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USING MATHEMATICAL MODELS TO EVALUATE FEEDLOT PERFORMANCE OF BEEF CATTLE FED DIFFERING CORN SILAGE:CORN RATIOS

by

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INTRODUCTION

Beef cattle in commercial feedlots are generally fed to market weight on high grain rations containing only enough roughage to prevent acidosis. Interest in feeding more roughage grows whenever grain prices increase in relation to roughage. Ultimately grain feeding may be limited due to its need for human food. Studies on roughage : concentrate ratios are somewhat limited, especially when economic analysis is concerned. One objective of this study then was to investigate the influence of differing corn silage : corn ratios on performance in a way that can be adapted to economic analysis.

The design of most feeding trials provides only averages over the entire trial on which to base conclusions. These do not reflect how performance changes relative to time. A second objective of the study, therefore, was to develop mathematical models which continuously describe feedlot performance as a function of both time and roughage : concentrate ratios.

Most feeding experiments terminate at either a predetermined length of time or body weight. Not all animals at the same chronological age or body weight will be physiologically equivalent. Consequently the steers in our experiment were killed at the same partial energy efficiency point of 7.0 Mcal NE_p/Kg gain.

REVIEW OF LITERATURE

I. ENERGY BALANCE AND FEED INTAKE REGULATION

The first law of thermodynamics states that energy can neither be created nor destroyed. The implication is that all energy input into an animal can be accounted for by summing all energy outputs (fesces, urine, methane, heat loss, milk, fetus, etc.) plus or minus energy balance (energy gained or lost by the body mass). While a positive energy balance is important to growing animals, it is critical for an adult to maintain a neutral energy balance. Regulation of energy balance involves altering input, output or a combination of both. For this reason understanding what controls feed intake (energy input) is of concern in understanding how to improve performance.

Feed intake regulation occurs on both short term and long term basis. The short term control is what starts and stops a single meal, while long term control involves regulating a large number of meals to maintain the proper long-term energy balance. This long term control is important because animals, like humans, don't concern themselves with exact caloric intake of each meal and yet if they were consistantly eating a few calories too much or too few the long range results would be devastating.

If animals eat to meet an energy requirement then there are two basic short term controls. An animal's intake may be limited simply by his gastro-intestinal capacity. However, if the animal meets his energy requirement before reaching physical capacity his appetite is limited by one or more negative feedback systems which respond to levels of specific metabolites. Maintaining homostatic energy intake under those conditions is known as 'chemostatic control'.

There is abundant evidence that animals 'eat for calories'. Adding a non-nutritive substance to swine diets (Baker et al., 1968) resulted in increased consumption of the diluted diet until the same energy intake was maintained or physical capacity of the gut was reached. When cattle on roughage diets were supplemented with four levels of acetate their dry matter intake decreased but total caloric intake remained the same (Dinius et al., 1968). Baumgardt (1970) used sawdust and sawdust with koalin clay to alter the energy density of cattle rations. Dilution was from 5 to 50% of the basal diet in 5% increments. Dry matter (DM) and digestible energy (DE) intakes per unit metabolic size were both positively correlated to digestible energy density (DED) of the ration when DED was less than 2.5 kcal/gm of the diet. Above a DED of 2.5 kcal/gm DM intake was negatively correlated ($r = -.76$) and DE intake was only slightly negatively correlated ($r = -.18$).

This is illustrated graphically in Figure 1 and describes the hypothesis that when a poor quality roughage (with a low DED) is fed intake will be limited by physical fill. Up to a point, as DED (or proportion concentrate) increases, DM and DE intakes also increase. At approximately 2.5 kcal/gm DED, however, DE intake becomes homostatic and DM intake decreases

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as DED continues to increase. This latter phase is referred to as 'chemostatic control' of intake.

