +$
$.00004527*TP$

Predicted Accumulative Weight increased to maturity (790.56265270 and 601.26380120 kg in Trials I and II, respectively) as days on feed increased. In both trials, maturity was reached significantly more

TABLE 5. ANALYSIS OF VARIANCE OF THE PWT MODEL (Eq. 37)
(TRIAL I)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	3	108,871,431	36,290,477	
Ration[b]	27	517,906	19,181	6.67[g]
Lack of fit[c]	24	38,249	1,593	.55[h]
Model[d]	3	479,657	159,885	
Animal/Ration[e]	30	86,224	2,874	
Residual[f]	566	626,137	1,106	

[a]$WT = A*(1-Be^{-KT})$ fitted to pooled data of 20 steers (Appendix Table 1).

[b]Regression $-$ [$WT = A*(1-Be^{-KT})$ fitted to data pooled by ration] (Appendix Table 1).

[c]PWT $-$ [$WT = A*(1-Be^{-KT})$ fitted to data pooled by ration] (Appendix Table 1).

[d]Ration $-$ Lack of fit.

[e][$WT = A*(1-Be^{-KT})$ fitted to data pooled by ration] $-$ [$WT = A*(1-Be^{-KT})$ fitted to data by animal] (Appendix Table 1).

[f]$WT = A*(1-Be^{-KT})$ fitted to data by animal (Appendix Table 1).

[g]($P<.0001$) Ration MS $\div$ Animal/Ration MS.

[h]($P<.9289$) Lack of fit MS $\div$ Animal/Ration MS.

TABLE 6.   ANALYSIS OF VARIANCE OF THE PWT MODEL (Eq. 38)
(TRIAL II)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	3	113,197,573	37,732,524	
Ration[b]	27	149,715	5,545	4.31[g]
Lack of fit[c]	24	68,495	2,853	2.22[h]
Model[d]	3	81,219	27,073	
Animal/Ration[e]	30	38,540	1,284	
Residual[f]	498	212,489	426	

[a]$WT = A*(1-Be^{-KT})$ fitted to pooled data of 20 steers (Appendix Table 2).

[b]Regression - $[WT = A*(1-Be^{-KT})$ fitted to data pooled by ration] (Appendix Table 2).

[c]PWT - $[WT = A*(1-Be^{-KT})$ fitted to data pooled by ration] (Appendix Table 2).

[d]Ration - Lack of fit.

[e]$[WT = A*(1-Be^{-KT})$ fitted to data pooled by ration] - $[WT = A*(1-Be^{-KT})$ fitted to data by animal] (Appendix Table 2).

[f]$WT = A*(1-Be^{-KT})$ fitted to data by animal (Appendix Table 2).

[g]($p < .0001$) Ration MS ÷ Animal/Ration MS.

[h]($p < .0197$) Lack of fit MS ÷ Animal/Ration MS.

(P<.0001) quickly as ration energy increased and animals ate more (Tables 5 and 6). Coefficients for TP in Trials I and II were of opposite signs as cattle in Trial I fed during the summer were exposed to heat stress as effective temperature increased, while in Trial II (winter), cattle were cold stressed as effective temperature increased.

In both trials, the F test for lack of fit accepted the null hypothesis that no differences exist between actual and predicted weights (Tables 5 and 6). Using actual feed intakes and effective temperatures, correlations between predicted (PWT) and observed values were .974 and .945 for Trials I and II, respectively.

Growth Rate

Selected models for Average Daily Gain as a function of Body Weight (PADGW) for Trials I and II, respectively, were:

Eq. 39 PADGW = K*(806.21745570 - WT)

$$K = -.00578900 + .00239562*ME + .00027643*DDMI - .00003196*TP$$

and

Eq. 40 PADGW = K*(711.67255583 - WT)

$$K = -.00975101 + .00285717*ME + .00065456*DDMI + .00008483*TP$$

WT = Body weight in kg

ME = Mcal ME/kg dry ration

DDMI = Weekly mean daily dry matter intake in kg

TP = Weekly mean effective temperature (C)

Predicted average daily gain as a function of body weight (PADGW) increased linearly with increasing energy density in both trials from rations 1 to 9. Ration 10 shows slightly less increase in rate of gain for increased ration energy density due to the unsatisfactory nature of an all concentrate diet. Figure 5 indicates that rations had a greater effect in Trial I than Trial II regardless of body weight, though ration differences were significant in both trials (P<.0001, Trial I, Table 7; P<.0023, Trial II, Table 8). As body weight increased, average daily gain decreased in a non-linear manner with the higher energy rations decreasing slightly faster than the low energy rations. At equal body weight and effective temperature, PADGW decreased more rapidly in Trial I than Trial II. In Trial I, PADGW of ration 1 dropped from 1.20 to .67 kg gain/day or a 44% decline, while ration 10 dropped from 1.84 to .99 kg gain/day or 46%. In Trial II, the same parameters were 1.31 to .79 kg gain/day (40%) and 1.50 to .86 kg gain/day (43%). This near linear decline in gain with increasing body weight is compatible with Brody's equation $\frac{dW}{dt} = -k(A - W)$ (Brody, 1945). Figures 6 and 7 show that models for both trials decreased performance with increased environmental stress regardless of ration or body weight. Percent gain declines due to environmental stress were greatest on high roughage rations and at lower body weights in both trials.

TABLE 7. ANALYSIS OF VARIANCE OF THE PADGW MODEL (Eq. 39)
(TRIAL I)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	2	734.9	367.4	
Ration[b]	18	31.9	1.7	6.24[g]
Lack of fit[c]	15	1.3	.0	.32[h]
Model[d]	3	30.5	10.1	
Animal/Ration[e]	20	5.6	.2	
Residual[f]	567	598.6	1.0	

[a]ADG = K(A-W) fitted to pooled data of 20 steers (Appendix Table 3).

[b]Regression - [ADG = K(A-W) fitted to data pooled by ration]
(Appendix Table 3).

[c]PADGW - [ADG = K(A-W) fitted to data pooled by ration] (Appendix
Table 3).

[d]Ration - Lack of fit.

[e][ADG = K(A-W) fitted to data pooled by ration] - [ADG = K(A-W)
fitted to data by animal] (Appendix Table 3).

[f]ADG = K(A-W) fitted to data by animal (Appendix Table 3).

[g](P<.0001) Ration MS ÷ Animal/Ration MS.

[h](P<.9849) Lack of fit MS ÷ Animal/Ration MS.

TABLE 8. ANALYSIS OF VARIANCE OF THE PADGW MODEL (Eq. 40)
(TRIAL II)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	2	549.3	274.6	
Ration[b]	18	35.3	1.9	3.85[g]
Lack of fit[c]	15	2.7	0.1	.36[h]
Model[d]	3	32.5	10.8	
Animal/Ration[e]	20	10.1	0.5	
Residual[f]	499	598.3	1.1	

[a]ADG = K(A-W) fitted to pooled data of 20 steers (Appendix Table 4).

[b]Regression - [ADG = K(A-W) fitted to data pooled by ration]
(Appendix Table 4).

[c]PADGW - [ADG = K(A-W) fitted to data pooled by ration] (Appendix
Table 4).

[d]Ration - Lack of fit.

[e][ADG = K(A-W) fitted to data pooled by ration] - [ADG = K(A-W)
fitted to data by animal] (Appendix Table 4).

[f]ADG = K(A-W) fitted to data by animal (Appendix Table 4).

[g](P<.0023) Ration MS ÷ Animal/Ration MS.

[h](P<.9750) Lack of fit MS ÷ Animal/Ration MS.

Fig. 5. Predicted average daily gain (kg) from 280 to 550 kg body weight over rations 1 to 10 at 5C for Trial I (Eq. 39) and II (Eq. 40).

Angle of view:
Elevation 30°, Azimuth 65°.
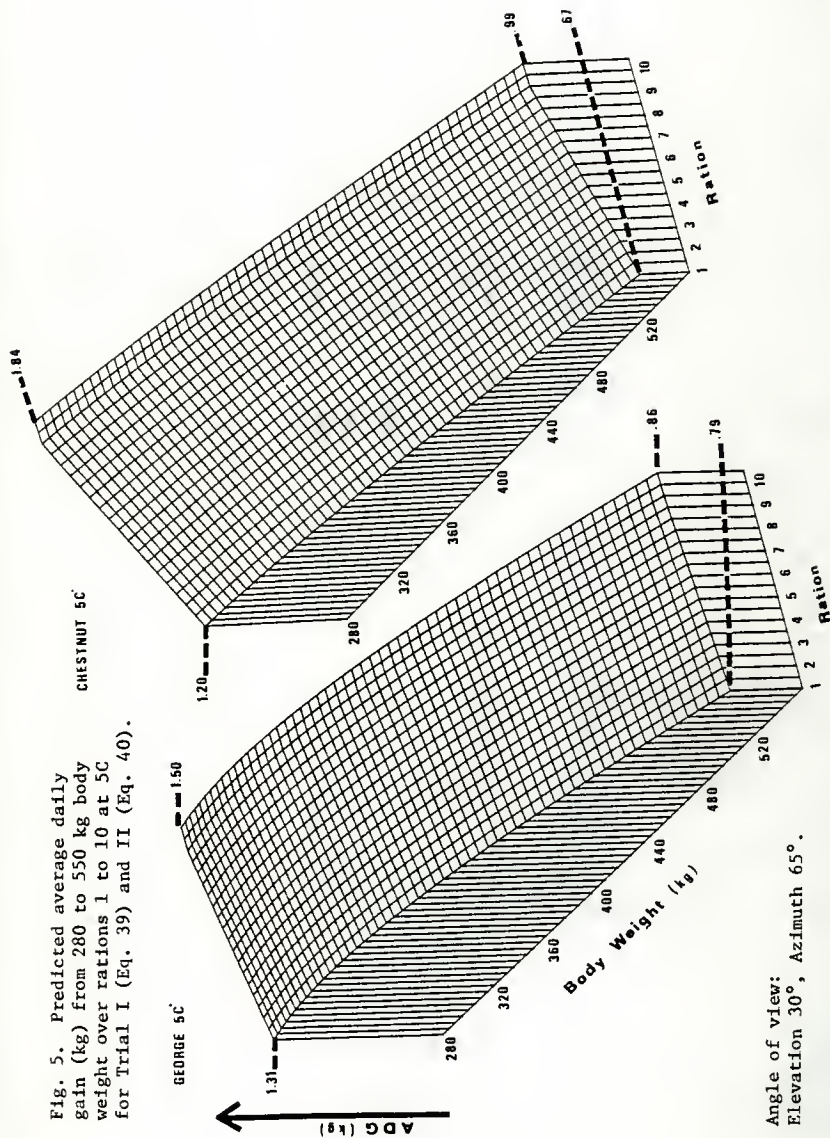
Fig. 6. Predicted Average daily gain (kg) from 280 to 550 kg body weight over rations 1 to 10 at 5C and 25C for Trial I (Eq. 39).

Angle of view:
Elevation 30°, Azimuth 65°.

Fig. 7. Predicted average daily gain (kg) from 280 to 550 kg body weight over rations 1 to 10 at 5C and -15C for Trial II (Eq. 40).

Angle of view:
Elevation 30°, Azimuth 65°.
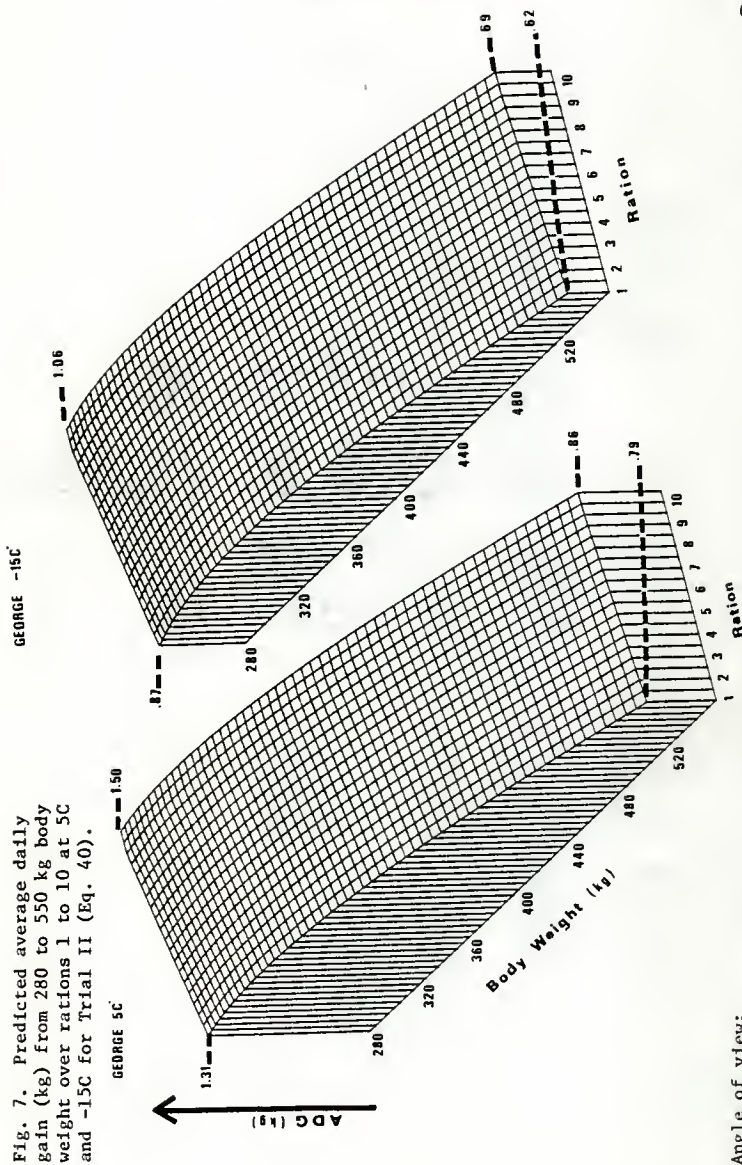
Selected models for Average Daily Gain as a function of Days on Feed (PADGT) for Trials I and II, respectively, were:

Eq. 41 PADGT = $(612.34327619)*(.6395042)*Ke^{-KT}$

$K = -.01133695 + .00295638*ME + .00092775*DDMI -$
$.00004358*TP$

and

Eq. 42 PADGT = $(1011.80245888)*(.38005912)*Ke^{-KT}$

$K = -.01036220 + .00246992*ME + .00078150*DDMI +$
$.00010334*TP$

T = Days on Feed

ME = Mcal ME/kg dry ration

DDMI = Weekly mean daily dry matter intake in kg

TP = Weekly mean effective temperature (C)

Predicted Average Daily Gain as a function of Days on Feed (PADGT) decreases non-linearly with days on feed, with animals gaining faster early in the feeding period and declining faster in gain as days on feed progressed. Growth rate differences between rations were significant in both trials (P<.0001). In Trial I, ration 7 (2.9806 Mcal ME/kg) produced a 102% faster gain than ration 1 (2.5420 Mcal ME/kg) at the beginning the feeding period (1.76 vs. .87 kg/day), but by the end of the trial, rate of gain on ration 7 had declined 64% compared to 28% for animals on ration 1. Trial II produced similar results, with ration 6 (2.9093 Mcal ME/kg) producing 75% faster gain

than ration 1 (2.5452 Mcal ME/kg) at the beginning of the feeding
period (1.89 vs. 1.08 kg/day). Gain on ration 6 declined 67% (from
1.89 to .62 kg/day) and ration 1's gain declined from 1.08 to .59
kg/day or 45%.

In both trials there were slight decreases in rate of gain when
ration energy density was over three Mcal ME/kg dry ration or when
less than 20% corn silage was included in the diet.

In both trials performance declined with increased environmental
stress regardless of ration. In both trials gain decline from tempera-
ture stress was greatest on high roughage rations and early in the
trial. In Trial II, rations producing the most rapid gains early in
the feeding period were less affected by temperature stress early in
the trial than animals on rations producing slower gains. Animals fed
rations containing less than 20% corn silage showed marked gain declines
with decreased temperature late in the feeding period.

Coefficients for TP within models between trials had opposite signs
as the trials were conducted during different seasons. An effective
temperature increase (Eq. 24) resulted in heat stress and subsequent
gain decline in Trial I (summer). PADGW increased (Eq. 25) with temp-
erature in Trial II (winter) because as temperature increased, cold
stress was increased.

Both weight models (Eqs. 39 and 40) fit the data more closely
than either of the time models (Eqs. 41 and 42) (Tables 7 to 10).
Including actual intake data instead of predicting intake from a pre-
diction equation increased growth rate model accuracy in both trials.

TABLE 9. ANALYSIS OF VARIANCE OF THE PADGT MODEL (Eq. 41)
(TRIAL I)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	2	762.2	381.1	
Ration[b]	18	19.4	1.0	5.95[g]
Lack of fit[c]	15	11.9	0.7	4.38[h]
Model[d]	3	7.5	2.5	
Animal/Ration[e]	20	3.6	0.1	
Residual[f]	567	570.7	1.0	

[a]$ADG = ABKe^{-KT}$ fitted to pooled data of 20 steers (Appendix Table 5).

[b]Regression − [$ADG = ABKe^{-KT}$ fitted to data pooled by ration] (Appendix Table 5).

[c]PADGT − [$ADG = ABKe^{-KT}$ fitted to data pooled by ration] (Appendix Table 5).

[d]Ration − Lack of fit.

[e][$ADG = ABKe^{-KT}$ fitted to data pooled by ration] − [$ADG = ABKe^{-KT}$ fitted to data by animal] (Appendix Table 5).

[f]$ADG = ABKe^{-KT}$ fitted to data by animal (Appendix Table 5).

[g]($p < .0001$) Ration MS ÷ Animal/Ration MS.

[h]($p < .0013$) Lack of fit MS ÷ Animal/Ration MS.

TABLE 10. ANALYSIS OF VARIANCE OF THE PADGT MODEL (Eq. 42)
(TRIAL II)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	2	581.2	290.6	
Ration[b]	18	30.1	1.6	6.23[g]
Lack of fit[c]	15	15.6	1.0	3.88[h]
Model[d]	3	14.5	4.8	
Animal/Ration[e]	20	5.3	0.2	
Residual[f]	499	566.3	1.1	

[a]ADG = $ABKe^{-KT}$ fitted to pooled data of 20 steers (Appendix Table 6).

[b]Regression − [ADG = $ABKe^{-KT}$ fitted to data pooled by ration]
(Appendix Table 6).

[c]PADGT − [ADG = $ABKe^{-KT}$ fitted to data pooled by ration] (Appendix
Table 6).

[d]Ration − Lack of fit.

[e][ADG = $ABKe^{-KT}$ fitted to data pooled by ration] − [ADG = $ABKe^{-KT}$
fitted to data by animal] (Appendix Table 6).

[f]ADG = $ABKe^{-KT}$ fitted to data by animal (Appendix Table 6).

[g]($p < .0001$) Ration MS ÷ Animal/Ration MS.

[h]($p < .0027$) Lack of fit MS ÷ Animal/Ration MS.

Fig. 8. Predicted average daily gain (kg) from 0 to 220 days on feed over rations 1 to 10 at 5C for Trials I (Eq. 41) and II (Eq. 42).