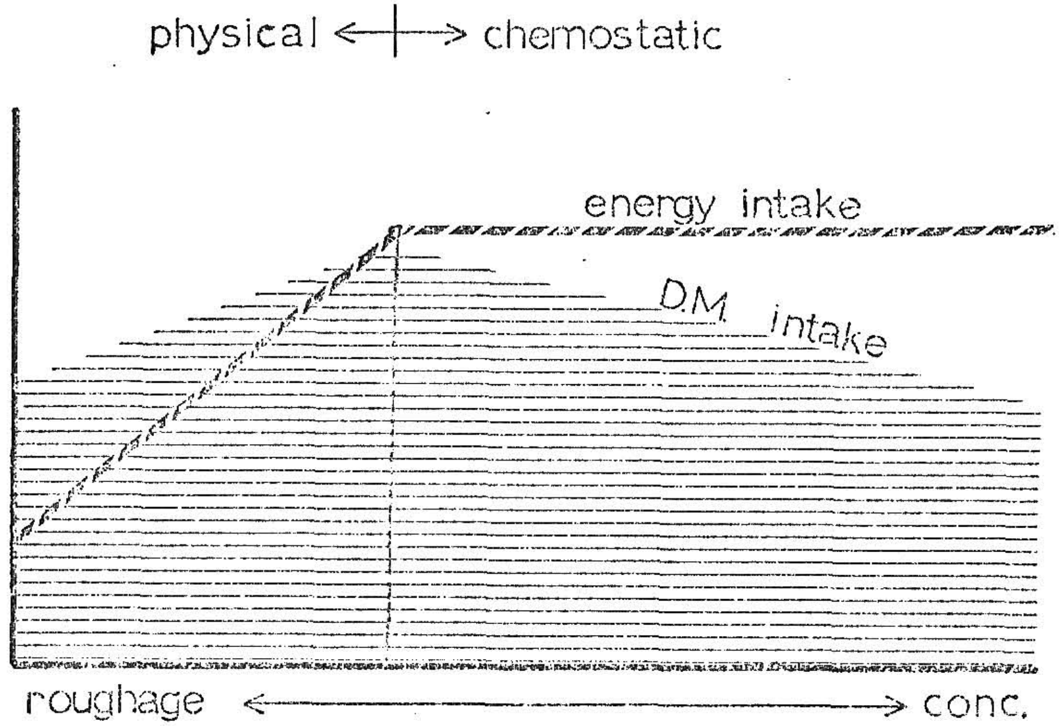

Fig. 1. Graphic Illustration of the Relationship Between Ration Energy Concentration, Digestible Energy Intake and Dry Matter Intake.

Physical Control

When an animal is limited by the physical capacity of the gastro-intestinal system, two factors will govern energy intake: (1) the energy availability of the feedstuff and (2) the rate of removal of DM from the rumen, which is partially influenced by energy availability. Several authors, including Campling (1969), give examples where ruminants eating dried grass or hay ate to a consistent DM limitation. Although DM contents of the rumen were similar for different roughages, Campling et al. (1961) and Freer and Campling (1963) observed that total consumption was directly related to rate of removal from the reticulorumen. Digestibility is significant in determining the rate of removal and thus total consumption. Adding small amounts of urea to poor quality roughages improves cellulolytic digestibility and thus rate of removal (Campling et al., 1962; Hemsley and Moir, 1963). Blaxter and Wilson (1962) also noted the correlation of digestibility of four forages and their voluntary intake by steers.

Digestible energy (a measure of energy availability) is important in determining total energy consumption for two reasons. First, a roughage containing more DE per unit DM will provide more available energy for absorption when consumption is equal to a poorer feed. Secondly, an increase in DE by definition leads to a faster rate of removal from the gut, thus allowing a greater DM consumption. The significance of this was demonstrated by Blaxter and Wilson (1962) feeding grass and straw. Digestibility of the grass was 1.5 times as great as straw but animals eating the grass consumed 3.3 times as much DE.

Realizing that both DE content and DM consumption determined total DE intake and thus animal performance, Crampton et al. (1960) developed the Nutritive Value Index (NVI) to evaluate forages. Consumption of a roughage is compared to consumption of a Standard Forage on a metabolic unit basis (kg roughage/$BW_{kg}^{.75}$) to find its Relative Intake (RI). The product of RI and energy digestion coefficient of the forage then gives the NVI.

An example of calculating the NVI for Timothy hay is as follows. A chopped, early cut, dried legume is used as the Standard Forage and found to be consumed at the rate of 1400 g/Body $wt_{kg}^{0.75}$. Timothy hay is consumed at the rate of 784 g/Body $wt_{kg}^{0.75}$ so its RI is 56 (784/1400 x 100). Energy coefficients for the Standard Forage and Timothy hay are 70% and 61%, respectively, so the NVI for the Standard Forage is 70 (100 x .70) and for Timothy hay 34 (56 x .61).

Chemostatic Control

The mechanism for chemostatic appetite control is not yet clearly understood. The following is a discussion of present hypotheses involved in both short-term and long-term regulation of energy balance.

A. The Hypothalmus - It has been well documented that the hypothalmus plays a role in appetite and energy balance. Lesions of the Lateral Hypothalmus (LH) in goats produced aphagia and adipsia for several days while lesions of the Ventromedial Hypothalmus (VMH) caused hyperphagia for as long as 60 days (Baile et al., 1968). Injection of gold thioglucose (GTG) is a popular way to lesion the VMH of mice and rats. Mayer and Arees (1968) concluded that the VMH contains glucose receptors which are destroyed by GTG and that these glucose receptors act as a 'satiety brake' on the LH. Other evidence (Powley and Keesey, 1970) suggests the LH is not totally dependent upon the VMH signals but has a set point of its own.

B. Glucose and VFA Levels - Evidence has already been mentioned of glucose receptors in the VMH of monogastrics, indicating blood glucose levels act in a feedback mechanism. However, since ruminants depend more on VFAs as their source of energy, it is not surprising that evidence of glucose receptors in the ruminant does not exist. Baile et al. (1970) failed to produce lesions in goats and sheep with GTG. They did decrease consumption by injecting acetate into the rumen, but did not see as large a response when injecting acetate into the jugular vein (Baile and Mayer, 1968a). This led them to believe acetate receptors exist on the lumen side of the rumen wall. Additions of propionate, but not butyrate, also significantly reduced feed intake (Baile and Mayer, 1970). Ruminal vein injections of propionate caused a large depression of intake, but carotid injections had no effect suggesting propionate receptors in the portal system.

Further evidence supporting propionate levels or acetate: propionate ratios being involved in a satiety feedback system were presented by Theurer and Noon (1975) and Rahnema et al. (1976), who monitored VFA plasma levels in ruminal and jugular veins. They found the ruminal: jugular ratio of propionate to be the highest of all VFAs before feeding (24:1 for steers) and also dropped the most postpradially (6:1 for steers). At both monitoring sites molar percentages of acetate decreased and propionate increased after feeding. Apparently as propionate levels increase in ruminal vein plasma, more propionate is allowed to pass through the liver and these changes in plasma propionate levels act in a feed intake regulatory system.

C. Thermostatic Regulation - Anderson and Larson (1961) studied the effects of hypothalamic temperature on feed intake and found that heating the hypothalmus decreased intake but cooling it had the opposite effect. The experiment was criticized by some because the temperature changes imposed were too large to be physiologically feasible. Later Bhattacharya and Warner (1968) infused cold water (5°C) and warm water (49°C) into the rumen in order to alter tympanic temperature. Hourly infusions had little effect on tympanic temperature and feed intake but half hour infusions altered temperature more and cool water treatments significantly increased intake.

Other evidence (Grossman, 1968) disproves thermoregulation of the hypothalmus. Rats fed small meals had an increase in preoptic temperature to the end of the meal, but rats fed large meals continued to eat after reaching a maximum temperature. In further work, cats were fed warm or cool meat. Those receiving warm meat had an increase in preoptic temperature and those eating cool meat exhibited a drop in temperature, but both groups ate normal amounts.

D. Endocrine Factors - Some interesting work by Smith <u>et al</u>. (1974) showed that injecting a small amount of food into the duodenum would cause satiety in the rat. This led to the investigation of intestinal hormones as a means of intake inhibition. They found a negative relationship between the dose of cholecystokin injected and feed intake, but secretin had no influence.

Estrogen may also play a role in regulation. In the cycling female rat feed intake is depressed during estrus. When ovaries were removed the cyclic depression of feed intake was also removed (Bray, 1974).

Insulin injections in rats have increased feed intake and weight gains (Bray, 1974). However, Baile and Mayer (1968b) showed that this did not hold true for ruminants. This points out another argument for difference in feed control mechanisms between ruminants and monogastrics.

E. Lipostatic Controls - Lipid content of the body has been linked to long-term intake regulation in several ways. Cohn and Joseph (1962) force fed rats twice their normal caloric intake until their weights were approximately 250 grams more than the control group. The obese rats were then allowed to feed *ad libitum*. They ate less feed than the control group until their weight had declined to that of the control. Conversely, Liebelt *et al.* (1965) found that GTG obese rats which were fasted and then returned to feed displayed hyperphagia until they regained their former obese weight. He also discovered that rats would increase fat stores to previous levels after fat organs were surgically removed. This lends support to the 'set point' theory (Baile, 1968) which states that the VMH regulates body energy stores to a predetermined level.

Lesions in the VMH adjust this 'set point' upward, which explains the temporary hyperphagia and then return to a feeding level appropriate to maintenance of the new, heavier weight. Although most work has been conducted on monogastrics, Bines et al. (1969) noted an inverse relationship between energy intake and fat content of cows.

The mechanism of lipostatic control is not yet clear. Free fatty acid and lipoprotein levels would be suspected as part of a feedback system, but no conclusive evidence supports their involvement (Baile, 1971). An interesting 'dilution' hypothesis was presented by Hervey (1969). The scheme requires a steroid like hormone which: 1) is produced at a constant rate, 2) is deactivated at a constant rate, 3) is soluble in both plasma and adipose tissue and 4) acts on a receptor involved in the feeding mechanism. If a given amount of hormone always exists then its concentration depends on the amount of adipose tissue in which it is diluted. A receptor would measure the concentration of the hormone and intergrate the information in a feedback system to stimulate or inhibit energy intake. Hervey suggests progesterone and adrenal glucocorticoids as possible candidates.

II. GROWTH MODELS

When normal growth of either an individual or population is plotted against time the function is sigmoid. Many examples of these functions are given by Brody (1945). The general sigmoid shape follows the curve used to describe auto-catalytic monomolecular reactions. An initial self-accelerating phase depends on the number of cells present. A self-inhibiting phase follows that depends on some limiting characteristics of the environment, such as nutrient availability. Brody (1945) presents the theory that relative growth rate (weight gain expressed as proportion of total weight with respect to time) is always constant and absolute growth rate (weight gain with respect to time) in the self-accelerating stage is dependent on the mass already accumulated. For example, if a bacteria cell divides each 12 hours then in 12 hours there would be 2, in 24 hours 4, in 36 hours 8, in 48 hours 16, etc. While the relative growth rate (100%/12 hours) remains constant, the absolute growth rate is increasing at an increasing velocity.

The self-inhibiting phase, however, is governed by some potential maximum size, probably fixed by the resources available. In populations this may be food supply or land area, while in individuals this may be the ratio of body mass to surface area or blood supply. The two combined phases meet at an inflection point where growth velocity reaches a maximum resulting in a sigmoid curve. Brody (1945) says puberty is reached at the inflection point and also notes this is the point of minimum mortality rate. However, Laird et al. (1965) state that they agree with Weymouth et al. (1931) that there is no biological significance of the inflection point.