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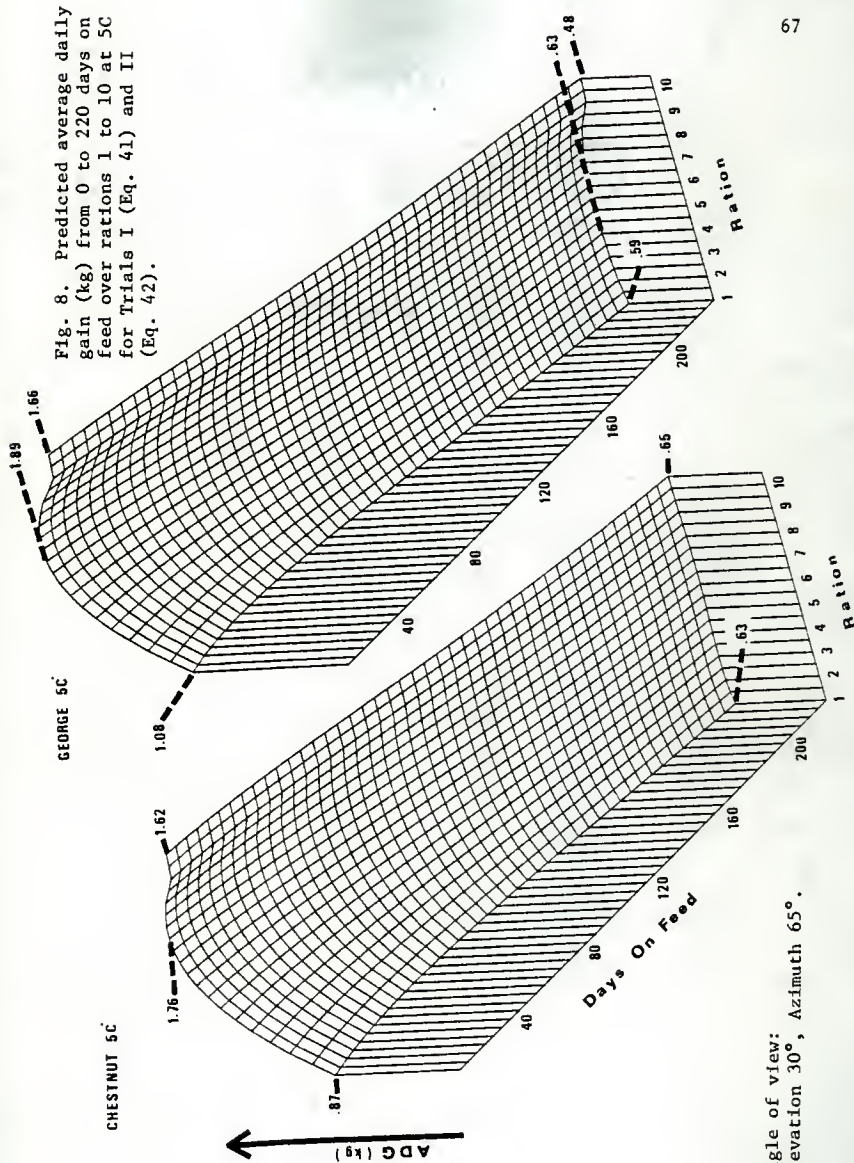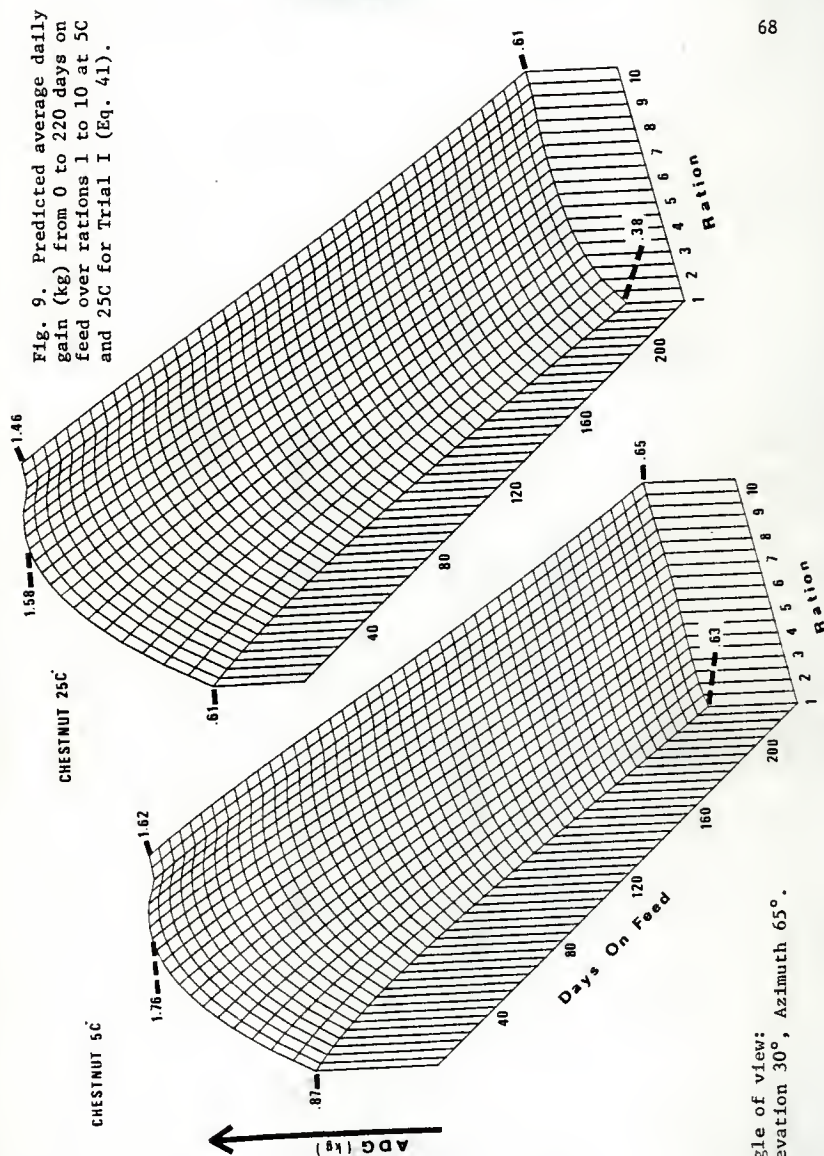
Fig. 9. Predicted average daily gain (kg) from 0 to 220 days on feed over rations 1 to 10 at 5C and 25C for Trial I (Eq. 41).

Angle of view:
Elevation 30°, Azimuth 65°.

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Fig. 10. Predicted average daily gain (kg) from 0 to 220 days on feed over rations 1 to 10 at 5C and -15C for Trial II (Eq. 42).

Angle of view:
Elevation 30°, Azimuth 65°.

69
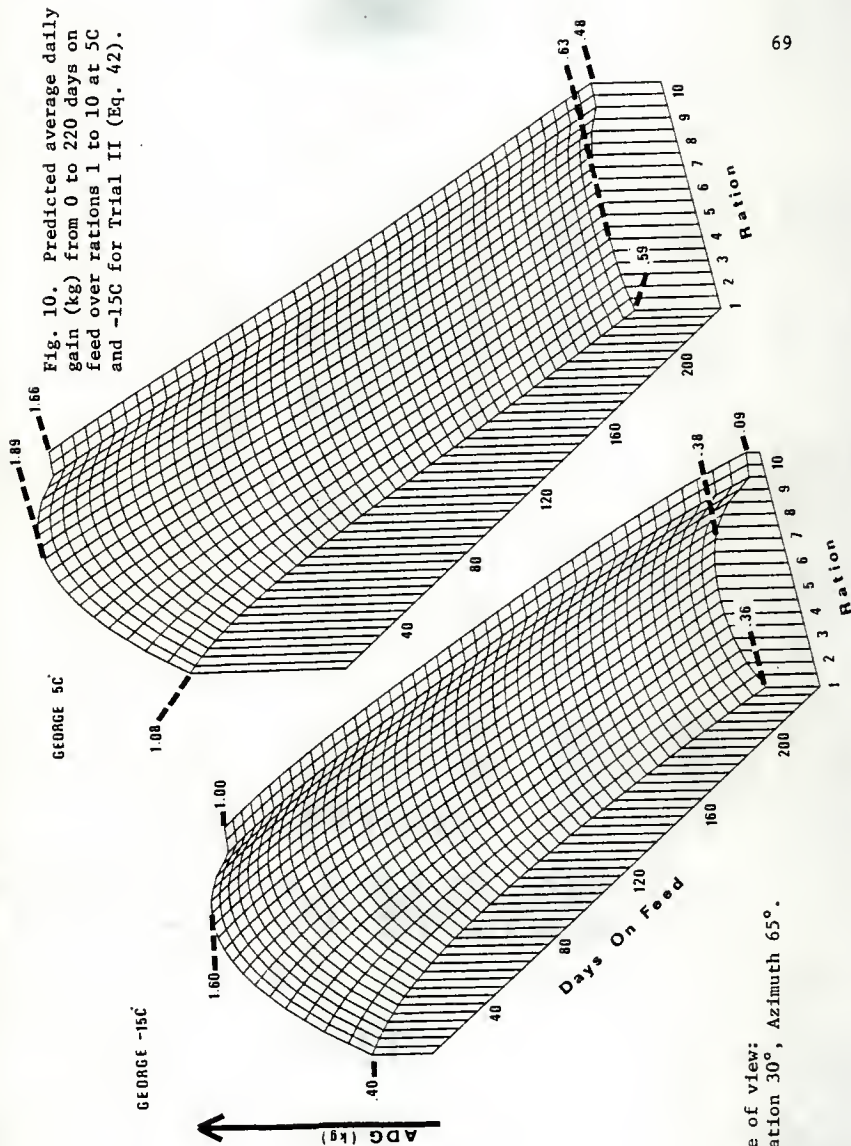
Table 11 shows poorer correlations of predicted to observed growth rate occurred when intake equations were used to estimate DDMI in PADGW and PADGT equations. All fill variation was accounted for in the models, so lower correlations for predicted rate with observed occur than if the cattle would have been shrunk prior to weighing.

TABLE 11. CORRELATION COEFFICIENTS OF GROWTH RATE MODELS

	Observed Intake	Predicted Intake Eq. 53-54	Predicted Intake Eq. 55-56	Observed Intake	Predicted Intake Eq. 59-60
Trial I	.30061	.28507	.16594	.33095	.31293
Trial II	.27398	.10256	.17695	.31348	.27393

Rate of gain at various days on feed can be determined by modeling actual weight changes and environmental data or by extracting the first derivative of the growth curve (Eq. 37 and 38). First derivatives of selected predicted accumulative weight models (PWT1) for Trials I and II, respectively, were:

Eq. 43 $PWT1 = (790.56265270)(.63595042)*Ke^{-KT}$

and

Eq. 44 $PWT1 = (601.26380120)(.38005912)*Ke^{-KT}$

K and T are defined in equations 37 and 38. Correlations shown in Table 12 of estimated to actual growth rate indicate there is no advantage to modeling growth rate over modeling growth and differentiating.

TABLE 12. CORRELATION COEFFICIENTS BETWEEN OBSERVED AND PREDICTED
(PADGT) RATES OF GAIN

	Modeled on observed weight gain and temperature	Modeled using first derivative of the weight curve (PWT)
Trial I	.33095	.31980
Trial II	.31348	.31582

Accumulative Dry Matter Intake

Selected cubic regression models for Predicted Accumulative Dry
Matter Intake as a function of Body Weight (PDMW) for Trials I and II,
respectively, were:

Eq. 45 $PDMW = 1481.27778726 + 542.85526362*ME^2 - 37.97697765*ME^3$
$+ 39.13370811*TP - 19.23624308*WT + .09478645*WT^2 - $
$.00006001*WT^3 - 7.10153893*ME*WT - .07272789*TP*WT$

and

Eq. 46 $PDMW = -109,664.01417739 + 148,457.64467733*ME - $
$49,865.37219251*ME^2 + 5,575.93998686*ME^3 - $
$45.06595215*TP + .34438775*TP^2 - .02423636*TP^3 - $
$254.09928351*WT + .58898552*WT^2 - .00042501*WT^3 - $
$2.29008274*ME*WT + .18539100*TP*WT$
$10.28185050*ME*TP$

TABLE 13. ANALYSIS OF VARIANCE OF THE CUBIC REGRESSION PDMW MODEL
(Eq. 45) (TRIAL I)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	3	225,479,242	75,159,747	
Ration[b]	36	35,995,334	110,981	1.69[g]
Lack of fit[c]	30	2,864,468	95,482	1.45[h]
Model[d]	6	33,130,866	5,521,811	
Animal/Ration[e]	40	2,626,637	65,665	
Residual[f]	565	38,885,683	68,824	

[a]$DM = WT + WT^2 + WT^3$ fitted to pooled data of 20 steers (Appendix Table 7).

[b]Regression — $[DM = WT + WT^2 + WT^3$ fitted to data pooled by ration] (Appendix Table 7).

[c]PDMW — $[DM = WT + WT^2 + WT^3$ fitted to data pooled by ration] (Appendix Table 7).

[d]Ration — Lack of fit.

[e]$[DM = WT_3 + WT^2 + WT^3$ fitted to data pooled by ration] — $[DM = WT + WT^2 + WT^3$ fitted to data pooled by animal] (Appendix Table 7).

[f]$DM = WT + WT^2 + WT^3$ fitted to data by animal (Appendix Table 7).

[g]($P < .0538$) Ration MS ÷ Animal/Ration MS.
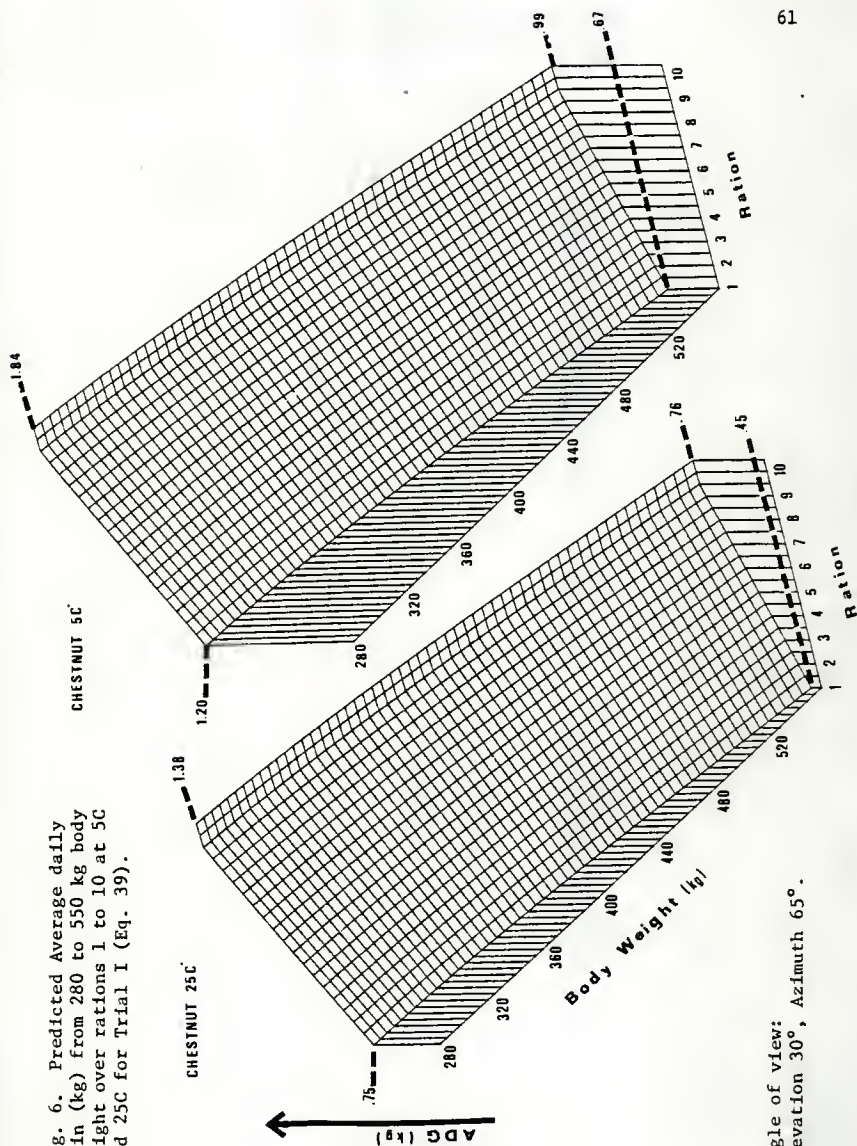
[h]($P < .1332$) Lack of fit MS ÷ Animal/Ration MS.

TABLE 14. ANALYSIS OF VARIANCE OF THE CUBIC REGRESSION PDMW MODEL (Eq. 46) (TRIAL II)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	3	119,523,394	39,841,131	
Ration[b]	36	18,906,785	525,188	2.37[g]
Lack of fit[c]	27	1,028,147	38,079	.17[h]
Model[d]	9	17,878,638	1,986,515	
Animal/Ration[e]	40	8,839,883	220,997	
Residual[f]	565	29,217,041	58,786	

[a] $DM = WT + WT^2 + WT^3$ fitted to pooled data of 20 steers (Appendix Table 8).

[b] Regression − [$DM = WT + WT^2 + WT^3$ fitted to data pooled by ration] (Appendix Table 8).

[c] PDMW − [$DM = WT + WT^2 + WT^3$ fitted to data pooled by ration] (Appendix Table 8).

[d] Ration − Lack of fit.

[e] [$DM = WT + WT^2 + WT^3$ fitted to data pooled by ration] − [$DM = WT + WT^2 + WT^3$ fitted to data pooled by animal] (Appendix Table 8).

[f] $DM = WT + WT^2 + WT^3$ fitted to data by animal (Appendix Table 8).

[g] $(P < .0042)$ Ration MS ÷ Animal/Ration MS.

[h] $(P < .9999)$ Lack of fit MS ÷ Animal/Ration MS.

Selected quadratic regression models for Predicted Accumulative
Dry Matter Intake as a function of Body Weight (PDMW) for Trials I
and II, respectively, were:

Eq. 47 PDMW = −3070.26176892 + 402.48272435*ME^2 +
17.08370663*WT + .01452755*WT^2 + 5.22479873*ME*TP
− 7.68902545*ME*WT − .01979268*TP*WT

and

Eq. 48 PDMW = −22,653.04937573 + 11,034.85734637*ME −
1,813.67645691*ME^2 + .69460836*TP^2 +
27.94915452*WT − .01209899*WT^2 −
7.69496535*ME*TP − 2.64527413*ME*WT +
.07866455*TP*WT

Correlations of predicted vs. observed intake in both trials were
higher and mean square errors lower for the cubic regressions (Table
17); however, Tables 13 through 16 indicate the quadratic polynomials
fit the data of both trials better. The cubic equation for Trial II
(Table 14) rejected the null hypothesis of no differences in intake
between rations at a much lower p value (.0001 vs. .0159) than the
quadratic equation (Table 16).

TABLE 15. ANALYSIS OF VARIANCE OF THE QUADRATIC REGRESSION
PDMW MODEL (Eq. 47) (TRIAL I)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	2	222,975,448	111,487,724	
Ration[b]	27	37,127,591	1,375,095	14.43[g]
Lack of fit[c]	23	2,015,417	87,626	1.08[h]
Model[d]	4	35,112,173	8,778,043	
Animal/Ration[e]	30	2,857,653	95,255	
Residual[f]	566	41,389,476	73,126	

[a]$DM = WT + WT^2$ fitted to pooled data of 20 steers (Appendix Table 9).

[b]Regression - $[DM = WT + WT^2$ fitted to data pooled by ration$]$ (Appendix Table 9).

[c]PDMW - $[DM = WT + WT^2$ fitted to data pooled by ration$]$ (Appendix Table 9).

[d]Ration - Lack of fit.

[e]$[DM = WT + WT^2$ fitted to data pooled by ration$] - [DM = WT + WT^2$ fitted to data pooled by animal$]$ (Appendix Table 9).

[f]$DM = WT + WT^2$ fitted to data by animal (Appendix Table 9).

[g]($p < .0001$) Ration MS $\div$ Animal/Ration MS.

[h]($p < .4095$ Lack of fit MS $\div$ Animal/Ration MS.

TABLE 16. ANALYSIS OF VARIANCE OF THE QUADRATIC REGRESSION
PDMW MODEL (Eq. 47) (TRIAL II)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	2	119,258,979	59,629,489	
Ration[b]	27	17,822,235	660,082	2.23[g]
Lack of fit[c]	21	2,521,767	120,084	.40[h]
Model[d]	6	15,301,468	2,550,244	
Animal/Ration[e]	30	8,849,759	294,991	
Residual[f]	498	29,481,455	59,199	

[a]$DM = WT + WT^2$ fitted to pooled data of 20 steers (Appendix Table 10).

[b]Regression − [$DM = WT + WT^2$ fitted to data pooled by ration] (Appendix Table 10).

[c]PDMW − [$DM = WT + WT^2$ fitted to data pooled by ration] (Appendix Table 10).

[d]Ration − Lack of fit.

[e][$DM = WT + WT^2$ fitted to data pooled by ration] − [$DM = WT + WT^2$ fitted to data pooled by animal] (Appendix Table 10).

[f]$DM = WT + WT^2$ fitted to data by animal (Appendix Table 10).

[g]($P<.0159$) Ration MS ÷ Animal/Ration MS.

[h]($P<.9821$) Lack of fit MS ÷ Animal/Ration MS.

TABLE 17. CORRELATION COEFFICIENTS AND MEAN SQUARE ERRORS
FOR ACCUMULATIVE DRY MATTER INTAKE (PDMW) MODELS

	Cubic Regression		Quadratic Regression	
	Correlation	MS Error	Correlation	MS Error
Trial I	.9890	10,294.75719328	.9881	11,169.57908540
Trial II	.9573	25,490.37702984	.9511	28,821.11261291

Correlations of predicted vs. observed intake were higher and mean square errors lower for the cubic polynomials in both trials (Table 18). Differences in intake between rations were highly significant in both models for both trials (Tables 19 to 22). All accumulative intake models based on time had higher correlations and lower mean square errors than those based on weight.

TABLE 18. CORRELATION COEFFICIENTS AND MEAN SQUARE ERRORS
FOR ACCUMULATIVE DRY MATTER INTAKE (PDMT) MODELS

	Cubic Regression		Quadratic Regression	
	Correlation	MS Error	Correlation	MS Error
Trial I	.9955	4,263.76042087	.9946	5,083.24674248
Trial II	.9915	5,128.01398779	.9897	6,177.35392479

TABLE 19. ANALYSIS OF VARIANCE OF THE CUBIC REGRESSION PDMT MODEL (Eq. 49) (TRIAL I)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	3	258,032,064	86,010,688	
Ration[b]	36	5,726,267	159,062	10.82[g]
Lack of fit[c]	29	1,872,583	64,571	4.39[h]
Model[d]	7	3,953,683	564,811	
Animal/Ration[e]	40	587,612	14,690	
Residual[f]	565	6,332,861	11,208	

[a]$DM = T + T^2 + T^3$ fitted to pooled data of 20 steers (Appendix Table 11).

[b]Regression - [$DM = T + T^2 + T^3$ fitted to data pooled by ration] (Appendix Table 11).

[c]PDMW - [$DM = T + T^2 + T^3$ fitted to data pooled by ration] (Appendix Table 11).

[d]Ration - Lack of fit.

[e][$DM = T + T^2 + T^3$ fitted to data pooled by ration] - [$DM = T + T^2 + T^3$ fitted to data pooled by animal] (Appendix Table 11).

[f]$DM = T + T^2 + T^3$ fitted to data by animal (Appendix Table 11).

[g]($P<.0001$) Ration MS ÷ Animal/Ration MS.

[h]($P<.0001$) Lack of fit MS ÷ Animal/Ration MS.

TABLE 20. ANALYSIS OF VARIANCE OF THE CUBIC REGRESSION PDMT MODEL
(Eq. 50) (TRIAL II)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	3	138,741,211	46,247,070	
Ration[b]	36	9,189,737	255,270	12.84[g]
Lack of fit[c]	29	1,703,240	58,732	2.95[h]
Model[d]	7	7,486,497	1,069,499	
Animal/Ration[e]	40	794,748	19,868	
Residual[f]	497	9,999,224	20,119	

[a]$DM = T + T^2 + T^3$ fitted to pooled data of 20 steers (Appendix Table 12).

[b]Regression – $[DM = T + T^2 + T^3$ fitted to data pooled by ration] (Appendix Table 12).

[c]PDMW – $[DM = T + T^2 + T^3$ fitted to data pooled by ration] (Appendix Table 12).

[d]Ration – Lack of fit.

[e]$[DM = T + T^2 + T^3$ fitted to data pooled by ration] – $[DM = T + T^2 + T^3$ fitted to data pooled by animal] (Appendix Table 12).

[f]$DM = T + T^2 + T^3$ fitted to data by animal (Appendix Table 12).

[g]($P < .0001$) Ration MS ÷ Animal/Ration MS.

[h]($P < .0008$) Lack of fit MS ÷ Animal/Ration MS.

TABLE 21. ANALYSIS OF VARIANCE OF THE QUADRATIC REGRESSION
PDMT MODEL (Eq. 51) (TRIAL I)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	3	258,017,410	86,005,803	
Ration[b]	36	5,716,509	158,791	10.76[g]
Lack of fit[c]	32	2,217,695	68,990	. 4.67[h]
Model[d]	4	3,498,813	874,703	
Animal/Ration[e]	40	590,030	14,750	
Residual[f]	565	6,347,514	11,234	

[a]DM = T + TP + T*TP fitted to pooled data of 20 steers (Appendix
Table 13).

[b]Regression − [DM = T + TP + T*TP fitted to data pooled by ration]
(Appendix Table 13).

[c]PDMW − [DM = T + TP + T*TP fitted to data pooled by ration] (Appendix
Table 13).

[d]Ration − Lack of fit.

[e][DM = T + TP + T*TP fitted to data pooled by ration] − [DM =
T + TP + T*TP fitted to data pooled by animal] (Appendix Table 13).

[f]DM = T + TP + T*TP fitted to data by animal (Appendix Table 13).

[g]($p < .0001$) Ration MS ÷ Animal/Ration MS.

[h]($p < .0001$) Lack of fit MS ÷ Animal/Ration MS.

TABLE 22. ANALYSIS OF VARIANCE OF THE QUADRATIC REGRESSION
PDMT MODEL (Eq. 52) (TRIAL II)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	3	139,235,393	46,411,797	
Ration[b]	36	8,658,578	240,516	12.18[g]
Lack of fit[c]	32	3,198,971	99,967	5.06[h]
Model[d]	4	5,459,606	1,364,901	
Animal/Ration[e]	40	789,764	19,744	
Residual[f]	497	9,505,042	19,124	

[a]DM = T + TP + T*TP fitted to pooled data of 20 steers (Appendix
Table 14).

[b]Regression - [DM = T + TP + T*TP fitted to data pooled by ration]
(Appendix Table 14).

[c]PDMW - [DM = T + TP + T*TP fitted to data pooled by ration] (Appendix
Table 14).

[d]Ration - Lack of fit.

[e][DM = T + TP + T*TP fitted to data pooled by ration] - [DM =
T + TP + T*TP fitted to data pooled by animal] (Appendix Table 14).

[f]DM = T + TP + T*TP fitted to data by animal (Appendix Table 14).

[g](P<.0001) Ration MS ÷ Animal/Ration MS.

[h](P<.0001) Lack of fit MS ÷ Animal/Ration MS.

Daily Dry Matter Intake

Selected non-linear models of Predicted Daily Dry Matter Intake as a function of Body Weight (PDDMW) for Trials I and II, respectively, were:

Eq. 53 $PDDMW = (12.13424410)(1-e^{-Z*WT}) - 1.25654477*ME + .05775674*TP - .00012629*TP^3$

$Z = .00750467$

and

Eq. 54 $PDDMW = (19.79240032)(1-e^{-Z*WT}) - 3.20004023*ME - .07260716*TP - .00215011*TP^2$

$Z = .00623831$

Equation 54 did not adequately describe daily feed intake for Trial II, as the model did not fit data pooled by ration or by animal.

Predicted Daily Dry Matter Intake as a function of Body Weight (PDDMW) (Figure 11) decreased linearly with increasing ME from rations 1 to 9 in both trials. In Trial I PDDMW declined 1.2572 kg for each Mcal ME/kg increase in ME up to ration 9 (3.1268 Mcal ME/kg) regardless of body weight. In Trial II ration differences were greater; PDDMW declined 3.2129 kg per Mcal ME/kg to ration 9 (3.1277 Mcal ME/kg) for all body weights. PDDMW decreased .0082 kg in Trial I and .0208 kg in Trial II for the additional increase in ME from ration 9 to 10 for all body weights.

TABLE 23.   ANALYSIS OF VARIANCE OF THE NON-LINEAR PDDMW MODEL
(Eq. 53) (TRIAL I)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	3	38,033.0	12,677.6	
Ration[b]	27	276.7	10.2	4.23[g]
Lack of fit[c]	25	219.3	8.7	3.62[h]
Model[d]	2	57.3	28.6	
Animal/Ration[e]	30	72.6	2.4	
Residual[f]	566	681.4	1.2	

[a]DDMI = X + Y*(1-e^{-Z*WT}) fitted to pooled data of 20 steers
(Appendix Table 15).

[b]Regression - [DDMI = X + Y*(1-e^{-Z*WT}) fitted to data pooled by
ration] (Appendix Table 15).

[c]PDDMW - [DDMI = X + Y*(1-e^{-Z*WT}) fitted to data pooled by ration]
(Appendix Table 15).

[d]Ration - Lack of fit.

[e][DDMI = X + Y*(1-e^{-Z*WT}) fitted to data pooled by ration] - [DDMI =
X + Y*(1-e^{-Z*WT}) fitted to data pooled by animal] (Appendix Table 15).

[f]DDMI = X + Y*(1-e^{-Z*WT}) fitted to data by animal (Appendix Table 15).

[g]($P < .0001$) Ration MS ÷ Animal/Ration MS.

[h]($P < .0005$) Lack of fit MS ÷ Animal/Ration MS.

Fig. 11. Predicted daily dry matter intake (kg) from 280 to 550 kg body weight over rations 1 to 10 at 5C for Trials I (Eq. 53) and II (Eq. 54).

Angle of view:
Elevation 30°, Azimuth 65°.

84
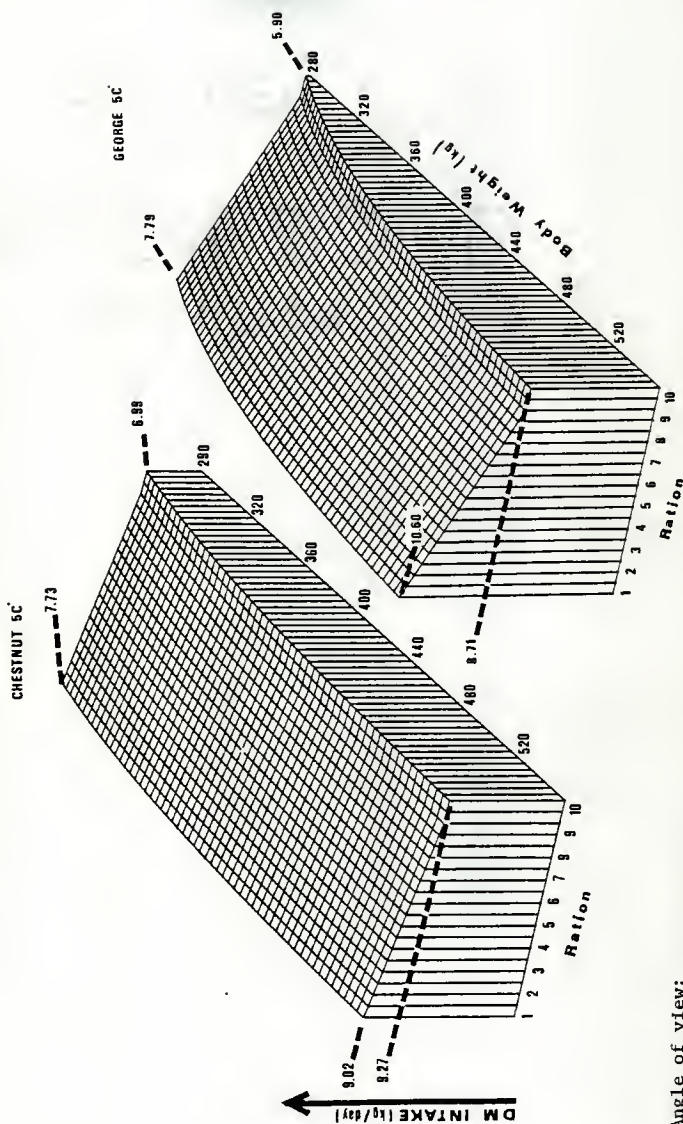
85

Fig. 12. Predicted daily dry matter intake (kg) from 280 to 550 kg body weight over rations 1 to 10 at 5C and 25C for Trial I (Eq. 53).
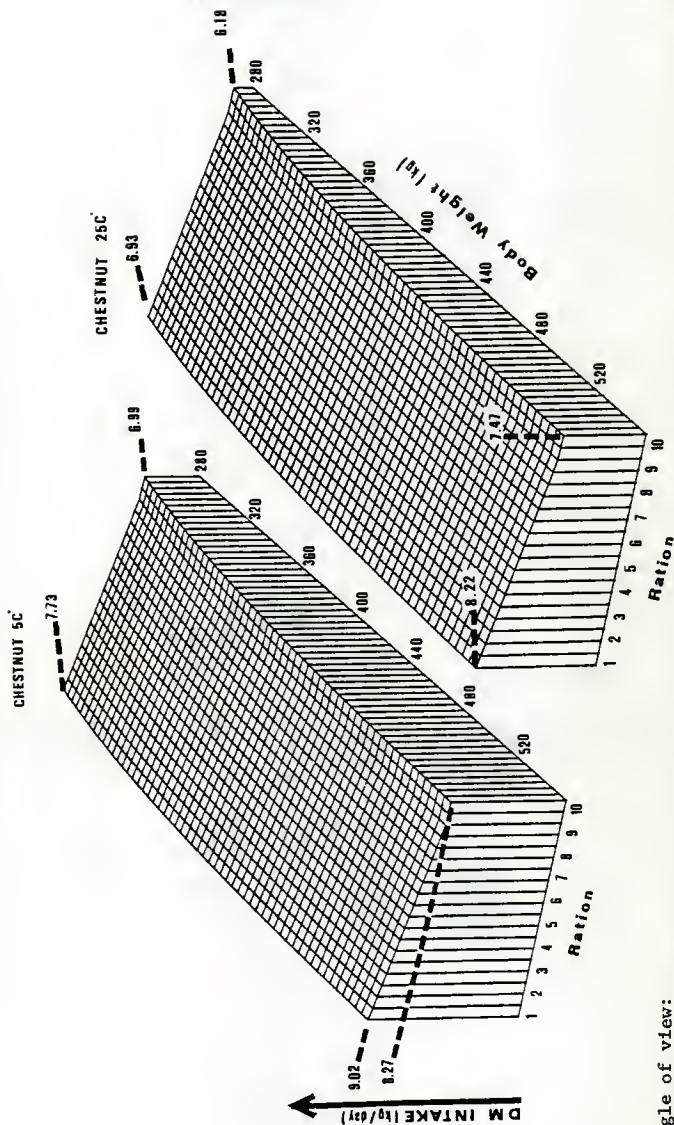
Angle of view:
Elevation 30°, Azimuth 65°.

Fig. 13. Predicted daily dry matter intake (kg) from 280 to 550 kg body weight over rations 1 to 10 at 5C and -15C for Trial II (Eq. 54).

Angle of view:
Elevation 30°, Azimuth 65°.

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PDDMW increased, but at a decelerating rate, with increasing body weight in both trials. These increases were greater for Trial II than Trial I. Increases for both trials within body weights between rations were similar. In Trial I PDDMW increased 1.28 kg from the beginning of the trial to the end for all rations and Trial II predicted increases of 2.81 kg over the trial duration, regardless of the ration. PDDMW decreased .75 kg for all rations and body weights when effective temperature increased to 25 C from 5 C (Figure 12). In Trial II PDDMW increased by 1.89 kg for all rations and body weights when effective temperature was lowered to -15 C from 5 C. The model predicted maximum intake when mean effective temperature was held constant at 15 C in Trial I.

TABLE 24. CORRELATION COEFFICIENTS AND MEAN SQUARE ERRORS
FOR PDDMW MODELS

	Non-linear	Cubic Regression	Quadratic Regression
Correlation			
Trial I	.38519	.68561	.69009
Trial II	.52672	.73260	.78488
MS Error			
Trial I	1.10658194	.69218752	.68781911
Trial II	1.90078690	1.23367128	1.02449729

Selected cubic and quadratic regression models of PDDMW for Trials I and II, respectively, were:

Eq. 55 $PDDMW = -105.57423788 + 72.90929552*ME -$
$.00666687*TP^2 - 14.39080014*ME^2 +$
$.04828502*ME*WT - .00008910*ME*WT^2 +$
$.00000005*ME*WT^3 + .00193480*ME*TP^2$,

Eq. 56 $PDDMW = -114.79511813 + 79.18098118*ME - 14.17501552*ME^2$
$- .26250930*TP - .00894012*TP^2 + .06019888*WT -$
$.00008143*WT^2 + .00134218*TP*WT + .00000583*ME*WT^2$
$+ .00001472*TP^2*WT - .00000160*TP*WT^2$

and

Eq. 57 $PDDMW = -34.05889247 + 68.40525895*ME +$
$4.20262171*TP - 18.15740770*ME^2 -$
$3.03417869*ME*TP + .00048652*ME*WT^2 -$
$.00143462*WT^2 + .00000210*WT^3 -$
$.00000071*ME*WT^3 + .53053431*ME^2*TP +$
$.00007103*ME*TP^3$,

Eq. 58 $PDDMW = -465.09663344 + 444.48946355*ME -$
$96.85009218*ME^2 + 2.37253320*TP - .03697078*TP^2 +$
$.00149570*WT^2 - .48269304*ME*WT -$
$.00998254*TP*WT + .16727611*ME^2*WT -$
$.00051963*ME*WT^2 + .00006958*TP^2*WT +$
$.00000999*TP*WT^2$

TABLE 25. ANALYSIS OF VARIANCE OF THE CUBIC REGRESSION PDDMW MODEL
(Eq. 55) (TRIAL I)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	3	108.3	32.7	
Ration[b]	36	337.8	9.3	4.68[g]
Lack of fit[c]	32	101.6	3.1	1.58[h]
Model[d]	4	236.1	59.0	
Animal/Ration[e]	40	80.1	2.0	
Residual[f]	565	624.4	1.1	

[a] $DDMI = WT + WT^2 + WT^3$ fitted to pooled data of 20 steers (Appendix Table 16).

[b] Regression − [$DDMI = WT + WT^2 + WT^3$ fitted to data pooled by ration] (Appendix Table 16).

[c] PDMW − [$DDMI = WT + WT^2 + WT^3$ fitted to data pooled by ration] (Appendix Table 16).

[d] Ration − Lack of fit.

[e] [$DDMI = WT + WT^2 + WT^3$ fitted to data pooled by ration] − [$DM = WT + WT^2 + WT^3$ fitted to data pooled by animal] (Appendix Table 16).

[f] $DDMI = WT + WT^2 + WT^3$ fitted to data by animal (Appendix Table 16).

[g] ($p < .0001$) Ration MS ÷ Animal/Ration MS.

[h] ($p < .0833$) Lack of fit MS ÷ Animal/Ration MS.

TABLE 26. ANALYSIS OF VARIANCE OF THE CUBIC REGRESSION PDDMW MODEL (Eq. 56) (TRIAL II)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	3	34.5	11.5	
Ration[b]	36	878.1	24.3	4.35[g]
Lack of fit[c]	24	212.0	8.8	1.57[h]
Model[d]	8	666.0	83.2	
Animal/Ration[e]	40	223.8	5.5	
Residual[f]	497	1,270.2	2.5	

[a]DDMI = $WT + WT^2 + WT^3$ fitted to pooled data of 20 steers (Appendix Table 17).