Brody (1945) derived his growth model from the equation:

$$k = \frac{dW/dt}{W} \quad \text{(eq. 1)}$$

where k = instantaneous (true) relative growth rate, W = weight, t = time and dW/dt = the derivative of weight with respect to time. Instantaneous relative growth rate is a more accurate means of determining k than the average relative growth rate, $R = \frac{W_2 - W_1}{W_1(t)}$ (eq. 2) where W_1 = first weight for the period, W_2 = final weight and t = the time period. Although the average relative growth rate is close to the instantaneous relative growth rate when $W_2 - W_1$ is small and equals dW/dt when $W_2 - W_1 \rightarrow 0$, it will be less exact when $W_2 - W_1$ is large. However, when $W_2 - W_1$ is small, weighing and fill errors make up a large portion of the difference. A more accurate way to calculate average relative growth would be:

$$\text{average relative growth rate} = \frac{W_2 - W_1}{1/2\ (W_2 + W_1)} \quad \text{(eq. 3).}$$

Even then there is an error in assuming the velocity of growth is the same at W_1 and W_2, especially when the two weighings are considerably separated in time.

Eq. 1 is in a derivative form. Its intergration would produce the equation representing self-accelerating growth in respect to time:

$$dW/dt = kW \quad \text{(eq. 4)}$$

$$\int_{W_o}^{W} \frac{dW}{W} = k \int_{o}^{t} dt \quad \text{(eq. 5)}$$

$$\ln W = \ln W_o + kt \quad \text{(eq. 6)}$$

$$W = W_o e^{kt} \quad \text{(eq. 7)}$$

where W = weight at time t, W_o = weight when t = 0 and e = base of natural logarithms.

From eq. 6 k can be calculated: $k = \frac{\ln W - \ln W_o}{t}$ (eq. 8)

Also t can be found from eq. 6: $t = \frac{\ln W - \ln W_o}{k}$ (eq. 9)

This form can be useful to find the time required for an animal to double in weight or to reach any given weight.

As stated before and seen from eq. 7 growth during the self-acceleration phase depends on the growth already present, W_o. During the self-inhibition phase, however, growth is governed by the amount of growth needed to reach maximum. This may be represented by:

$$\frac{dW}{dt} = -k(A-W) \quad \text{(eq. 10)}$$

which upon intergrating becomes:

$$W = A-B_e{}^{-kt} \quad \text{(eq. 11)}$$

where A = maximum mature weight and B = an intergration constant found at the y intercept when plotting log (A-W) against time. Relative growth rate is expressed as a negative k because rate of growth is decelerating. When t = t* (intercept of age axis) then A = B so eq. 11 can be rewritten:

$$W = A-A_e{}^{-k(t-t*)} \quad \text{(eq. 12)}$$

or

$$W = A(1-{}_e{}^{-k(t-t*)}) \quad \text{(eq. 13)}$$

Brody's equation was taken one step further by Grover *et al.* (1970) in application to rat growth data. Although an excellent fit was obtained with an equation identical to Brody's they noticed a systematic error. The curve over-estimated early weights and under-estimated later weights. The assumption was made that A (mature weight) is not reached but increases with time and an additional term, α, was added.

$$W = (A+\alpha t)\ (1-e^{-(t-\theta)/\tau}) \quad \text{(eq. 14)}$$

In this case $(t-\theta)$ is synonomus with $t-t^*$ and $1/\tau$ with k in Brody's work. The addition of α still provided an excellent fit and also removed the systematic errors.

A second approach to the sigmoid curve (Laird *et al.*, 1965; and Gall, 1969) reasons that growth is the net result of catabolism and anabolism. This idea yields the following equation (Bertalanffy, 1960):

$$\frac{dW}{dt} = aw^m - bw^n \quad \text{(eq. 15).}$$

Thus, 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 m^{th} power and the rate of catabolism (b) times weight to the n^{th} power. Catabolism is considered to be directly proportional to weight so n is considered to be 1. Anabolism, however, is a function of metabolism. Bertalanffy assumes metabolism to be related to body weight in the same manner as surface area is related to volume. Therefore he gives m the value 2/3, since surface area = body weight $^{2/3}$.

Eq. 15 can be written: $\frac{dW}{dt} = aw^{2/3} - bw$ (eq. 16) which on intergration becomes: $W = (\sqrt[3]{W^*} - (\sqrt[3]{W^*} - \sqrt[3]{W_o})_e{}^{-kt})^3$ (eq. 17) where W_o = weight at time t = 0, W* = final weight and k = b/3. This is very similar to the monomolecular equation derived by Brody. First, rate of growth depends on both initial and final weight. Second, the velocity of growth rate change is dependent on the difference between weight at time t and final weight.

Richards (1959) felt that Bertalanffy's equation was limited because of the theoretical value given to m. Richards (1959, 1969) noticed that Bertalanffy's equation, along with other asymptotic curves could be written in the general form:

$$W = (A^{1-m} + B_e{}^{-kt})^{1/1-m} \quad \text{(eq. 18).}$$

When m=0 the equation yields a monomolecular curve, when m = 2 a auto-catalytic 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 auto-catalytic. Curves also exist for values of m greater than 2.

A method for fitting Richard's curve to data is discussed by Johnson _et al_. (1975). Only m and k effect the shape of the curve and rate of approach to the asymptote. Therefore by providing good estimates of A and B he was able to find m and k by using an iteration program to obtain convergence of the parameter estimates to least squares values.

Following is a brief outline of some of the commonly used growth functions.