[b]Regression – [DDMI = $WT + WT^2 + WT^3$ fitted to data pooled by ration] (Appendix Table 17).

[c]PDMW – [DDMI = $WT + WT^2 + WT^3$ fitted to data pooled by ration] (Appendix Table 17).

[d]Ration – Lack of fit.

[e][DDMI = $WT + WT^2 + WT^3$ fitted to data pooled by ration] – [DM = $WT + WT^2 + WT^3$ fitted to data pooled by animal] (Appendix Table 17).

[f]DDMI = $WT + WT^2 + WT^3$ fitted to data by animal (Appendix Table 17).

[g]($p < .0001$) Ration MS ÷ Animal/Ration MS.

[h]($p < .0996$) Lack of fit MS ÷ Animal/Ration MS.

TABLE 27. ANALYSIS OF VARIANCE OF THE QUADRATIC REGRESSION
PDDMW MODEL (Eq. 57) (TRIAL I)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	2	101.2	50.6	
Ration[b]	27	321.3	11.9	4.05[g]
Lack of fit[c]	19	73.7	3.8	1.32[h]
Model[d]	8	247.6	30.9	
Animal/Ration[e]	30	87.9	2.9	
Residual[f]	566	631.4	1.1	

[a]DDMI = $WT + WT^2$ fitted to pooled data of 20 steers (Appendix Table 18).

[b]Regression − [DDMI = $WT + WT^2$ fitted to data pooled by ration] (Appendix Table 18).

[c]PDDMW − [DDMI = $WT + WT^2$ fitted to data pooled by ration] (Appendix Table 18).

[d]Ration − Lack of fit.

[e][DDMI = $WT + WT^2$ fitted to data pooled by ration] − [DDMI = $WT + WT^2$ fitted to data pooled by animal] (Appendix Table 18).

[f]DDMI = $WT + WT^2$ fitted to data by animal (Appendix Table 18).

[g]($p < .0002$) Ration MS ÷ Animal/Ration MS.

[h]($p < .2407$) Lack of fit ÷ Animal/Ration MS.

TABLE 28. ANALYSIS OF VARIANCE OF THE QUADRATIC REGRESSION
PPDMW MODEL (Eq. 58) (TRIAL II)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	2	34.4	17.2	
Ration[b]	27	861.8	31.9	4.31[g]
Lack of fit[c]	18	92.5	5.1	.69[h]
Model[d]	9	769.3	85.4	
Animal/Ration[e]	30	221.8	7.3	
Residual[f]	498	1,270.3	2.5	

[a]DDMI = $WT + WT^2$ fitted to pooled data of 20 steers (Appendix Table 19).

[b]Regression - [DDMI = $WT + WT^2$ fitted to data pooled by ration] (Appendix Table 19).

[c]PDDMW - [DDMI = $WT + WT^2$ fitted to data pooled by ration] (Appendix Table 19).

[d]Ration - Lack of fit.

[e][DDMI = $WT + WT^2$ fitted to data pooled by ration] - [DDMI = $WT + WT^2$ fitted to data pooled by animal] (Appendix Table 19).

[f]DDMI = $WT + WT^2$ fitted to data by animal (Appendix Table 19).

[g](P<.0001) Ration MS ÷ Animal/Ration MS.

[h](P<.7894) Lack of fit MS ÷ Animal/Ration MS.

Selected models of Predicted Daily Dry Matter Intake as a function of Days on Feed (PDDMT) for Trials I and II, respectively, were:

Eq. 59 $PDDMT = -113.59954637 + 85.08902883*ME - 14.90598867*ME^2 + .03242130*T - .00005388*T^2 - .00473974*ME*T - .00144625*TP^2 + .02266913*ME*TP - .00037530*T*TP$

and

Eq. 60 $PDDMT = -152.01002279 + 113.45767903*ME - 19.88142219*ME^2 + .09885352*T - .00013078*T^2 - .02693901*ME*T + .00160476*TP^2 + .00063580*ME*TP - .00005591*T*TP$

Three-dimensional graphs for both trials (Figure 14) show PDDMT increases as ME increases from rations 1 to 5 and then decreases with increasing ME to 10.

Maximum PDDMT across rations was maintained on ration 5 throughout Trial I but decreased from ration 5 to 3 in Trial II as cattle were fed longer, indicating that the cross-over point between physical fill and chemostatic control is in the neighborhood of 2.8 Mcal ME/kg dry ration. The model constructed from Trial II data indicates that animals increase rumen size and development as they are on feed longer so physical fill no longer limits daily feed intake. These models conflict with the non-linear PDDMW models in which daily intake decreases linearly with increasing ME so animals never appear to be under physical control. However, the models do not contain a quadratic energy term to show this effect if present.

TABLE 29. ANALYSIS OF VARIANCE OF THE PDDMT MODEL (Eq. 59)
(TRIAL I)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	4	52.8	13.2	
Ration[b]	45	364.1	8.0	3.55[g]
Lack of fit[c]	41	113.6	2.7	1.21[h]
Model[d]	4	250.5	62.6	
Animal/Ration[e]	50	113.7	2.2	
Residual[f]	564	679.8	1.2	

[a]DDMI = Day + TP^2 + Day*TP + Day^2 fitted to pooled data of 20 steers
(Appendix Table 20).

[b]Regression - [DDMI = Day + TP^2 + Day*TP + Day^2 fitted to data pooled
by ration] (Appendix Table 20).

[c]PDMT - [DDMI = Day + TP^2 + Day*TP + Day^2 fitted to data pooled by
ration] (Appendix Table 20).

[d]Ration - Lack of fit.

[e][DDMI = Day + TP^2 + Day*TP + Day^2 fitted to data pooled by ration] -
[DDMI = Day + TP^2 + Day*TP + Day^2 fitted to data by animal]
(Appendix Table 20).

[f]DDMI = Day + TP^2 + Day*TP + Day^2 fitted to data by animal
(Appendix Table 20).

[g]($p < .0001$) Ration MS ÷ Animal/Ration MS.

[h]($p < .2508$) Lack of fit ÷ Animal/Ration MS.

TABLE 30. ANALYSIS OF VARIANCE OF THE PDDMT MODEL (Eq. 60)
(TRIAL II)

Source	df	Residual Sum of Squares	Mean Sum of Squares	f test
Regression[a]	4	129.8	32.4	
Ration[b]	45	907.1	20.1	7.94[g]
Lack of fit[c]	41	387.0	9.4	3.71[h]
Model[d]	4	520.1	130.0	
Animal/Ration[e]	50	126.9	2.5	
Residual[f]	496	1,174.9	2.3	

[a]DDMI = Day + TP^2 + Day*TP + Day^2 fitted to pooled data of 20 steers (Appendix Table 21).

[b]Regression − [DDMI = Day + TP^2 + Day*TP + Day^2 fitted to data pooled by ration] (Appendix Table 21).

[c]PDMT − [DDMI = Day + TP^2 + Day*TP + Day^2 fitted to data pooled by ration] (Appendix Table 21).

[d]Ration − Lack of fit.

[e][DDMI = Day + TP^2 + Day*TP + Day^2 fitted to data pooled by ration] − [DDMI = Day + TP^2 + Day*TP + Day^2 fitted to data by animal] (Appendix Table 21).

[f]DDMI = Day + TP^2 + Day*TP + Day^2 fitted to data by animal (Appendix Table 21).

[g]($P<.0001$) Ration MS ÷ Animal/Ration MS.

[h]($P<.0001$) Lack of fit MS ÷ Animal/Ration MS.

Fig. 14. Predicted daily dry matter intake (kg) from 0 to 220 days on feed over rations 1 to 10 at 5C for Trials I (Eq. 59) and II (Eq. 60).

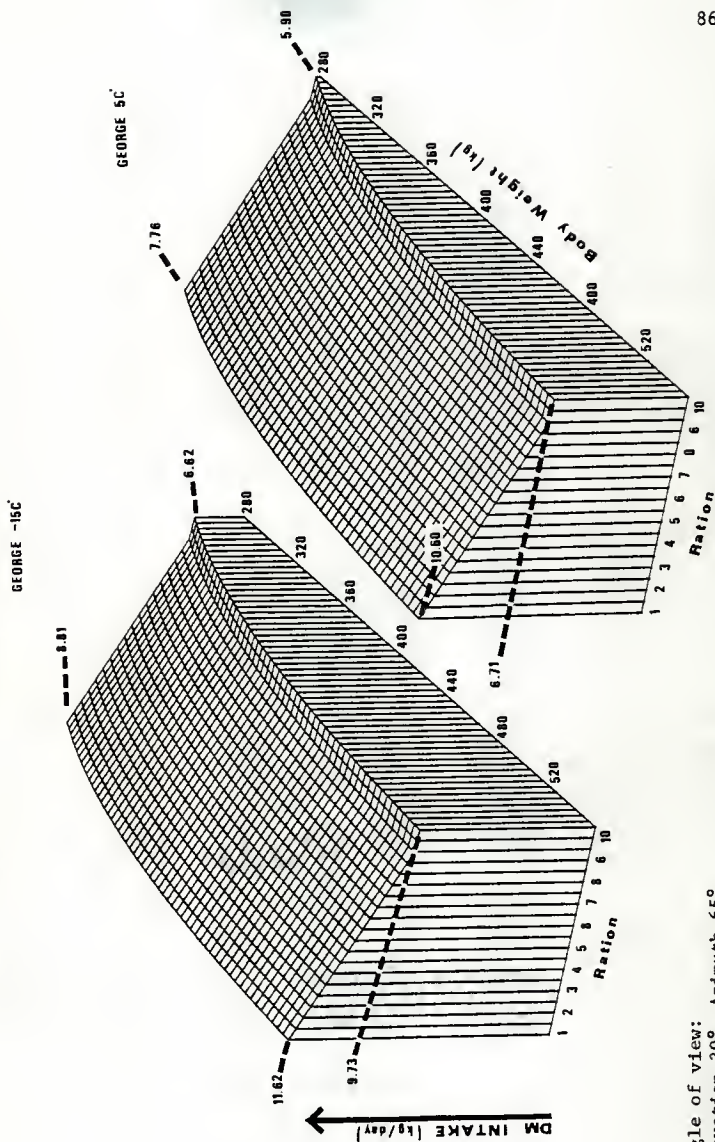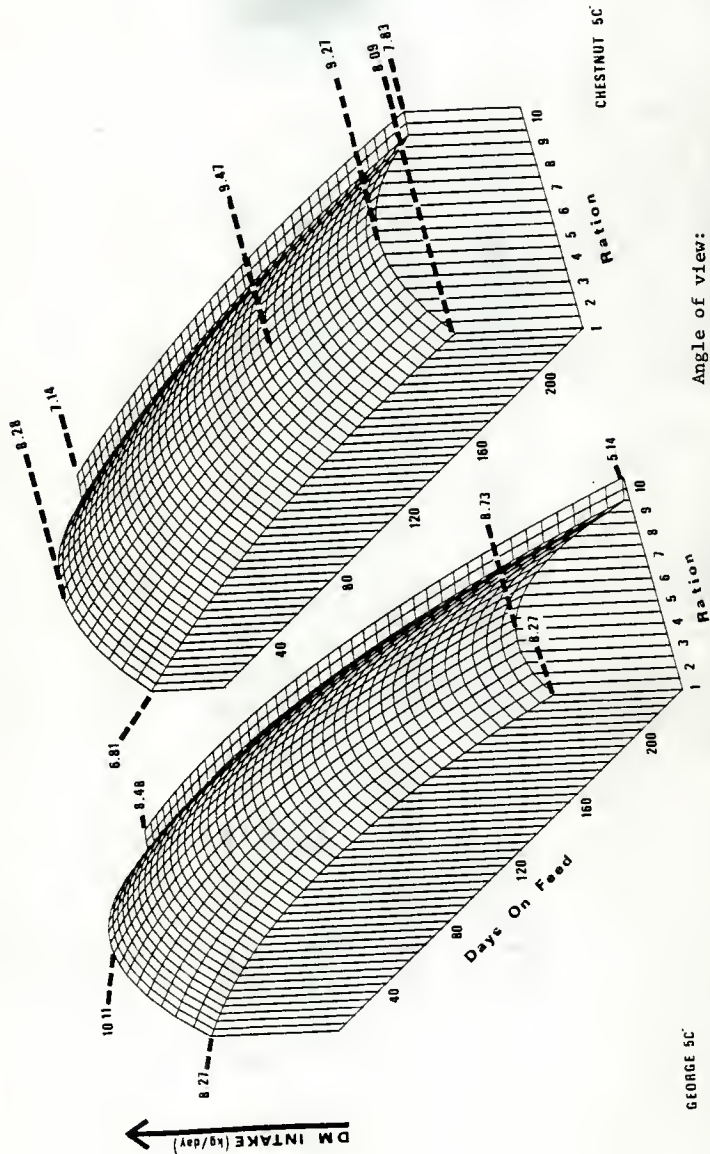Angle of view:
Elevation 30°, Azimuth 65°.

Fig. 15. Predicted daily dry matter intake (kg) from 0 to 220 days on feed over rations 1 to 10 at 5C and 25C for Trial I (Eq. 59).
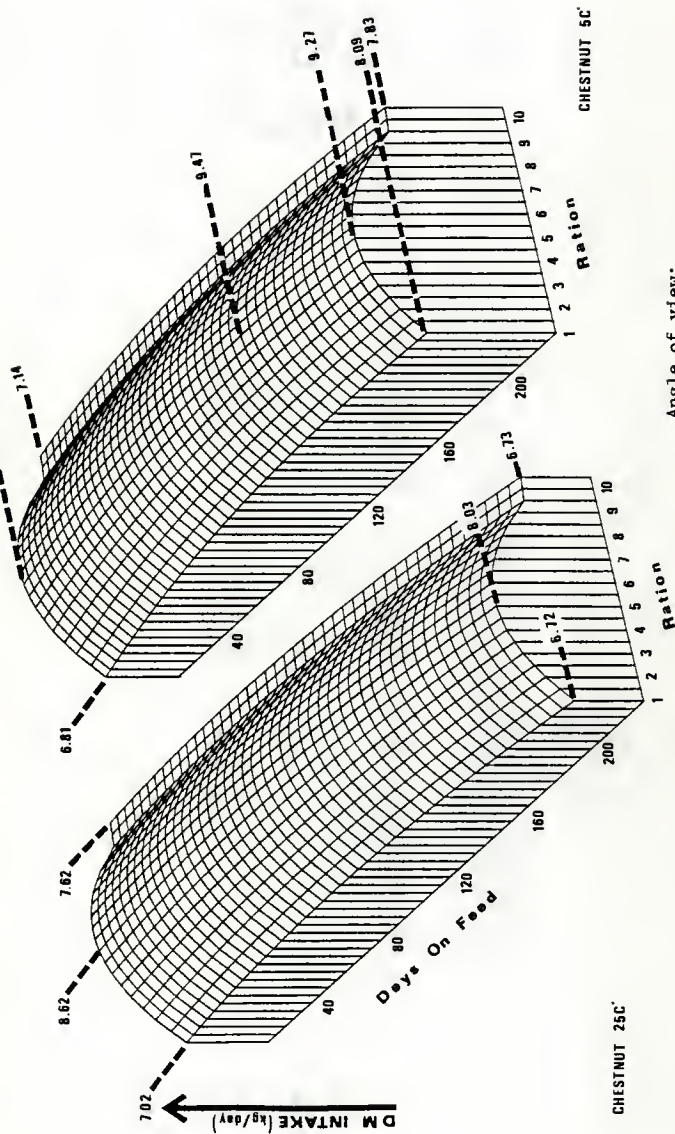
Angle of view:
Elevation 30°, Azimuth 65°.

Fig. 16. Predicted daily dry matter intake (kg) from 0 to 220 days on feed over rations 1 to 10 at 5C and -15C for Trial II (Eq. 60).

Angle of view:
Elevation 30°, Azimuth 65°.

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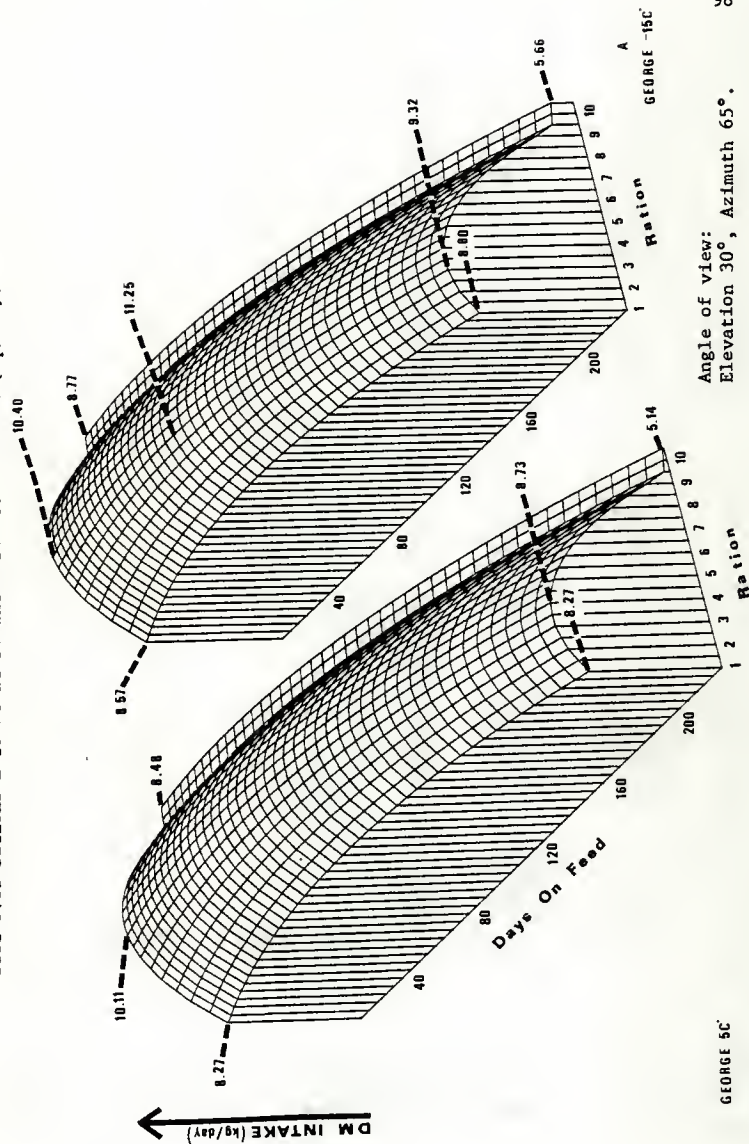
PDDMT increased within concentrate level to 150 or 160 days on
feed in Trial I, then decreased. PDDMT at the beginning of Trial II
increased with ME on rations 1 to 5 and then decreased as ME increased
to ration 10. Maximum PDDMT was reached on ration 4 after 80 days,
but was reached much sooner on high corn diets. PDDMT maxima of 8.8114
and 8.7311 kg for rations 9 and 10 respectively were reached in 50 days
on feed. Maximum PDDMT of ration 1 (9.7067 kg) was reached in 120 days;
ration 2 (10.2889 kg) in 110 days. Animals on higher energy rations
and gaining faster declined in feed intake sooner. The decline is more
rapid in high energy rations.

In Trial I PDDMT decreased when mean effective temperature was
increased to 25 C from 5 C. Environmental stress had more effect at
the end of the trial than the beginning. Near the start of the trial,
thermal stress decreased PDDMT more on rations 9 and 10 (high corn).
Late in the trial, stress influence was greatest on rations 1 and 2
(high roughage). In Trial II, lowering the mean effective temperature
to -15 C from 5 C increased PDDMT, with the greatest increases occurring
in rations with the highest PDDMT.

Animals on high corn diets reached maximum PDDMT sooner in both
trials with increased environmental stress. In Trial I maximum PDDMT
ration 10 (7.8514 kg) and ration 1 (7.4747 kg) were reached in 80 and
100 days on feed respectively when simulated at a constant 25 C.
Maximum PDDMT in Trial II on ration 10 (9.0771 kg) and ration 1
(10.1295 kg) were reached in 60 and 120 days respectively when simu-
lated at a constant -15 C.

Correlations of PDDMT models with daily DM intake for Trials I and II, respectively, were: .64344 and .70580. Mean square errors of PDDMT models for the respective trials were .76675484 and 1.33090816.

Feed Efficiency

Feed efficiency (feed/gain) tables and three-dimensional graphs were extrapolated from equations 35 and 36 and selected models of PDDMW, PDDMT, PADGW, and PADGT. Predicted Feed Efficiency as a function of Body Weight (PFEW) (Figure 17) increased as body weight and proportion of corn silage increased on both trials. In Trial I, PFEW increased on ration 1 from 6.4494 to 13.3639 and on ration 10, from 3.8056 to 8.3998. PFEW in Trial II increased from 5.9456 to 13.4504 on ration 1 and on ration 10, from 3.9193 to 10.1141. PFEW increased in both trials as environmental stress increased (Figures 18 and 19).

TABLE 31. PFEW (Trial I)

Body Wt.	Ration	5 C	25 C	Change kg/kg	Change %
280	1	6.45	9.29	+2.84	44.0
550	1	13.36	18.09	+4.73	35.4
280	10	3.81	4.47	+.66	17.3
550	10	8.40	9.77	+1.37	16.3

Fig. 17. Predicted feed efficiency (dm/gain) from 280 to 550 kg body weight over rations 1 to 10 at 5C for Trials I (Eq. 24 and 38) and II (Eq. 25 and 39).
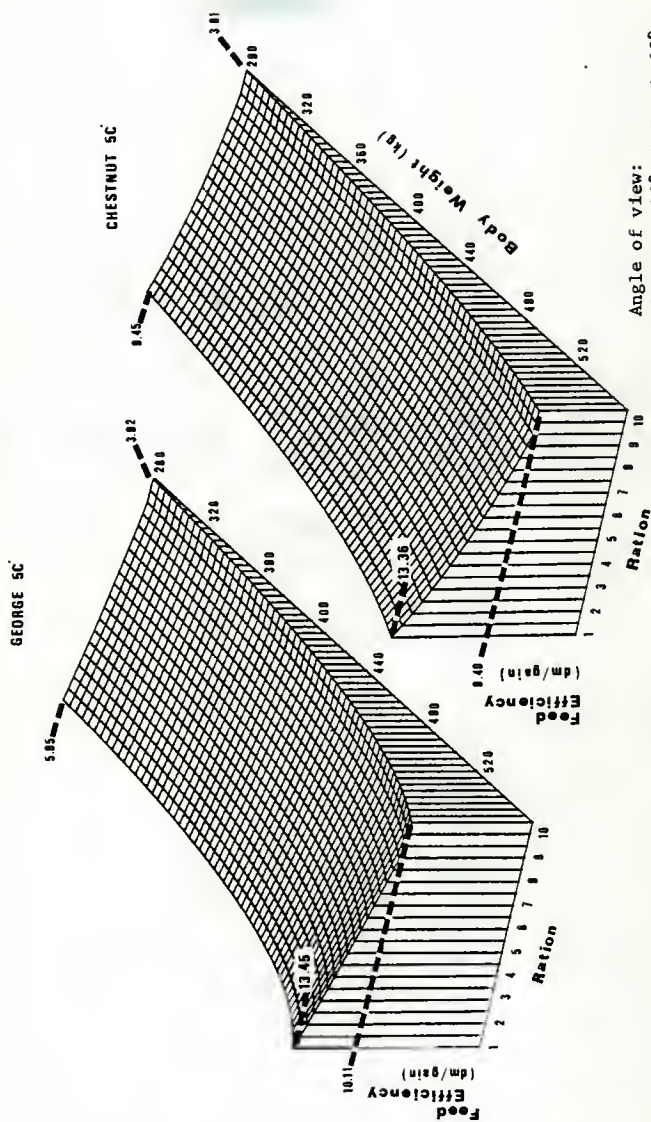
Angle of view:
Elevation 30°, Azimuth 65°.

Fig. 18. Predicted feed efficiency (dm/gain) from 280 to 550 (kg) body weight over rations 1 to 10 at 5C and 25C for Trial I (Eq. 24 and 38).

Angle of view: Elevation 30°, Azimuth 65°.

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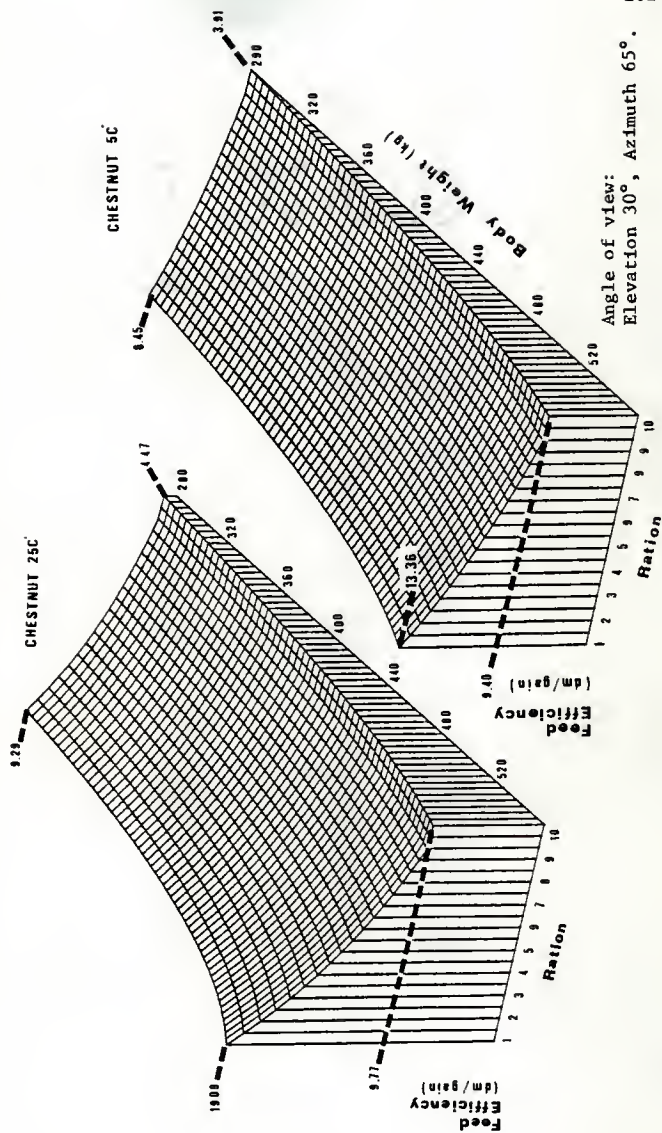
Fig. 19. Predicted feed efficiency (dm/gain) from 280 to 550 (kg) body weight over rations 1 to 10 at 5C and -15C for Trial II (Eq. 25 and 39).

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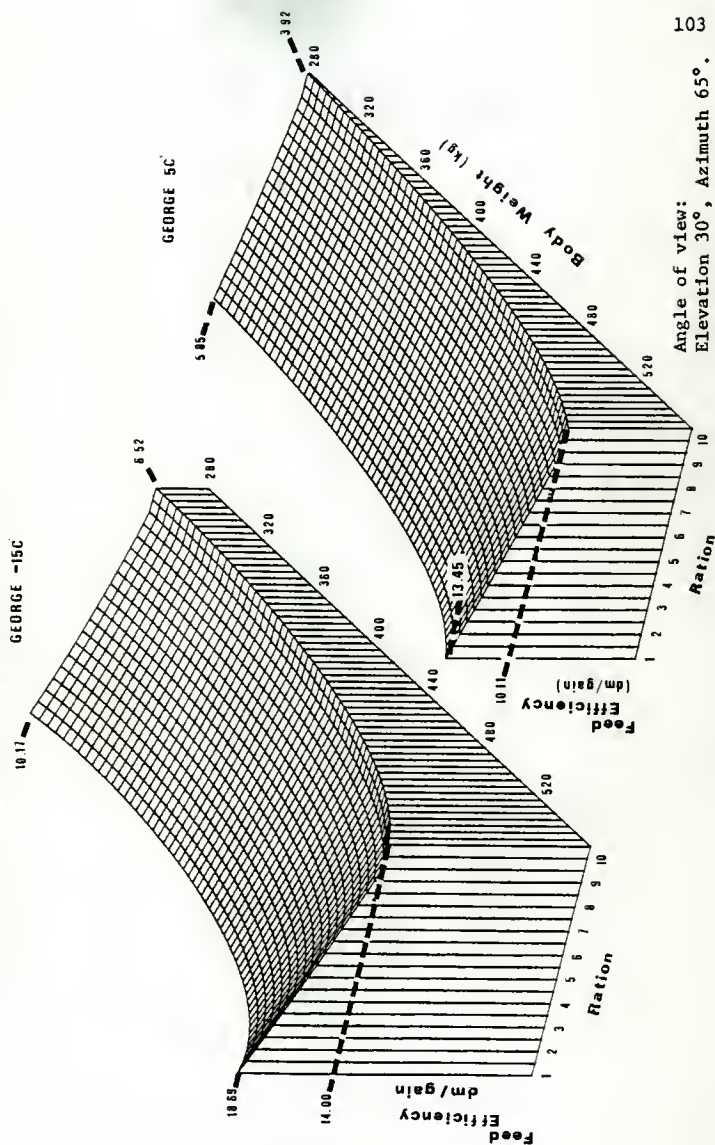
TABLE 32. PFEW (Trial II)

Body Wt.	Ration	5 C	-15 C	Change kg/kg	Change %
280	1	5.95	10.17	+4.22	70.9
550	1	13.45	18.69	+5.24	66.3
280	10	3.92	6.52	+2.60	39.0
550	10	10.11	14.00	+3.89	38.5

PFEW increased the most in response to stress on high roughage rations (Tables 31 and 32). The percentage increase of PFEW was greatest on high roughage rations and lower body weights in both trials.

Predicted Feed Efficiency as a function of Days on Feed (PFET) generally increased with decreasing ME and increasing days on feed (Figure 20). At the beginning of both trials, ration 1 had the poorest PFET; but as days on feed increased, PFET deteriorated faster on the higher concentrate rations.

In Trial I, PFET increased the most as effective temperature increased from 5 C to 25 C on high corn silage rations and at the beginning of the trial (Table 33). However, the increase to environmental stress lowered after 140 days on high energy rations because the decline in intake was greater than the proportional decline in gain.
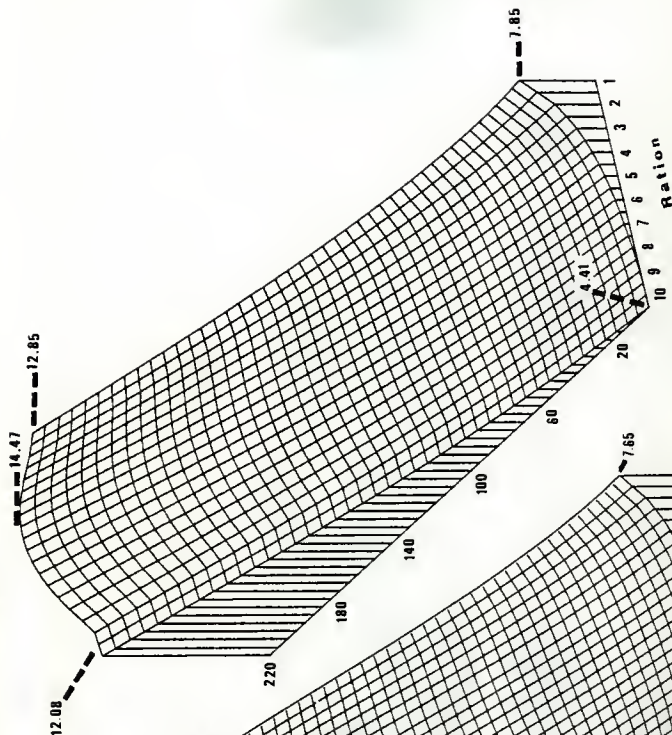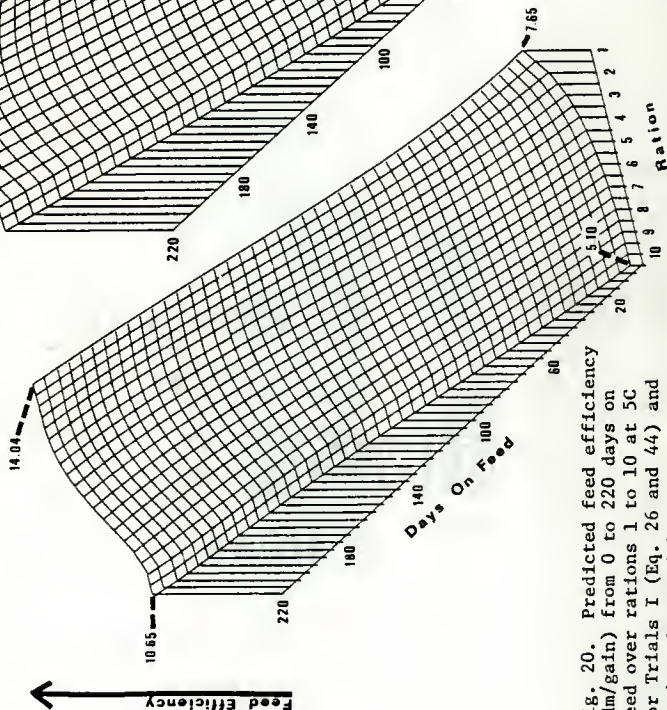
Fig. 20. Predicted feed efficiency (dm/gain) from 0 to 220 days on feed over rations 1 to 10 at 5C for Trials I (Eq. 26 and 44) and II (Eq. 27 and 45).

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Fig. 21. Predicted feed efficiency (dm/gain) from 0 to 220 days on feed over rations 1 to 10 at 5C and 25C for Trial I (Eq. 26 and 44).

Angle of view: Elevation 30°, Azimuth 65°.

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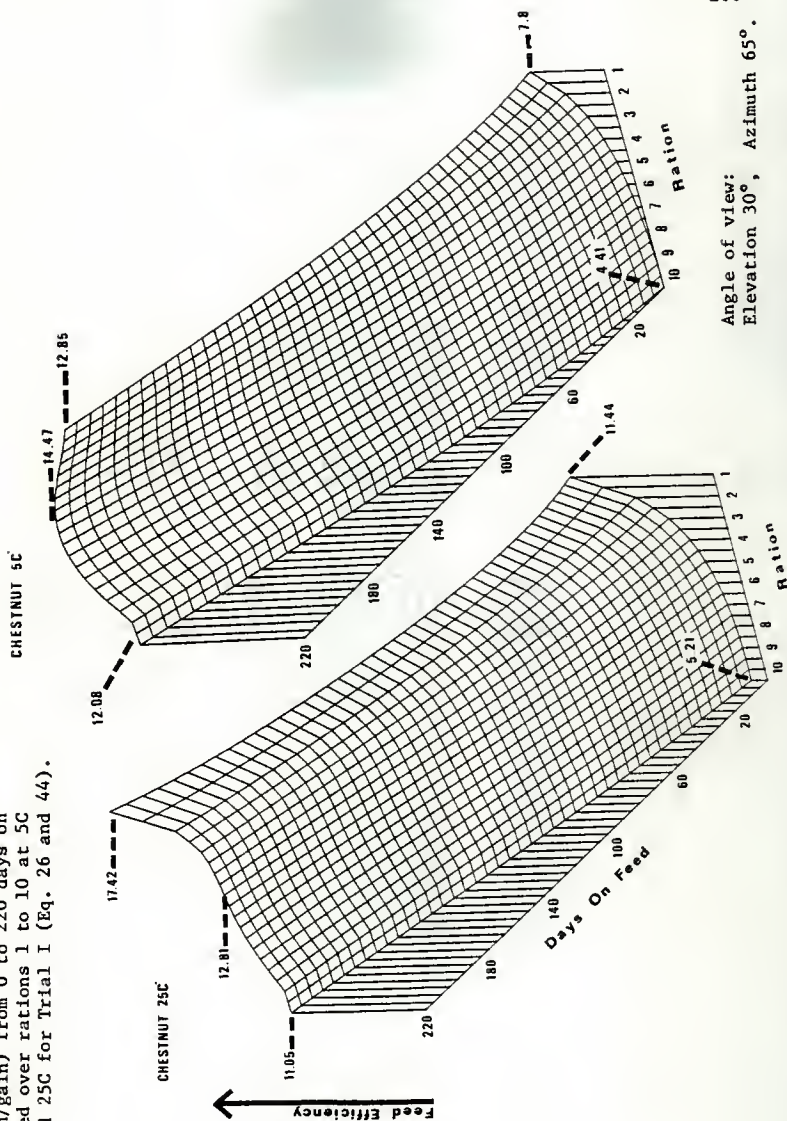
Fig. 22. Predicted feed efficiency (dm/gain) from 0 to 220 days on feed over rations 1 to 10 at 5C and −15C for Trial II (Eq. 27 and 45).

Angle of view:
Elevation 30°, Azimuth 65°.

GEORGE 5C'

GEORGE −15C'

Feed Efficiency
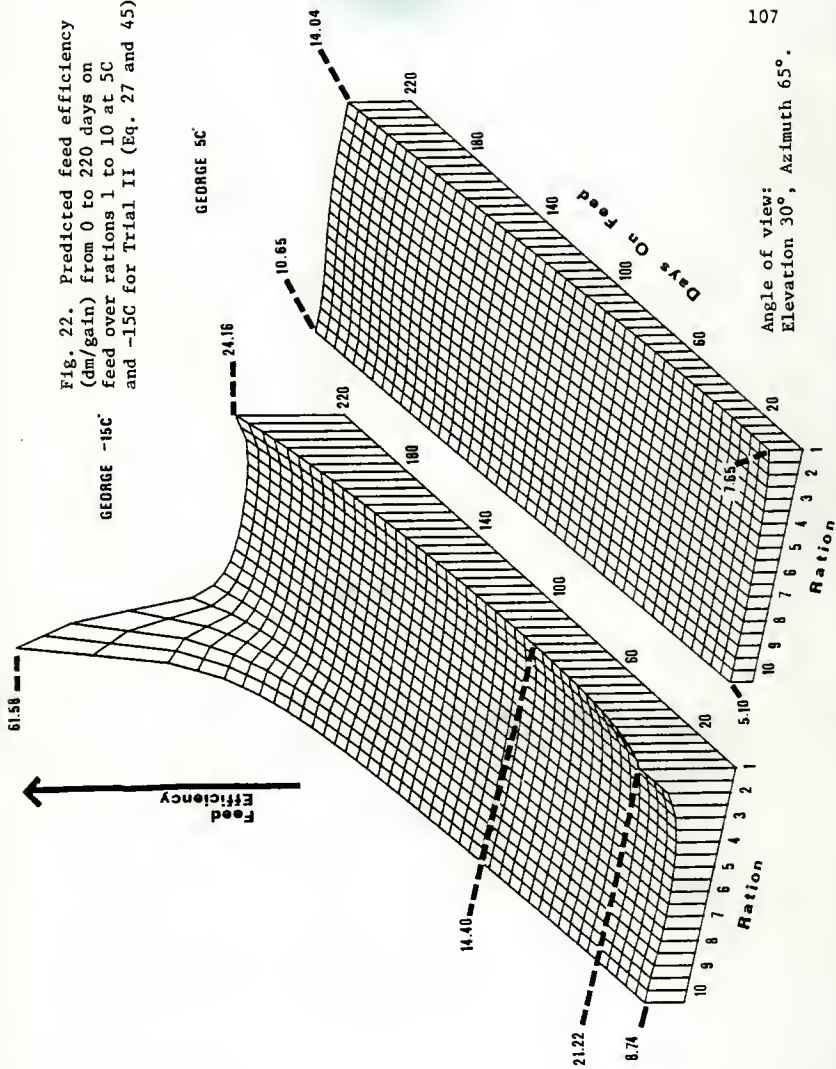
Days On Feed

Ration

TABLE 33. PFET (Trial I)

Days on Feed	Ration	5 C	25 C	Change kg/kg	Change %
0	1	7.85	11.44	+3.59	45.7
220	1	12.85	17.42	+4.57	35.6
0	10	4.41	5.21	+.80	18.1
220	10	12.08	11.05	-1.03	-8.5

Lowering the mean effective temperature from 5 C to -15 C increased PFET throughout Trial II (Table 34), with the greatest increase at the beginning of the trial for animals fed high corn silage diets and late in the feeding period for high concentrate rations. PFET of high energy rations increased rapidly after 180 days on feed as animals gaining more rapidly reached mature weight sooner. Also, intake increased the most in higher energy rations in response to a decrease in temperature with a corresponding decline in gain.