	Function	Growth Rate dW/dt	Weight	Inflexion Point
1.	Exponential	kW	$W_o e^{kt}$	None
2.	Decaying Exponential or Monomolecular	$k(A-W)$	$A(1-B_e{}^{-kt})$	None
3.	Logistic or Autocatalytic	$kW(A-W)$	$A/(1+Be^{-kAt})$	0.5 A
4.	Gompertz	$WkB_e{}^{-kt}$	$A_e{}^{-Be^{-kt}}$	0.37 A

Neither the exponential nor decaying exponential functions can describe the entire growth period by themselves because they are not sigmoid. Brody used the first exponential function to describe self-accelerating growth and the decaying exponential function for self-inhibiting growth. The autocatalytic function is sigmoid shaped with an inflection point at 0.5 mature weight, but animals reach puberty and declining growth rate earlier than this. For this reason animals' total growth may be better fitted with the Gompertz curve having an inflection point at one third mature weight.

There are two general lines of reasoning for selecting the right growth function (Richards, 1969). One approach is to simply find the function with three or four terms having the best fit. Others argue that the fit obtained this way may have little or no biological significance. The second approach describes the function by summing all terms representing any biological contributions to growth. While accounting for all physiological reactions is desirable, it requires a large number of terms. Each additional term adds another inflection point and too many inflection points will become hopelessly confusing. Presently the first approach provides the only means of describing growth, but systematic deviations from these simplified best fit curves should be investigated for further improvement.

III. EFFECT OF NUTRITIONAL PLANE ON PERFORMANCE

Intake

Under *ad libitum* feeding, energy intake is limited by either physical fill or chemostatic control, which is in turn dependent on the energy density of the ration. A low energy density ration will be consumed until the capacity of the rumen is reached while a higher energy density ration will be eaten until a set energy requirement is met. A more detailed explanation is given under ENERGY BALANCE REGULATION.

Dinius and Baumgardt (1970) showed that under chemostatic control as DE concentration of the ration increased the ruminants' DM intake decreased linearly and DE intake remained constant. Later Dinius *et al*. (1976) re-examined these relationships and concluded that since DE intake is calculated by multiplying DM intake by DE concentration, it is mathematically impossible for both to be related linearly with DE intake.
If DM intake is linearly related to diet DE concentration, then

DE intake must be a quadratic function of DE concentration. But if DM intake is a hyperbolic function of DE concentration then DE intake is a linear function of it. When ad libitum diets ranging from 2.8 to 3.6 Kcal/Kg were fed to 20 Angus and 20 Santa Gertrudis steers, a linear or a hyperbolic function could describe DM intake equally well and both DE intakes calculated from these functions accurately represented the observed DE intakes.

If the random variability and small number of observations did not allow distinguishing between linear and hyperbolic functions it is also possible that other functions exist. It is even possible that DM intake should be partitioned into two separate functions as DE concentration increases. A depression in DM intake was noted by Jesse et al. (1976) and Vance et al. (1972) on rations approaching 90% corn. Postmortem examination by Vance revealed that steers fed rations containing 88.5% corn had more hair accumulation and papillae clumping in the rumen than steers fed lower concentrate levels. Rumen pH readings were significantly lower also, which indicates a possible reason for the depression of intake on rations having little or no roughage. These data, and a number of other studies (Bucy and Bennion, 1962; Davis et al. 1963; Durham et al. 1966) on all-concentrate rations suggests a discontinuity in the intake vs. DE concentration curve.

There may be another problem in assuming an animal's intake control mechanism measures DE rather than ME, NE_p or NE_m.

If DE intake remains constant in chemostatic control then energy intake measured as ME, NE_p or NE_m actually increases with increasing DE concentration because these energy fractions account for a higher percent of DE as proportion of concentrate in a ration increases. No one knows yet how or in what form energy intake is measured and it may be that none of the existing energy systems describes energy intake as the energy fraction measured by the intake control mechanism.

Rate of Gain

Steers limited to .9 Kg or less corn plus corn silage *ad libitum* gained less (P<.01) than those fed greater amounts of corn (Perry and Beeson, 1976). When Vance *et al*. (1972) fed crimped corn and corn silage (40% DM) he obtained maximum gains from steers receiving less than 3.6 Kg corn silage DM/head/day. Jesse *et al*. (1976) formulated rations with corn: corn silage rations of 30:70, 50:50, 70:30 and 80:20 on DM basis and found only the first ration yielded significantly lower gains. It appears from these trials that 70% or more corn silage on DM basis in a ration can limit gains, which agrees with the physical fill hypothesis, since maximum gains can be made only when DE intake is maximized.

Efficiency of Feed Utilization

Feed efficiency should improve as the caloric density of the ration increases. Jesse *et al*. (1976) and Dinius *et al*. (1976) observed significant improvements in gross efficiency (feed DM/unit gain) as the concentrate increased from approximately 30 to 80% of the ration. Perry and Beeson (1976) also showed improved gross efficiency as the proportion of corn in the diet increased, but efficiency of TDN utilization was as good or better for the high corn silage diets. They suggested that because trials were conducted during the winter the heat increment from silage may have contributed more for maintenance of body temperature. Another explanation is that associative effects between corn silage and corn do not allow either to be utilized as well when fed in combination. Also TDN values of corn silage or corn could be wrong.

Almquist et al. (1971) and Jesse et al. (1976) observed that efficiency of both DE and Gross Energy Utilization became poorer as live weight increased.

Associative Effects of Feeding

Associative effects of feeding is defined as "the supplementing effect of one feed upon another", (Schneider and Flatt, 1975). As far back as Ewing and Wells (1915) it was recognized that the nutritional value of a concentrate depended upon the type of roughage it was combined with in a ration.