TABLE 34. PFET (Trial II)

Days on Feed	Ration	5 C	-15 C	Change kg/kg	Change %
0	1	7.65	21.22	+13.57	177.4
220	1	14.04	24.16	+9.76	69.5
0	10	5.10	8.74	+3.64	71.4
220	10	10.65	61.58	+50.93	478.2

SUMMARY

Mathematical models were developed to adequately describe growth and feed consumption of feedlot steers fed various ratios of corn silage:corn. The models or their first derivatives allowed growth rate, intake rate, and feed efficiency to be evaluated continuously over time and body weight.

Growth rate decreases non-linearly with increasing days on feed or increasing body weight and increases as consumption and ration energy density increase. Increased environmental stress decreased growth rate regardless of ration with the higher roughage rations and lower body weights affected most.

Daily dry matter intake increased at a decelerating rate with increasing body weight and time until 150 to 160 days on feed, then decreased. Animals fed higher energy rations and thus gaining faster declined in feed intake sooner and more rapidly. Intake increases with ration energy to 2.8 Mcal ME/kg dry ration, then decreases as ration energy continues to increase, inferring a feed intake cross-over point between physical fill and chemostatic control of approximately 2.8 Mcal ME/kg. This crossover point decreased from 2.9 to 2.7 during the duration of the trial, indicating that animals pass from physical to chemostatic feed intake control as rumen size and development progresses.

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Feed efficiency (feed/gain) increased at an increasing rate as body weight, days on feed, proportion of corn silage, and environmental stress increased. Environmental stress increased feed efficiency the most on high roughage rations and at lighter body weights.

No advantage was found for directly modeling growth rate over modeling growth and differentiating. Predicted growth rate was more highly correlated with actual growth rate if actual intake rather than predicted intake was included in the model.

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APPENDIX

TABLE 1.   VALUE OF TRIAL I PWT MODEL $A*(1-Be^{-KT})$

	A	B	K	Residual Sum of Squares	df
All Animals Pooled	794.8	.6285	.00276	626,137	566
Fitted by Animal					
1	950.0	.6795	.00138	3,230	43
2	950.0	.7121	.00165	2,590	43
3	569.6	.5045	.00475	151	14
4	950.0	.7393	.00184	4,706	43
5	496.2	.4064	.00887	276	14
6	578.2	.5110	.00598	576	21
7	950.0	.7046	.00198	2,332	43
8	610.4	.5570	.00472	286	31
9	828.4	.5878	.00343	95	14
10	646.5	.5720	.00488	328	21
11	864.8	.6504	.00324	216	14
12	557.6	.5137	.00690	316	13
13	637.8	.5397	.00640	277	14
14	798.4	.6371	.00331	410	17
15	649.2	.5643	.00558	245	17
16	864.2	.6646	.00321	924	43
17	622.0	.5432	.00558	299	13
18	574.2	.5519	.00725	418	13
19	815.4	.6149	.00333	1,887	35
20	950.0	.7082	.00245	2,435	43
			Total	22,000	509
Fitted by Ration					
1	950.0	.6957	.00151	10,218	89
2	950.0	.7174	.00171	13,511	60
3	587.2	.5040	.00545	1,388	38
4	950.0	.7053	.00192	7,672	77
5	518.7	.4217	.01085	35,451	38
6	929.1	.6881	.00265	11,504	30
7	611.6	.5269	.00649	4,249	34
8	894.3	.6771	.00297	2,023	63
9	594.3	.5444	.00646	2,268	29
10	950.0	.6839	.00238	19,943	81
			Total	108,231	539

TABLE 2.   VALUE OF TRIAL II PWT MODEL $A*(1-Be^{-KT})$

	A	B	K	Residual Sum of Squares	df
All Animals Pooled	577.0	.3579	.00842	212,489	498
Fitted by Animal					
1	850.0	.5764	.00300	272	20
2	758.4	.5252	.00310	610	28
3	752.1	.5278	.00412	418	20
4	620.9	.4240	.00664	1,083	25
5	529.1	.3540	.00807	805	28
6	850.0	.5441	.00215	1,095	23
7	590.0	.3676	.00838	400	24
8	640.1	.3797	.00453	2,228	27
9	850.0	.5574	.00221	2,118	24
10	850.0	.5474	.00225	4,142	23
11	738.5	.5161	.00412	1,507	21
12	695.0	.4741	.00491	418	21
13	550.7	.3325	.01209	2,038	27
14	678.4	.4585	.00725	786	16
15	551.7	.3291	.01706	835	18
16	605.0	.3716	.01233	218	13
17	578.4	.3439	.01013	1,042	18
18	609.0	.3825	.00859	710	18
19	850.0	.5491	.00197	2,198	24
20	850.0	.5498	.00206	1,300	23
			Total	24,233	441
Fitted by Ration					
1	650.0	.4522	.00531	5,899	51
2	627.2	.4364	.00674	2,418	48
3	535.2	.3320	.00902	21,745	54
4	596.5	.3556	.00701	3,979	54
5	850.0	.5523	.00223	7,126	50
6	712.8	.4931	.00454	2,575	45
7	544.5	.3489	.01654	10,431	46
8	554.2	.3329	.01840	2,997	34
9	593.6	.3633	.00927	1,987	39
10	850.0	.5493	.00201	3,612	50
			Total	62,773	471

TABLE 3. VALUE OF TRIAL I PADGW MODEL K(A-W)

	A	K	Residual Sum of Squares	df
All Animals Pooled	885.9	.00244	598.6	567
Fitted by Animal				
1	950.0	.00145	83.2	44
2	950.0	.00172	46.6	44
3	542.7	.00566	7.8	15
4	784.5	.00245	67.0	44
5	503.8	.00841	18.3	15
6	563.8	.00679	20.0	22
7	767.8	.00322	60.5	44
8	619.4	.00448	13.6	32
9	635.5	.00699	5.1	15
10	623.7	.00540	8.9	22
11	933.1	.00272	7.7	15
12	835.5	.00278	14.5	14
13	638.4	.00614	14.4	15
14	652.0	.00536	17.3	18
15	591.8	.00785	13.6	18
16	777.7	.00448	47.3	44
17	950.0	.00218	12.3	14
18	950.0	.00238	18.0	14
19	895.1	.00282	40.5	36
20	950.0	.00243	43.4	44
		Total	561.0	529
Fitted by Ration				
1	950.0	.00159	130.3	90
2	761.3	.00262	75.1	61
3	552.4	.00676	38.8	39
4	744.3	.00317	75.2	78
5	681.7	.00483	15.6	39
6	950.0	.00243	22.7	31
7	648.5	.00564	31.9	35
8	771.9	.00438	62.2	64
9	950.0	.00228	30.5	30
10	950.0	.00246	84.0	82
		Total	566.7	549

TABLE 4. VALUE OF TRIAL II PADGW MODEL K(A-W)

	A	K	Residual Sum of Squares	df
All Animals Pooled	786.5	.00330	598.3	499
Fitted by Animal				
1	774.0	.00382	9.2	21
2	850.0	.00241	17.3	29
3	850.0	.00307	18.2	21
4	648.6	.00595	35.8	26
5	583.6	.00461	35.1	29
6	850.0	.00237	33.8	24
7	581.0	.01037	17.6	25
8	605.0	.00752	29.2	28
9	850.0	.00241	36.9	25
10	850.0	.00262	35.9	24
11	850.0	.00335	23.4	22
12	707.3	.00492	14.1	22
13	577.0	.01092	42.6	28
14	827.7	.00438	23.6	17
15	565.0	.01569	30.1	19
16	655.6	.00891	10.9	14
17	677.0	.00554	15.4	19
18	626.4	.00813	26.1	19
19	850.0	.00186	57.2	25
20	850.0	.00219	39.4	24
		Total	552.8	461
Fitted by Ration				
1	832.7	.00282	27.5	52
2	708.3	.00462	54.5	49
3	850.0	.00194	70.7	55
4	590.0	.00903	47.2	55
5	850.0	.00251	72.9	51
6	797.5	.00373	37.9	46
7	634.7	.00797	70.4	47
8	593.4	.01262	42.7	35
9	644.6	.00692	41.8	40
10	850.0	.00202	96.9	51
		Total	562.9	481

TABLE 5. VALUE OF TRIAL I PADGT MODEL $ABKe^{-KT}$

	A	K	Residual Sum of Squares	df
All Animals Pooled	715.1	.00367	570.7	567
Fitted by Animal				
1	850.0	.00188	82.3	44
2	850.0	.00229	46.4	44
3	368.2	.00682	7.4	15
4	717.7	.00314	65.6	44
5	291.1	.01081	17.1	15
6	425.4	.00771	19.0	22
7	721.9	.00381	58.9	44
8	530.8	.00474	13.2	32
9	463.9	.00737	4.8	15
10	532.9	.00569	8.6	22
11	840.6	.00330	7.6	15
12	604.1	.00440	14.1	14
13	489.7	.00710	13.7	15
14	525.2	.00633	16.6	18
15	488.4	.00849	12.8	18
16	776.3	.00484	45.7	44
17	850.0	.00270	12.2	14
18	850.0	.00307	17.8	14
19	826.3	.00333	39.6	36
20	850.0	.00318	43.3	44
		Total	547.6	529
Fitted by Ration				
1	850.0	.00209	129.0	90
2	689.2	.00317	73.5	61
3	371.4	.00845	36.7	39
4	647.5	.00400	72.8	78
5	508.1	.00628	13.6	39
6	727.3	.00372	21.9	31
7	508.3	.00668	30.3	35
8	714.1	.00516	59.7	64
9	850.0	.00289	30.2	30
10	850.0	.00319	82.9	82
		Total	551.2	549

TABLE 6. VALUE OF TRIAL II PADGT MODEL ABKe^{-KT}

	A	K	Residual Sum of Squares	df
All Animals Pooled	747.6	.00603	566.3	499
Fitted by Animal				
1	1018.3	.00427	8.9	21
2	1100.0	.00297	17.0	29
3	1100.0	.00383	17.7	21
4	701.2	.00741	34.1	26
5	504.7	.00659	33.7	29
6	1100.0	.00280	33.3	24
7	570.4	.01150	16.2	25
8	540.1	.01049	27.5	28
9	1100.0	.00291	36.3	25
10	1100.0	.00301	35.4	24
11	1100.0	.00435	22.9	22
12	845.2	.00559	13.6	22
13	541.9	.01481	38.5	28
14	1000.2	.00580	22.8	17
15	528.8	.01680	27.1	19
16	687.1	.00967	10.2	14
17	677.8	.00694	14.7	19
18	614.9	.00993	24.4	19
19	1100.0	.00213	56.5	25
20	1100.0	.00246	39.0	24
		Total	530.8	461
Fitted by Ration				
1	1080.5	.00347	26.6	52
2	817.2	.00576	52.3	49
3	638.2	.00521	67.7	55
4	551.9	.01113	44.0	55
5	1100.0	.00297	71.7	51
6	999.0	.00470	36.7	46
7	665.3	.01025	63.1	47
8	574.5	.01352	38.2	35
9	634.4	.00850	39.5	40
10	1100.0	.00230	95.7	51
		Total	536.2	481

TABLE 7. VALUE OF TRIAL I PDMW MODEL I + WT + WT² + WT³

	I	WT	WT²	WT³	Residual Sum of Squares	df
All Animals Pooled	4,267.6	-37.674	0.10185428	-0.00007481	38,885,683	565
Fitted by Animal						
1	8,064.7	-71.729	0.19511738	-0.00015200	208,145	42
2	1,027.0	-15.943	0.05475782	-0.00003811	113,108	42
3	-6,464.7	54.226	-0.16328985	0.00018475	12,831	13
4	-470.9	-3.141	0.02318308	-0.00001496	305,852	42
5	14,091.3	-118.622	0.31826871	-0.00026269	35,010	13
6	571.5	-7.615	0.01978856	0.00000076	51,299	20
7	2,187.6	-21.544	0.06058504	-0.00003893	184,625	42
8	-1,239.5	6.965	-0.01749728	0.00003216	37,227	30
9	-7,848.8	51.217	-0.11801408	0.00010307	6,596	13
10	-4,562.1	31.934	-0.07798854	0.00007792	20,721	20
11	-8,148.4	58.373	-0.14365276	0.00012989	11,142	13
12	-2,340.9	17.184	-0.04771292	0.00005906	12,253	12
13	-3,359.8	24.233	-0.06384581	0.00006854	16,143	13
14	-6,199.3	44.759	-0.11123577	0.00010489	15,138	16
15	-2,808.1	19.392	-0.04978489	0.00005635	13,266	16
16	-1,091.7	3.038	0.00105686	0.00000460	69,691	42
17	-3,932.5	30.089	-0.08275921	0.00008871	6,986	12
18	-629.1	3.379	-0.00915796	0.00002061	12,395	12
19	-75.1	-2.903	0.01011747	-0.00000016	64,380	34
20	33.1	-3.932	0.01578881	-0.00000735	66,903	42
				Total	1,263,721	489

TABLE 7. (Continued)

	I	WT	WT^2	WT^3	Residual Sum of Squares	df
Fitted by Ration						
1	4,579.0	-43.070	0.12073647	-0.00008997	589,363	88
2	2,426.9	-25.740	0.07858796	-0.00005841	582,934	59
3	6,055.4	-52.496	0.13977401	-0.00010432	102,935	37
4	3,256.0	-30.100	0.08282343	-0.00005731	367,595	76
5	11,865.0	-95.041	0.24511236	-0.00019519	1,434,587	37
6	3,961.8	-36.949	0.10611682	-0.00008672	157,212	29
7	-4,965.6	35.993	-0.09136200	0.00008988	132,765	33
8	-1,432.8	4.935	-0.00203689	0.00000609	135,936	62
9	2,057.6	-18.612	0.04922779	-0.00003011	36,108	28
10	1,583.0	-13.927	0.03555130	-0.00001971	350,919	80
				Total	3,890,358	529

TABLE 8. VALUE OF TRIAL II PDMW MODEL $I + WT + WT^2 + WT^3$

	I	WT	WT^2	WT^3	Residual Sum of Squares	df
All Animals Pooled	17,048.8	-118.496	0.26105216	-0.00017519	29,217,041	497
Fitted by Animal						
1	-2,417.6	10.581	-0.02016242	0.00002573	19,555	19
2	-7,128.6	43.993	-0.10046062	0.00009203	96,375	27
3	394.4	-7.628	0.01844613	-0.00000002	41,526	19
4	12,980.1	-86.526	0.17939566	-0.00010726	107,864	24
5	-25,505.3	186.078	-0.46773268	0.00041249	260,598	27
6	68,721.3	-459.232	1.00114642	-0.00070480	126,767	22
7	18,816.9	-121.952	0.24734834	-0.00014751	45,227	23
8	55,553.5	-366.031	0.78129267	-0.00053203	412,220	26
9	11,802.5	-96.906	0.24142911	-0.00017905	135,933	23
10	3,380.6	-53.874	0.16969369	-0.00013962	285,398	22
11	28,903.6	-199.735	0.44612532	-0.00031512	53,995	20
12	-7,078.5	42.274	-0.09309346	0.00008302	38,319	20
13	52,293.6	-334.767	0.69259270	-0.00045424	283,390	26
14	8,266.1	-56.372	0.11849256	-0.00007069	70,471	15
15	7,632.3	-38.124	0.04485499	0.00000858	167,956	17
16	-3,238.3	25.215	-0.07294185	0.00007657	19,056	12
17	52,198.4	-337.407	0.71097992	-0.00048296	92,517	17
18	10,641.3	-67.618	0.13285027	-0.00007424	38,131	17
19	27,998.8	-198.561	0.45329595	-0.00032821	121,361	23
20	4,578.1	-47.532	0.13169135	-0.00010261	53,715	22
Total					2,470,383	421

TABLE 8. (Continued)

Fitted by Ration

	I	WT	WT^2	WT^3	Residual Sum of Squares	df
1	-10,945.9	69.543	-0.15620116	0.00013108	673,934	50
2	5,719.4	-39.932	0.08170599	-0.00004009	200,511	47
3	83,736.7	-584.923	1.33760671	-0.00099254	4,668,033	53
4	34,547.9	-226.612	0.47647180	-0.00031251	558,334	53
5	10,484.2	-91.348	0.23425722	-0.00017608	520,646	49
6	19,912.8	-137.858	0.30512847	-0.00020867	196,334	44
7	65,888.8	-431.969	0.92406961	-0.00063797	2,546,136	45
8	25,881.8	-160.524	0.31791208	-0.00019427	499,668	33
9	32,920.7	-212.770	0.44520647	-0.00029615	199,617	38
10	14,031.0	-107.925	0.25894518	-0.00019075	247,048	49
				Total	10,310,266	461

TABLE 9. VALUE OF TRIAL I PDMW MODEL I + WT + WT^2

	I	WT	WT^2	Residual Sum of Squares	df
All Animals Pooled	-2,271.2	7.892	-0.00078864	41,389,476	566
Fitted by Animal					
1	-3,398.8	10.971	-0.00059142	285,351	43
2	-1,690.4	4.183	0.00624377	127,505	43
3	1,264.2	-12.978	0.03029629	13,570	14
4	-1,469.8	4.468	0.00444027	309,223	43
5	1,180.4	-12.216	0.02779924	36,596	14
6	612.4	-7.944	0.02065800	51,300	21
7	-971.7	0.986	0.00859251	211,979	43
8	625.2	-7.747	0.02049800	38,897	31
9	59.1	-5.015	0.01431707	7,594	14
10	-221.5	-2.638	0.01251927	23,610	21
11	-204.5	-2.711	0.01137562	13,565	14
12	209.4	-4.824	0.01501487	12,496	13
13	656.2	-7.116	0.01686034	17,072	14
14	-287.8	-2.049	0.01083957	18,267	17
15	416.5	-6.031	0.01617833	14,478	17
16	-608.8	-0.133	0.00777068	70,596	43
17	492.5	-6.277	0.01602138	7,410	13
18	278.4	-4.420	0.01292342	12,443	13
19	-91.0	-2.798	0.00989235	64,380	35
20	-709.2	1.006	0.00519612	68,891	43
			Total	1,405,232	509

TABLE 9. (Continued)

Fitted by Ration	I	WT	WT^2	Residual Sum of Squares	df
1	-1,941.8	4.819	0.00591103	709,477	89
2	1,428.5	3.678	0.00579833	643,163	60
3	372.0	-7.017	0.01982662	108,288	38
4	-1,264.0	2.430	0.00702469	468,370	77
5	51.2	-3.443	0.01188879	1,486,865	38
6	-752.6	0.882	0.00626510	162,846	30
7	176.2	-4.498	0.01371145	136,770	34
8	-827.7	0.888	0.00669326	138,196	63
9	681.9	-6.943	0.01658945	36,318	29
10	-426.0	-0.659	0.00717583	372,587	81
			Total	4,262,885	539