There is no single explanation for interactional effects. In cases where a limiting nutrient in one feedstuff may be supplied by another a positive association results. Staples et al. (1951) showed digestibility of prairie hay to improve with addition of oats and soybean oil meal. The improvement probably was due to the extra protein. In other cases a negative association exists. Kromann et al. (1975) and Swift and French (1954) reported a decrease in crude fiber (CF) digestion as starch was added to the diet. Fat (Randle, 1971) and other carbohydrates (Lofgreen and Otagaki, 1960) have had similar influences on CF digestion.

By using simultaneous equations Kromann et al. (1975) found digestibility of nitrogen free extract (NFE), ether extract (EE) and crude protein (CP) to improve for both dehydrated alfalfa and corn as corn was added to the ration, but there were no interactional effects on DE, ME or NE_{m+p} values. Possibly the improved digestibility of NFE, EE and CP offset the decline in CF digestibility. Kromann (1967) and Lofgreen and Otagaki (1960), however, reported that there were associative effects on DE and NE_{m+p} fractions of individual feeds.

To date no energy system has included associative effects as a factor for ration formulation because of the lack of knowledge. This leaves a hole in the information needed to predict animal performance. One area that deserves more research is how rumen microbial populations are altered by combinations of feedstuffs. While roughages favor cellulolytic microbes and concentrates amylolytic microbes, combinations of roughage and concentrates may hinder both.

Carcass Composition

Koch et al. (1976) partitioned growth into metabolically inactive tissue (hide, hoofs, horn, skeleton and fat) and metabolically active tissue (MAT). They found MAT increased at a rate which was decreasing exponentially, while fat was deposited at a linear rate. The magnitude of both rates depended on the plane of nutrition. Guenther et al. (1965) also noted rate of fat deposition was greater for faster gaining steers and did not diminish over time, as did lean. By 10.8 months of age, high and moderate gaining calves had produced 86 and 78% respectively, of their ultimate lean. Steers fed to equivalent slaughter weights had the same fat and lean compositions though the ones on a higher plane of nutrition attained final weight sooner.

IV. PHYSIOLOGICAL AGE

Physiological maturity is defined by Allen et al. (1974) as "a term used to refer to the relative stage of development of body processes, functions or composition." Physiological maturity can be a better means of comparing two animals than chronological age or body weight. Brody (1945) showed that the sigmoid shaped growth curve held true for a number of domestic animals. We know, however, that species and even breeds within a species vary in the chronological time or weight required to reach either puberty or mature weight. Since puberty (inflection point of sigmoid curve) represents 100% of sexual maturity and mature weight (point when curve becomes asymptotic with horizontal axis) represents 100% of mature weight these points can serve as a reference point for comparing animals. Other physiological traits, such as bone length, can also serve as reference points.

Several physiological traits were evaluated in cattle with two different body types by Guenther (1974). He measured live weight, body length, width, depth, metacarpal length, body composition, muscle fiber diameter and nitrogen content of Angus and Charolais steers from 1 to 14 months of age. Angus calves approached their mature body weight and length faster. At one month of age metacarpal length of both breeds was 73 to 76% of mature length while body weight was only 11.6 to 14.5% of the mature value. They concluded that neither animals differing in mature size nor physical components of an individual reach physiological maturity at the same chronological age. Another example sited by Allen et al. (1974) compared Hormel Miniature (HM) pigs with Minnesota 3x1 (M 3x1) pigs. Maximum muscle fiber diameter for both breeds was 75 to 85 μ but the earlier maturing HM pigs reached this at 28 to 54 kg and M 3x1 at 83 to 109 kg. Both breeds had 40% extramuscular fat by the time fiber diameter had matured.

Nutrition is one of the most important environmental factors that affects physiological maturing. McCance and Widdowson (1954) reviewed a number of experiments with rats, guinea pigs and swine and concluded that when nutrients are restricted prenatally or immediately after birth the subsequent mature size is limited. When returned to a high plane of nutrition they will grow normally but will reach their mature (but lighter) weight at the same chronological age as their unrestricted counterparts. However, if energy is not restricted until later, they will reach the same mature size but require more time because of a slower growth rate. Koch et al. (1976) reviewed data from steers fed on high, medium and low planes of nutrition and found the metabolically active portion (total weight minus hide, hoofs, horns, skeleton and fat) approaches the same ultimate mass in all cases but at rates corresponding to plane of nutrition.

Some physiological components are more dependent on nutrition than others. Mitchell (1929) observed that skeletal growth was not affected by lower levels of nutrition while weight was. McCance and Widdowson (1974) gave examples of head, ears, teeth and ovaries or penis of pigs approaching normal size through body weight was extremely curtailed by energy or protein deficiencies.

When it is accurately measured, physiological age can be a more desirable basis for comparing animals than chronological age or body weight. However, caution should be used in which body components to evaluate for physiological age since they do not all reach maturity simultaneously nor does nutrition have the same magnitude of effect on rate of maturity among various components.

EXPERIMENTAL PROCEDURE

Ten rations differing in corn silage:corn ratios were given *ad libitum* to 20 individually fed Hereford steers, two steers per ration. Sources of roughage and concentrate were whole plant corn silage (33-40% dry matter) and cracked No. 2 yellow dent corn. Ration 1 containing all roughage and ration 10 containing all concentrate were first formulated and balanced for protein and minerals. Digestible protein (DP) requirements were calculated from Preston's equation, $DP = 2.79W^{.75}(1 + 1.905G)$, 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 NAS-NRC Nutrient Requirements of Beef Cattle (No. 4). Soybean meal was added to bring total ration DP to 108% of the DP requirement. Rations 1 and 10 had 1.0078 and 1.4362 Mcal/Kg NE_p respecfully. The remaining rations, 2 through 9, were formulated to have equal increment increases in NE_p. Ration composition, NE_p, NE_m and DP are shown in tables 1 and 2.

The steers averaged 283.1 Kg and ranged in weight from 248.6 to 332.0 Kg. The 10 heaviest steers were randomly allotted to a ration and then the lightest. A 21 day period was allowed for animals to adjust to their rations. Beginning March 10, 1976 steers were individually weighed each Wednesday, 8:00 prior to receiving their morning feed (Appendix II). At the

Table 1. Composition of Rations (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 Kcal/kg	1.5788	1.6484	1.7182	1.7879	1.8576	1.9273	1.9970	2.0666	2.1363	2.2060
NE_p Kcal/kg	1.0078	1.0554	1.1030	1.1506	1.1982	1.2458	1.2934	1.3410	1.3886	1.4362
ME Kcal/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 2.

Table 2. Composition of SBM Supplement (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
Calcium 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

same time all feed remaining in the individual bunks was weighed back and samples taken for dry matter (DM) and protein 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 basis.

A Wang 700 mini-computer with an N^{th} order regression program was used to plot least squares polynomial regression curves through weekly body weights and accumulative DM intake data for each steer. Third and fourth order polynomial equations were fitted to body weight and DM intake observations respectfully. The first derivatives of these equations was then used to determine instantaneous rate of gain and DM consumption. Maintenance requirements for energy were figured from Lofgreen and Garrett's tables (Lofgreen and Garrett, 1968). NE_p efficiency was calculated by subtracting the amount of DM needed to supply NE_m requirements from total DM consumption and then dividing the NE_p content of the remaining DM by the weight gain. Each steer was killed when he used 7.0 or more Mcal NE_p/Kg gain. This efficiency end point was chosen after reviewing similar work by Lipsey (1977) in which he used two end points, 8.0 and 10.0 Mcal NE_p/Kg gain. At both end points he found cattle to be fatter than was desirable.

Carcass quality and yield grades were determined and the 9-10-11 rib section from the right side removed. Rib sections were boned, ground and evaluated for nitrogen, ether extract and DM. Total carcass composition was then calculated according to Hawkins and Howe (1946).

Although a third order polynomial regression curve had been used on weekly body weight observations it was decided that a monomolecular curve, synonymous with Brody's proposed curve (Brody, 1945), would be best in developing an overall model. The form of the curve is: $Wt = A(1-Be^{-kt})$, where Wt equals live body weight, A is mature body weight, B is an integration constant, k is the relative rate of growth and t is time on feed. The unknown parameters A, B and k were estimated for each steer using the Marquardt nonlinear least squares procedure (Marquardt, 1963). A mathematical model to describe body weight as a function of both time on feed and energy concentration of the ration was formulated.

In the first attempt to produce a growth model, the rations (expressed in terms of Mcal of metabolizable energy/Kg (ME)) were related to the A, B, and k values of the individual steers by weighted regression analysis. Data from steers 1, 2, 4 and 20 were not used in finding A, B and k because they had not reached the NE_p efficiency end point when the experiment was terminated. There was not a significant regression of B on ME so it was assigned its mean value. When A and k were expressed in terms of ME the predicted weight equation showed that weight increased at any given time with increasing ME which was not the case in rations 9 and 10. Therefore daily DM intake and ME together were related to A and k by weighted regression analysis. Incorporating the DM term in the equation reduced the residual sum of squares for rations 9 and 10 from 29,219.0057 and 77,753.5576 respectively to 15,541.8824 and 21,310.3261 but increased the pooled residual sums of squares of all steers from 436,366.6489 to 526,898.3104.

Mitchell (1929) stated that ultimate mature weight is not effected by plane of nutrition but the rate at which this weight is reached is. Therefore we decided to let A and B be constant and only let the relative rate of growth, k, be effected by ME and DM intake. Values for A, B and k were found by non-linear least squares. The equation for predicted weight (PWT) is given by Eq. 19. Pooled residual sums of squares was reduced to 194,806.6787 (Appendix I).

First to fifth order polynomial regression curves were fitted to individual accumulative DM intake records. Both the linear and quadratic coefficients of the second order equations were significant for 13 animals. Six steers had one or more insignificant (P>.05) coefficients at any of the polynomial powers. However, it was decided that a quadratic curve best described the function of accumulative DM intake. A general quadratic model with B_1 and B_2 each expressed in terms of ME was then fitted to all animals by multiple regression. The intercept coefficient was not included since DM intake is 0.0 at time t=0. Eq. 21 gives the form and values for the Predicted Accumulative Dry Matter Intake model (PDM).

The first derivatives of the equations for PWT and PDM taken in respect to time describes the rate of change of these functions which would be rate of gain (RWT) and rate of DM intake (RDM) respectively. RWT (Eq. 20) and RDM (Eq. 22) are both expressed in Kg/day, since time is expressed in days. Feed efficiency in DM/gain (PFE) is then found by dividing RDM by RWT (Eq. 23).