TABLE 10. VALUE OF TRIAL II PDMW MODEL $I + WT + WT^2$

	I	WT	WT^2	Residual Sum of Squares	df
All Animals Pooled	-30.1	-6.274	0.01724190	29,481,455	498
Fitted by Animal					
1	27.7	-5.628	0.01535690	19,764	20
2	1,767.3	-14.682	0.02737700	101,362	28
3	392.4	-7.615	0.01841750	41,526	20
4	2,805.3	-18.936	0.03121977	114,107	25
5	6,282.4	-39.430	0.06215117	273,721	28
6	-1,423.9	-2.300	0.01520762	198,523	23
7	3,914.1	-25.261	0.03976829	49,980	24
8	781.2	-13.235	0.02858348	450,206	27
9	-6,130.2	19.695	-0.00965217	143,702	24
10	-11,704.9	41.743	-0.03106691	291,589	23
11	-882.5	-1.415	0.01084196	123,180	21
12	1,116.7	-11.332	0.02288930	40,716	21
13	6,512.6	-37.235	0.05339983	352,926	27
14	769.8	-8.465	0.01729431	72,571	16
15	8,525.4	-43.854	0.05703547	167,964	18
16	4,857.3	-26.456	0.03632224	19,613	13
17	2,580.7	-17.634	0.02829695	121,117	18
18	2,949.8	-18.183	0.02760559	38,787	18
19	-4,115.0	11.645	-0.00288352	133,313	24
20	-5,537.1	18.485	-0.01121836	54,782	23
Total				2,809,460	441

TABLE 10. (Continued)

Fitted by Ration

	I	WT	WT^2	Residual Sum of Squares	df
1	1,649.9	-13.680	0.02548276	689,734	51
2	1,924.5	-14.719	0.02639182	202,065	48
3	-5,353.7	16.969	-0.00648324	5,513,466	54
4	2,775.8	-20.992	0.03594315	594,034	54
5	-7,839.4	26.292	-0.01585533	541,062	50
6	-38.8	-5.720	0.01619937	247,432	45
7	-227.2	-6.197	0.01780354	2,887,997	46
8	5,482.1	-30.024	0.04132833	507,698	34
9	2,358.7	-16.093	0.02594857	220,885	39
10	-4,698.6	14.503	-0.00643476	254,841	50
			Total	11,659,220	471

TABLE 11. VALUE OF TRIAL I FDMT MODEL $I + T + T^2 + T^3$

	I	T	T^2	T^3	Residual Sum of Squares	df
All Animals Pooled	-36.4	9.383	-0.01224464	0.00002529	6,332,861	565
Fitted by Animal						
1	13.1	6.515	0.00642384	-0.00001051	2,205	42
2	10.9	6.657	0.00593984	-0.00000345	2,452	42
3	-4.2	7.248	0.00578574	0.00004247	129	13
4	3.3	6.582	0.00613261	-0.00000551	2,534	42
5	-6.4	8.375	0.00691935	-0.00001309	58	13
6	-11.9	8.950	-0.00320045	0.00001748	305	20
7	-18.4	7.994	0.00247877	-0.00000255	1,491	42
8	-7.6	7.704	0.00386996	-0.00000978	715	30
9	-3.9	9.738	-0.01203876	0.00012312	148	13
10	1.6	8.186	0.00978098	-0.00004453	210	20
11	-3.1	9.116	-0.00583681	0.00009010	84	13
12	-4.4	7.474	0.00797851	-0.00003190	333	12
13	8.1	7.397	0.02431104	-0.00006840	167	13
14	-1.6	9.284	-0.01950376	0.00011733	760	16
15	-8.9	7.499	0.02310487	-0.00008083	91	16
16	-36.2	9.929	-0.00628793	0.00000677	2,872	42
17	-0.8	5.194	0.04548130	-0.00022593	52	12
18	-3.7	5.145	0.03963995	-0.00019407	229	12
19	-7.6	6.169	0.01105012	-0.00002908	3,613	34
20	0.1	5.973	0.00375094	-0.00000395	526	42
Total					18,980	489

TABLE 11. (Continued)

Fitted by Ration

	I	T	T^2	T^3	Residual Sum of Squares	df
1	12.0	6.586	0.00618184	-0.00000698	204,059	88
2	-16.8	7.924	-0.00364504	0.00001290	59,693	59
3	-9.6	8.649	-0.00334423	-0.00001250	2,027	37
4	-17.2	8.108	-0.00016160	0.00000489	24,387	76
5	6.2	8.043	0.02324937	-0.00012526	52,593	37
6	-21.4	10.092	-0.04082941	0.00029262	82,500	29
7	12.6	7.435	0.02238459	-0.00009411	20,969	33
8	-42.4	9.825	-0.00483777	0.00000328	9,543	62
9	-2.2	5.170	0.04256063	-0.00021000	4,457	28
10	-5.4	6.125	0.00709699	-0.00001634	146,358	80
				Total	606,593	529

TABLE 12. VALUE OF TRIAL II PDMT MODEL $I + T + T^2 + T^3$

	I	T	T^2	T^3	Residual Sum of Squares	df
All Animals Pooled	-26.8	10.557	-0.0069096	0.00001494	9,999,224	497
Fitted by Animal						
1	1.4	7.900	0.01343869	-0.00000752	125	19
2	-0.2	7.943	0.00749472	0.00000259	174	27
3	13.6	8.711	0.02961434	-0.00010377	542	19
4	-2.1	8.503	0.01569713	-0.00005251	512	24
5	1.1	9.443	0.01523965	-0.00006636	1,440	27
6	-10.3	7.230	0.03571581	-0.00012509	1,601	22
7	-20.9	12.188	-0.00008233	-0.00004071	601	23
8	-4.2	11.418	-0.00568357	0.00000175	740	26
9	24.5	8.989	0.00204509	-0.00000070	1,668	23
10	5.0	9.854	0.00631549	-0.00000627	656	22
11	6.9	9.079	0.01287250	-0.00005684	650	20
12	19.0	9.434	0.02304760	-0.00009239	662	20
13	-33.8	13.141	-0.01639883	0.00000647	1,934	26
14	1.9	9.484	0.03095047	-0.00013626	127	15
15	-19.9	10.443	0.02458729	-0.00016659	419	17
16	-5.4	9.737	0.03931876	-0.00019685	76	12
17	-17.1	7.385	0.03533542	-0.00017179	1,010	17
18	-17.8	7.691	0.02369112	-0.00012562	439	17
19	-0.7	5.220	0.01923629	-0.00005408	837	23
20	-8.6	5.410	0.01696070	-0.00006394	414	22
				Total	14,637	421

TABLE 12. (Continued)

	I	T	T^2	T^3	Residual Sum of Squares	df
Fitted by Ration						
1	3.2	7.633	0.01667635	-0.00003534	37,469	50
2	19.9	7.500	0.04163177	-0.00016457	173,259	47
3	-14.2	8.993	0.01574171	-0.00005733	85,354	53
4	-11.8	11.751	-0.00209209	-0.00002267	50,134	53
5	27.1	8.565	0.01711629	-0.00005544	232,752	49
6	13.0	9.256	0.01796005	-0.00007462	157,941	44
7	-26.6	11.957	-0.00041812	-0.00004532	15,107	45
8	-7.5	9.508	0.04679343	-0.00028178	12,719	33
9	-17.5	7.538	0.02951327	-0.00014871	14,127	38
10	-10.4	5.712	0.01210538	-0.00003494	30,619	49
				Total	809,486	461

TABLE 13. VALUE OF TRIAL I PDMT MODEL I + T + TP + T*TP

	I	T	TP	T*TP	Residual Sum of Squares	df
All Animals Pooled	-18.7	7.846	4.68507084	-0.02308351	6,347,514	565
Fitted by Animal						
1	-3.1	7.533	-2.50761600	0.00723957	2,705	42
2	-20.5	8.085	-2.65473058	-0.00302609	9,090	42
3	-11.8	7.960	-4.19869997	0.06652859	1,053	13
4	-23.8	7.903	-2.56730407	-0.00072596	5,448	42
5	-12.2	8.911	-1.59048506	0.02111010	128	13
6	-10.6	8.966	-1.34574348	0.00361292	349	20
7	-30.2	8.509	-0.91142844	0.00010909	2,511	42
8	-11.6	8.084	-1.05903813	0.00722658	673	30
9	-2.0	9.564	-3.47031328	0.04864959	1,211	13
10	-8.3	8.825	0.67472885	-0.00957960	782	20
11	-3.2	9.180	-3.50989534	0.05310648	810	13
12	-10.3	7.992	-0.83797530	0.00924763	358	12
13	-7.7	8.844	-3.22422162	0.06075002	605	13
14	14.0	8.094	-1.06654578	0.03228568	1,908	16
15	-27.5	9.079	-2.48802557	0.02924576	365	16
16	-9.8	8.658	2.35936081	-0.00007052	5,359	42
17	-23.9	7.505	-2.27589612	0.03524009	328	12
18	-25.3	7.275	-2.42012619	0.03032272	428	12
19	-26.0	7.205	-1.51623884	0.01447941	4,508	34
20	-16.5	6.741	-1.40244830	0.00012065	2,048	42
Total					40,975	489

TABLE 13. (Continued)

	I	T	TP	T*TP	Residual Sum of Squares	df
Fitted by Ration						
1	-11.8	7.809	-2.58117329	0.00210674	208,831	88
2	-20.0	7.863	0.79844546	-0.01563048	57,805	59
3	-15.2	9.062	-0.69892705	-0.00280690	1,964	37
4	-29.0	8.437	-0.06388765	-0.00781863	28,058	76
5	-23.9	9.776	2.89203185	-0.05916573	59,853	37
6	-3.3	8.526	-3.95652593	0.05753518	86,934	29
7	-7.0	8.898	-0.88762185	0.00803733	21,893	33
8	-21.8	8.712	2.38771070	0.00152055	10,949	62
9	-24.6	7.390	-2.34801116	0.03278141	4,935	28
10	-14.7	6.900	-2.15809887	0.01376183	149,777	80
				Total	631,005	529

TABLE 14. VALUE OF TRIAL II PDMT MODEL I + T + TP + T*TP

	I	T	TP	T*TP	Residual Sum of Squares	df
All Animals Pooled	-30.8	10.015	3.41795872	-0.06177172	9,505,042	497
Fitted by Animal						
1	-27.2	9.821	3.71386288	-0.00846158	2,366	19
2	-40.6	9.478	1.24757809	0.01565195	5,362	27
3	-34.5	11.143	2.82906956	-0.02577325	820	19
4	-29.8	9.837	2.19115655	-0.02223314	478	24
5	-10.2	10.223	2.14654584	-0.03916380	6,197	27
6	-39.5	9.975	6.69418242	-0.06009533	2,026	22
7	12.6	10.994	-0.66373151	-0.02685880	9,847	23
8	18.2	10.435	-0.64253968	-0.01024958	2,784	26
9	16.5	9.334	0.18218500	0.00322914	1,878	23
10	-12.0	10.763	1.27881600	-0.00084797	2,203	22
11	-3.0	9.815	0.81506679	-0.01427348	802	20
12	-4.7	10.990	2.04001230	-0.02501162	900	20
13	28.0	10.382	-1.26074883	-0.03436147	13,407	26
14	-24.1	11.331	1.73934986	-0.02678055	327	15
15	-16.7	10.737	-1.23552218	-0.02193375	2,029	17
16	-25.6	11.748	2.34456000	-0.03572340	304	12
17	-36.8	9.184	1.47888628	-0.02904886	1,691	17
18	-26.9	8.684	0.56401730	-0.02044169	850	17
19	-23.4	6.974	1.83740663	-0.00492270	2,509	23
20	-10.8	6.530	2.41093649	-0.02008843	910	22
Total					57,700	421

TABLE 14. (Continued)

	I	T	TP	T*TP	Residual Sum of Squares	df
Fitted by Ration						
1	-31.3	9.547	1.62677845	0.00863595	32,257	50
2	-22.9	10.205	3.15874139	-0.04784369	196,528	47
3	-36.3	10.233	4.45432970	-0.04958603	73,905	53
4	16.1	10.707	0.13714761	-0.02800990	62,692	53
5	8.4	9.968	0.07353164	0.00075978	232,461	49
6	-3.8	10.403	1.42753955	-0.01964255	158,313	44
7	8.2	10.576	0.47769936	-0.05115217	24,563	45
8	-13.7	10.815	-0.19027976	-0.04397548	18,393	33
9	-31.8	8.934	1.02145179	-0.02474528	15,154	38
10	-25.2	6.817	1.40052850	-0.00822484	32,194	49
				Total	846,464	461

TABLE 15. VALUE OF TRIAL I PDDMW MODEL $X + Y*(1-e^{-Z*WT})$

	Y	Z	X	Residual Sum of Squares	df
All Animals Pooled	35.0	.0121	-26.5	681.4	566
Fitted by Animal					
1	35.0	.0121	-27.2	22.5	43
2	9.8	.0024	1.8	23.2	43
3	35.0	.0010	-2.6	5.9	14
4	13.8	.0068	-5.0	20.7	43
5	35.0	.0090	-24.8	2.1	14
6	35.0	.0121	-25.8	7.9	21
7	35.0	.0110	-26.1	12.7	43
8	35.0	.0134	-26.7	12.5	31
9	35.0	.0005	3.1	4.7	14
10	35.0	.0294	-26.4	6.8	21
11	4.9	-0.0001	11.9	87.7	14
12	35.0	.0110	-26.2	7.3	13
13	14.1	.0031	-0.7	5.6	14
14	35.0	.0001	6.3	16.4	17
15	35.0	.0083	-24.5	4.3	17
16	35.0	.0233	-26.5	46.0	43
17	35.0	.0082	-25.8	4.4	13
18	35.0	.0091	-26.4	6.9	13
19	35.0	.0104	-27.5	20.4	35
20	8.2	.0059	-0.9	13.0	43
			Total	332.0	509
Fitted by Ration					
1	-3.4	-0.0006	6.4	85.0	89
2	35.0	.0106	-26.2	41.8	60
3	35.0	.0111	-25.5	11.2	38
4	35.0	.0115	-26.3	27.4	77
5	35.0	.0001	6.4	33.5	38
6	35.0	.0005	1.9	22.5	30
7	35.0	.0002	5.1	25.8	34
8	.0	-0.0015	9.1	72.9	63
9	2.0	-0.0015	9.4	49.2	29
10	35.0	.0106	-27.7	35.6	81
			Total	404.7	539

TABLE 16. VALUE OF TRIAL I PDDMW MODEL $I + WT + WT^2 + WT^3$

	I	WT	WT^2	WT^3	Residual Sum of Squares	df
All Animals Pooled	-12.3	.119	-0.00021811	.00000013	624.4	565
Fitted by Animal						
1	44.0	-0.289	.00074090	-0.00000061	20.2	42
2	26.9	-0.163	.00042955	-0.00000035	21.9	42
3	-11.7	.125	-0.00029840	.00000030	5.9	13
4	15.6	-0.083	.00024822	-0.00000022	19.6	42
5	-219.3	1.835	-0.00492259	.00000440	1.7	13
6	-75.6	.662	-0.00172364	.00000149	7.3	20
7	-12.2	.126	-0.00025460	.00000017	12.4	42
8	-24.4	.234	-0.00055504	.00000043	12.0	30
9	-11.5	.187	-0.00055628	.00000055	3.3	13
10	27.3	-0.181	.00056564	-0.00000057	4.5	20
11	-37.0	.372	-0.00101600	.00000094	3.0	13
12	-161.6	1.432	-0.00402037	.00000375	6.4	12
13	129.0	-0.974	.00257359	-0.00000221	4.6	13
14	52.4	-0.305	.00067764	-0.00000047	14.1	16
15	-44.4	.329	-0.00065422	.00000042	2.2	16
16	-29.9	.248	-0.00050960	.00000033	33.4	42
17	-107.0	.782	-0.00173133	.00000124	.6	12
18	-86.5	.691	-0.00167345	.00000133	4.4	12
19	-57.1	.391	-0.00077975	.00000051	16.0	34
20	2.1	.019	-0.00002445	.00000001	12.9	42
				Total	207.4	489

TABLE 16. (Continued)

	I	WT	WT^2	WT^3	Residual Sum of Squares	df
Fitted by Ration						
1	18.9	-0.100	.00027027	-0.00000022	62.4	88
2	-4.9	.065	-0.00009439	.00000003	39.4	59
3	-42.9	.382	-0.00094151	.00000077	10.9	37
4	-11.8	.130	-0.00027978	.00000020	27.0	76
5	-98.7	.842	-0.00217690	.00000186	27.8	37
6	-96.6	.847	-0.00228318	.00000206	17.1	29
7	98.0	-0.693	.00175380	-0.00000144	23.7	33
8	-40.6	.313	-0.00063696	.00000041	37.2	62
9	-31.0	.205	-0.00028072	.00000003	7.0	28
10	-11.3	.102	-0.00018864	.00000011	34.6	80
				Total	287.6	529

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TABLE 17. VALUE OF TRIAL II PDDMW MODEL $I + WT + WT^2 + WT^3$

	I	WT	WT^2	WT^3	Residual Sum of Squares	df
All Animals Pooled	.8	.013	.00005601	-0.00000009	1,270.2	497
Fitted by Animal						
1	30.3	-0.175	.00042488	-0.00000031	1.0	19
2	11.3	-0.035	.00008415	-0.00000004	3.3	27
3	106.5	-0.701	.00166794	-0.00000129	8.4	19
4	29.5	-0.196	.00056052	-0.00000049	3.5	24
5	329.4	-2.425	.00609952	-0.00000507	11.9	27
6	-529.7	3.298	-0.00668381	.00000449	8.0	22
7	-277.3	1.747	-0.00345099	.00000222	4.1	23
8	-22.8	.187	-0.00031339	.00000014	12.1	26
9	132.3	-0.765	.00157258	-0.00000107	15.1	23
10	-136.0	.918	-0.00192163	.00000135	8.6	22
11	-2.7	.055	-0.00005456	-0.00000001	14.5	20
12	224.5	-1.451	.00326142	-0.00000242	9.7	20
13	-470.2	3.044	-0.00631708	.00000429	19.6	26
14	-26.8	.160	-0.00018007	.00000003	4.5	15
15	-100.2	.407	-0.00019582	-0.00000035	8.1	17
16	75.5	-0.578	.00155110	-0.00000129	2.7	12
17	-370.2	2.220	-0.00428034	.00000271	7.8	17
18	-303.8	1.811	-0.00343927	.00000213	4.1	17
19	-74.7	.372	-0.00048583	.00000014	6.7	23
20	-500.7	3.186	-0.00663768	.00000458	13.4	22
Total					168.1	421

TABLE 17. (Continued)

	I	WT	WT^2	WT^3	Residual Sum of Squares	df
Fitted by Ration						
1	19.3	-0.094	.00023080	-0.00000015	5.9	50
2	65.7	-0.433	.00108180	-0.00000087	34.4	47
3	-88.8	.631	-0.00133022	.00000092	68.3	53
4	-139.5	.902	-0.00175382	.00000110	24.7	53
5	-108.7	.779	-0.00170521	.00000124	49.8	49
6	60.9	-0.375	.00091116	-0.00000072	41.7	44
7	-376.9	2.460	-0.00513930	.00000353	80.6	45
8	-261.6	1.535	-0.00281340	.00000167	46.1	33
9	-333.0	1.985	-0.00378578	.00000236	13.4	38
10	-306.8	1.906	-0.00384051	.00000256	26.6	49
				Total	392.0	461

TABLE 18. VALUE OF TRIAL I PDDMW MODEL $I + WT + WT^2$

	I	WT	WT^2	Residual Sum of Squares	df
All Animals Pooled	-1.3	0.042	-0.00004590	631.4	566
Fitted by Animal					
1	-2.1	0.043	-0.00004755	21.4	43
2	2.0	0.020	-0.00001412	23.1	43
3	0.6	0.018	0.00001095	5.9	14
4	1.0	0.027	-0.00002597	20.3	43
5	-3.0	0.053	-0.00005692	2.2	14
6	4.7	0.016	-0.00001583	8.0	21
7	1.5	0.028	-0.00002755	13.0	43
8	0.7	0.035	-0.00004126	12.3	31
9	30.4	-0.111	0.00014563	3.3	14
10	-4.1	0.068	-0.00009125	4.6	21
11	20.3	-0.069	0.00010405	3.1	14
12	0.2	0.035	-0.00003823	7.4	13
13	-0.4	0.036	-0.00003012	5.6	14
14	25.9	-0.095	0.00012977	14.2	17
15	-20.5	0.142	-0.00016670	2.3	17
16	5.1	0.018	-0.00002203	38.2	43
17	-45.2	0.274	-0.00035237	0.7	13
18	-27.7	0.186	-0.00024475	4.6	13
19	-6.3	0.056	-0.00005685	18.0	35
20	3.1	0.012	-0.00000930	13.0	43
			Total	222.1	509
Fitted by Ration					
1	2.7	0.018	-0.00001422	63.2	89
2	-2.7	0.048	-0.00005198	39.4	60
3	-0.8	0.045	-0.00005132	11.2	38
4	3.9	0.016	-0.00001510	28.3	77
5	13.8	-0.030	0.00004572	32.5	38
6	15.3	-0.050	0.00008737	20.3	30
7	15.4	-0.043	0.00006656	24.8	34
8	0.5	0.037	-0.00004190	47.7	63
9	-29.7	0.194	-0.00024987	7.0	29
10	0.2	0.025	-0.00002389	35.3	81
			Total	310.1	539

TABLE 19. VALUE OF TRIAL II PDDMW MODEL $I + WT + WT^2$

	I	WT	WT^2	Residual Sum of Squares	df
All Animals Pooled	-8.4	0.074	-0.00007602	1,270.3	498
Fitted by Animal					
1	1.3	0.016	0.00000311	1.1	20
2	7.7	-0.010	0.00003150	3.4	28
3	-14.8	0.106	-0.00010841	9.0	20
4	-17.0	0.112	-0.00011686	3.6	25
5	-61.6	0.348	-0.00041935	13.9	28
6	-82.8	0.387	-0.00040162	10.9	23
7	-53.5	0.295	-0.00033264	5.2	24
8	-8.3	0.094	-0.00011403	12.1	27
9	25.4	-0.069	0.00007530	15.4	24
10	9.5	-0.005	0.00001640	9.1	23
11	-3.9	0.063	-0.00007203	14.5	21
12	-14.6	0.112	-0.00012302	11.8	21
13	-37.5	0.232	-0.00027550	25.9	27
14	-24.0	0.142	-0.00014287	4.5	16
15	-136.1	0.637	-0.00068564	8.1	18
16	-61.2	0.294	-0.00029556	2.9	13
17	-91.3	0.423	-0.00044371	8.7	18
18	-82.6	0.389	-0.00041294	4.6	18
19	-61.2	0.284	-0.00029359	6.4	24
20	-48.7	0.236	-0.00025228	15.6	23
			Total	187.5	441
Fitted by Ration					
1	4.4	0.003	0.00001660	5.9	51
2	-16.5	0.113	-0.00011837	35.2	48
3	-6.1	0.072	-0.00008306	69.0	54
4	-28.1	0.181	-0.00020940	25.1	54
5	20.5	-0.050	0.00006017	50.8	50
6	-8.2	0.082	-0.00009152	42.4	45
7	-10.6	0.101	-0.00011842	91.1	46
8	-86.2	0.412	-0.00043466	46.7	34
9	-89.0	0.415	-0.00043821	14.8	39
10	-55.0	0.260	-0.00027324	28.0	50
			Total	409.4	471

TABLE 20. VALUE OF TRIAL I PDDMT MODEL $I + T + TP^2 + T*TP + T^2$

	I	T	TP^2	$T*TP$	T^2	Residual Sum of Squares	df
All Animals Pooled	7.3	.024	-0.00003600	-0.0002626281	-0.00008330	679.8	564
Fitted by Animal							
1	6.7	.011	-0.00050489	-0.00000087	-0.00003161	21.3	41
2	6.8	.011	-0.00127244	.00006163	-0.00001038	21.8	41
3	7.1	.022	-0.04423491	.01323175	-0.00096929	4.7	12
4	6.2	.029	-0.00248847	-0.00004816	-0.00007596	14.9	41
5	7.9	.031	-0.01813277	.00464056	-0.00045562	1.7	12
6	8.4	.010	-0.02757819	.00753416	-0.00055180	7.2	19
7	6.9	.030	-0.00071469	-0.00022052	-0.00009041	10.7	41
8	7.2	.018	.00134715	-0.00035357	-0.00005360	11.9	29
9	9.4	-0.010	-0.01063413	.00387874	-0.00010929	3.8	12
10	7.9	.030	.00823566	-0.00352658	.00014020	3.6	19
11	8.9	-0.005	-0.00717040	.00177462	.00010841	2.7	12
12	7.6	.007	-0.03954616	.00947346	-0.00049438	4.1	11
13	7.4	.047	.01803130	-0.00611758	.00029181	5.3	12
14	9.5	-0.031	-0.05796451	.01791488	-0.00113060	12.8	15
15	6.9	.062	-0.02645433	.00867893	-0.00104733	2.0	15
16	8.8	.003	.00051188	-0.00010581	-0.00002654	39.1	41
17	4.7	.094	.00912938	-0.00304497	-0.00040224	1.4	11
18	4.9	.077	-0.01893143	-0.00624726	-0.00102027	5.1	11
19	5.8	.021	.00397245	-0.00051201	-0.00007118	13.9	33
20	5.8	.010	-0.00003630	-0.00002949	-0.00002318	13.0	41
					Total	201.9	469

TABLE 20. (Continued)

I	T	TP²	T*TP	T²	Residual Sum of Squares	df
Fitted by Ration						
1	.011	-0.00088866	.00003038	-0.00002099	62.0	87
2	.038	-0.00236161	-0.00020156	-0.00011532	37.3	58
3	.020	-0.02131682	.00552866	-0.00045274	9.9	36
4	.025	-0.00023735	-0.00024026	-0.00007652	25.6	75
5	.042	.00879442	-0.00327651	.00002045	29.0	36
6	-0.007	-0.02806483	.00699752	-0.00021499	29.5	28
7	.007	-0.01990283	.00593141	-0.00042523	28.1	32
8	.020	.00075954	-0.00027193	-0.00008264	49.9	61
9	.086	-0.00490102	.00160115	-0.00071125	7.6	27
10	.015	.00108147	-0.00015756	-0.00004491	36.3	79
				Total	315.7	519

I values: 6.8, 6.4, 8.1, 7.0, 8.0, 8.4, 8.5, 8.1, 4.8, 5.9

TABLE 21. VALUE OF TRIAL II PDDMT MODEL $I + T + TP^2 + T*TP + T^2$

	I	T	TP^2	T*TP	T^2	Residual Sum of Squares	df
All Animals Pooled	9.5	-0.006	-0.00069022	-0.00071843	.00005229	1,174.9	496
Fitted by Animal							
1	7.9	.021	.00053591	-0.00003748	.00001008	1.0	18
2	8.1	.006	-0.00076448	-0.00021653	.00005815	2.7	26
3	9.1	.035	.00527874	.00022555	-0.00017443	6.0	18
4	8.8	.009	.00086221	-0.00036219	-0.00002119	2.7	23
5	9.7	.007	.00338814	-0.00031160	-0.00006883	9.1	26
6	7.3	.038	.00237686	-0.00055664	-0.00013717	9.9	21
7	11.4	.011	-0.00198707	-0.00021307	-0.00014452	7.8	22
8	11.3	-0.005	-0.00466252	-0.00029436	-0.00000947	5.5	25
9	10.7	-0.053	.00123026	-0.00067665	.00029500	10.3	22
10	10.6	-0.031	.00284443	-0.00056947	.00023784	5.4	21
11	10.0	-0.012	-0.00201238	-0.00072380	.00006734	12.1	19
12	11.1	-0.023	.00326996	-0.00063435	.00012395	6.8	19
13	11.8	-0.008	.00083128	.00013705	-0.00007304	19.2	25
14	9.4	.052	.00263914	.00021877	-0.00032188	3.9	14
15	8.6	.107	-0.00126143	.00038393	-0.00081600	5.8	16
16	8.8	.114	-0.01216410	-0.00209743	-0.00089352	2.3	11
17	5.5	.129	.00225643	.00110343	-0.00082712	6.3	16
18	5.7	.116	-0.00216740	.00064291	-0.00075865	3.4	16
19	5.1	.025	.00143227	-0.00039916	-0.00006011	7.3	22
20	4.5	.051	.00331116	.00041007	-0.00029249	12.0	21
				Total		146.7	401

TABLE 21. (Continued)

Fitted by Ration

	I	T	TP^2	T*TP	T^2	Residual Sum of Squares	df
1	7.6	.029	-0.00015673	.00007905	-0.00006117	10.6	49
2	8.9	.023	.00256980	-0.00014831	-0.00010781	28.1	46
3	8.3	.031	.00349277	-0.00021818	-0.00015672	31.3	52
4	11.4	-0.000	-0.00230153	-0.00019216	-0.00005938	21.0	52
5	10.4	-0.030	.00199852	-0.00041273	.00019400	49.1	48
6	10.6	-0.018	.00062879	-0.00067908	.00009564	35.7	43
7	10.8	.013	.00239675	.00003356	-0.00016256	37.6	44
8	8.6	.115	-0.00160989	.00018730	-0.00086117	14.2	32
9	5.6	.122	.00004452	.00087317	-0.00079289	13.1	37
10	4.9	.029	.00217627	-0.00021019	-0.00010991	26.5	48
					Total	267.7	451

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TABLE 22. CARCASS COMPOSITION OF STEERS KILLED AT THE NE_p EFFICIENCY POINT OF 7.0 Mcal/kg GAIN (TRIAL I)

Ration	Steer	Days	Quality Grade	Yield Grade	Fat Thickness	REA	KK	Carcass Weight	% Water	% Fat	% Protein
1	1[a]	322	C+	3.55	.70	12.5	2.5	726	50.65	34.86	14.92
1	2[b]	322	P-	5.05	1.15	12.5	2.0	759	46.07	38.77	13.32
2	3	119	G+	2.25	.30	10.3	2.0	504	54.31	29.67	14.55
2	4[c]	322	Co	3.45	.50	11.2	2.0	740	51.14	34.67	14.74
3	5	119	C-	2.15	.30	11.4	2.0	549	51.51	33.67	13.19
3	6	168	C-	2.55	.35	11.2	2.0	611	51.36	34.14	15.19
4	7	322	C+	5.05	1.10	12.2	2.5	841	47.68	39.30	13.44
4	8	238	C+	3.30	.45	11.2	3.0	687	49.13	38.77	14.04
5	9	119	C-	3.25	.50	11.4	2.5	674	51.92	33.07	15.02
5	10	168	G+	2.85	.35	11.3	3.0	654	53.06	33.13	14.86
6	11	119	C-	3.37	.40	9.9	3.0	630	51.68	34.68	14.97
6	12	112	C-	3.00	.35	8.9	2.0	546	53.08	33.35	15.40

TABLE 22. (Continued)

Ration	Steer	Days	Quality Grade	Yield Grade	Fat Thickness	REA	KK	Carcass Weight	% Water	% Fat	% Protein
7	13	119	C⁻	2.40	.35	12.4	3.0	613	51.48	32.73	15.21
7	14	140	C⁻	3.60	.70	11.6	3.0	640	50.91	34.73	14.05
8	15	140	C⁻	3.80	.55	9.8	3.0	637	46.89	39.14	13.93
8	16	322	C⁻	6.80	1.70	11.8	2.5	948	42.28	45.95	12.05
9	17	112	Cº	3.40	.60	10.8	2.5	594	Missing Data		
9	18	112	C⁻	3.25	.40	9.5	3.0	580	53.04	31.48	15.39
10	19	266	C⁺	4.50	.80	12.4	2.5	882	47.65	39.40	13.40
10	20[d]	322	Cº	7.10	1.40	10.5	2.5	914	42.38	45.66	12.40

[a,b,c,d]These steers did not reach the NE_p end point. At slaughter their NE_p efficiencies were 1, 1.5219; 2, 3.9604; 4, 3.8007; 20, 4.7095.

TABLE 23. CARCASS COMPOSITION OF STEERS KILLED AT 544.3 Kg (TRIAL II)

Ration	Steer	Days	Live Wt.	Hot Car. Wt.	Dress %	Quality Grade	Mat.	Marb.	Yield Grade	Fat Thick.	LEA	%KK
1	1	168	1160	720	62	C^-	60A	40 Sm	3.4	.65	11.8	1.5
1	2	217	1180	738	63	C^0	70A	10 Md	3.5	.70	12.2	3.0
2	3	161	1156	716	62	C^-	50A	40 Sm	4.8	1.00	10.4	2.0
2	4	196	1200	754	63	C^0	80A	10 Mt	2.5	.40	12.8	1.5
3	5	217	1045	630	60	C^-	60A	0 Sm	3.2	.50	10.1	1.5
3	6	182	1140	721	63	C^0	70A	20 Mt	3.7	.65	11.1	1.5
4	7	189	1170	774	66	C^-	70A	60 Sm	4.6	1.00	11.2	1.5
4	8	210	1125	740	66	C^0	90A	70 Md	4.2	.75	10.5	2.5
5	9	189	1200	754	63	C^-	60A	70 Sm	4.0	.65	10.6	2.5
5	10	189	1240	782	63	C^-	60A	10 Sm	2.9	.60	12.3	2.0
6	11	168	1210	756	62	C^-	70A	90 Sm	2.4	.40	13.9	2.0
6	12	168	1180	752	64	G^+	70A	80 Sl	3.5	.70	12.7	2.0
7	13	210	1160	784	68	C^-	70A	30 Sm	4.2	.80	12.2	3.0
7	14	133	1255	773	62	C^-	40A	30 Sm	4.3	.80	11.2	2.5

TABLE 23. (Continued)

Ration	Steer	Days	Live Wt.	Hot Car. Wt.	Dress %	Quality Grade	Mat.	Marb.	Yield Grade	Fat Thick.	LEA	%KK
8	15	147	1150	738	64	C⁻	50A	20 Sm	5.0	1.00	19.3	2.5
8	16	112	1190	738	62	C⁻	50A	20 Sm	4.8	1.05	11.6	3.0
9	17	147	1140	722	63	C⁻	50A	0 Sm	4.0	.85	12.2	2.5
9	18	147	1160	728	63	C⁻	50A	30 Sm	5.2	1.00	10.3	3.5
10	19	189	1120	731	65	C⁻	60A	80 Sm	3.3	.50	11.6	2.5
10	20	182	1145	758	66	Std⁺	80A	70 Tr	3.4	.40	10.8	2.5

USING MATHEMATICAL MODELS TO EVALUATE
FEEDLOT PERFORMANCE OF CATTLE FED DIFFERING
CORN: CORN SILAGE RATIOS DURING WINTER AND SUMMER

by

PHILIP DANA GEORGE

B.S., Kansas State University, 1976

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AN ABSTRACT OF A MASTER'S THESIS

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Mathematical models were constructed to describe feedlot performance vs. level of metabolizable energy (ME) in the ration and either time on trial or body weight. In each of two trials twenty individually ad libitum fed Hereford steers were allotted to 10 rations (2 steers per ration) varying in corn: corn silage ratios and equal increment increases in ME. Rations were formulated using corn silage, cracked yellow corn, and soybean supplement (SBM) from NRC values. In Trial I, ration 1 (2.54 Mcal ME/kg) contained 89.95% corn silage and 10.05% SBM and ration 10 (3.20 Mcal ME/kg) contained 87.16% cracked corn and 12.84% SBM. In Trial II, ration 1 (2.55 Mcal ME/kg) contained 89.67% corn silage and 10.33% SBM and ration 10 (3.20 Mcal ME/kg) contained 86.86% cracked corn and 13.14% SBM. Steers averaging 283.1 kg in Trial I and 339.7 kg in Trial II were allowed 21 day and 7 day adjustment periods, respectively. Steer weights and dry matter consumption were recorded prior to each Wednesday morning feeding beginning March 10th for Trial I and October 26th for Trial II. Animals in Trial I were slaughtered at an efficiency end point of 7.0 Mcal NEp/kg and in Trial II at 544.3 kg. All environmental data were as reported to the National Weather Service in Local Climatological Data bulletin. Selected prediction models contained those combinations of variables which produced the smallest mean square error and those variables with the narrowest 95% confidence intervals which did not contain zero.

Models of average daily gain as a function body weight (ADGW) were K*(806.22-WT) where K is -.0058+.0024*ME+.0003*DDMI-.0001*TP, ME is Mcal ME/kg dry ration, DDMI is kg daily dry matter intake,

TP is effective temperature (C), and WT is body weight in kg and K*
(711.67-WT) where K equals -.0098+.0029*ME+.0007*DDMI+.0001*TP for
Trials I and II, respectively. Models describing average daily gain
as a function of days on feed (ADGT) were $(612.34)(.6395)*Ke^{-KT}$ where
K is -.0113+.0030*ME+.0008*DDMI+.0001*TP and T is days on feed and
$(1011.80)(.3801)*Ke^{-KT}$ where K is -.0104+.0025*ME+.0008*DDMI+.0001*TP
for the respective trials. Models of daily dry matter intake as a
function of body weight (DDMW) were $(12.1342)(1-e^{-.0075*WT})$ -1.2565*ME
+.0577*TP-.0001*TP^3 and $(19.7924)(1-e^{-.0062*WT})$ -3.2000*ME-.0726*TP
-.0022*TP^2 for Trials I and II, respectively. Models describing daily
dry matter intake as a function of days on feed (DDMT) were -113.60
+85.0890*ME-14.9060*ME^2+.0324*T-.0001*T^2-.0047*ME*T-.0014*TP^2
+.0227*ME*TP-.0004*T*TP and -152.01+113.4577*ME-19.8814*ME^2+.0989*T-
.0001*T^2-.0269*ME*T+.0016*TP^2+.0006*ME*TP-.001*T*TP for the respective
trials. Feed efficiency as a function of body weight (FEW) or days on
feed (FET) was defined as DDMW/ADGW or DDMT/ADGT, respectively.

Average daily gain decreased as body weight and days on feed
increased. Rations producing the fastest gains early in the trial
had the fastest decline in gain as body weight increased or as the
trial progressed. DDMW decreased with increasing ME and increased
non-linearly with increasing body weight. Maximum DDMT across rations
was maintained on ration 5 (50% corn silage) indicating physical fill
controlled daily feed intake on rations containing less than 2.83
Mcal ME/kg and rations containing more than 2.91 Mcal ME/kg are chemo-
statically controlled. DDMW and DDMT increased as effective temperature
decreased. Feed efficiency increased at an increasing rate as body
weight or days on feed and proportion of roughage increased. Gain

declined and feed efficiency increased with increased environmental stress regardless of ration, days on feed, or body weight.

Comparisons of growth rate modeling methods showed no advantage to modeling the change in weight per unit time over modeling accumulative weight, then differentiating.

Three dimensional graphs were constructed of ADGW, ADGT, DDMW, DDMT, FEW, and FET using a line plotter and the Surface II Graphics System adapted for a ITEL AS/5 processor.