Eq. 19 Predicted Weight (PWT) = $A(1-Be^{-kt})$

Eq. 20 Predicted Rate of Gain (RWT) = $AB(-k)e^{-kt}$

A = Mature Weight = 883.47 kg

B = Intergration constant = .671

e = Base of the natural log

k = Relative rate of growth

= -.00508986 + .0021084(ME) + .0001768(DM)

ME = Metabolizable energy Mcal/kg

DM = Kg dry matter intake/day

t = time in days

Eq. 21 Predicted Accumulative Dry Matter Intake (PDM) = $B_1t + B_2t^2$

Eq. 22 Predicted Rate of Dry Matter Intake/Day (RDM) = $B_1 + 2B_2t$

B_1 = 738.8768 - 823.89183979(ME) + 307.1124619$(ME)^2$ - 37.86315756$(ME)^3$

B_2 = .17035293 - .11670502(ME) + .01993668$(ME)^2$

ME = Metabolizable energy Mcal/kg

t = time in days

Eq. 23 Predicted Feed Efficiency (PFE) = $\frac{B_1 + 2B_2t}{AB(-k)e^{-kt}}$

Table 3 lists the predicted values of PWT, RWT, PDM, RDM and PFE for each ration at 10-day intervals.

3-Dimensional Graphics

Three dimensional perspective plots of PWT, RWT, PDM, RDM and PFE were drawn by a line plotter and 370 IBM using a Surface II Graphics System program (Sampson, 1975). The Surface II Graphics System was developed by the Kansas Geological Survey to map surfaces using least squares polynomial regression equations. It is easily adapted to most data where two independent variables are related to one dependent variable.

The two independent variables, X and Y, are represented by the horizontal axes while the dependent variable, Z, is located by the vertical axis. In this case X represents time on feed and Y the energy concentration of the ration, where ration 1 has the lowest concentration and 10 the highest. The program will draw the graph as seen from any given angle of view. All graphs in Figures 2-15 are viewed from an elevation of 30° above the horizontal plane X·Y and at an azimuth of either 65° or 115° to the right or -115° to the left of the Y·Z plane.

RESULTS AND DISCUSSION

Statistical Analysis

The adequacy of the models, PWT and PDM, were tested by analysis of variance where the components of analysis were Ration and Animals within Ration effects (Tables 4 and 5). The Ration

Table 3. Predicted Values of PWT, RWT, PDM, RDM and PFE.

RATION	DAYS	PWT	DWT	PDM	DDM	PFE
1	0	290.662	.9669	0.00	7.09919	7.3422
1	10	300.252	.95126	71.24	7.14948	7.5158
1	20	309.688	.93587	142.99	7.19978	7.6931
1	30	318.970	.92073	215.24	7.25008	7.8743
1	40	328.103	.90583	287.99	7.30038	8.0593
1	50	337.083	.89118	361.25	7.35067	8.2483
1	60	345.927	.87676	435.00	7.40097	8.4413
1	70	354.624	.86258	509.27	7.45127	8.6384
1	80	363.180	.84862	584.03	7.50157	8.8397
1	90	371.597	.83489	659.30	7.55187	9.0453
1	100	379.878	.82138	735.07	7.60216	9.2553
1	110	388.025	0.8081	811.34	7.65246	9.4697
1	120	396.041	.79502	888.12	7.70276	9.6887
1	130	403.927	.78216	965.40	7.75306	9.9124
1	140	411.635	.76951	1043.19	7.80335	10.1407
1	150	419.317	.75706	1121.46	7.85365	10.3739
1	160	426.827	.74481	1200.25	7.90395	10.6120
1	170	434.214	.73276	1279.54	7.95425	10.8552
1	180	441.482	.72091	1359.34	8.00455	11.1035
1	190	448.633	.70924	1439.63	8.05484	11.3570
1	200	455.668	.69777	1520.43	8.10514	11.6158
1	210	462.589	.68648	1601.74	8.15544	11.8801
1	220	469.398	.67537	1683.54	8.20574	12.1499
1	230	476.097	.66445	1765.85	8.25603	12.4254
1	240	482.688	0.6537	1848.66	8.30633	12.7067
1	250	489.172	.64312	1931.98	8.35663	12.9939
1	260	495.551	.63272	2015.79	8.40693	13.2870
1	270	501.826	.62248	2100.12	8.45723	13.5863
1	280	508.001	.61241	2184.94	8.50752	13.8919
1	290	514.075	0.6025	2270.27	8.55782	14.2038
1	300	520.051	.59275	2356.10	8.60812	14.5222
1	310	525.931	.58317	2442.43	8.65842	14.8473
1	320	531.715	.57373	2529.26	8.70872	15.1791
2	0	290.662	1.1212	0.00	7.43690	6.6333
2	10	301.768	1.1001	74.52	7.46689	6.7872
2	20	312.666	1.0795	149.34	7.49688	6.9445
2	30	323.360	1.0593	224.46	7.52688	7.1054
2	40	333.853	1.0395	299.88	7.55687	7.2700
2	50	344.150	1.02	375.59	7.58686	7.4382
2	60	354.254	1.0009	451.61	7.61685	7.6101
2	70	364.169	.98213	527.93	7.64684	7.7860
2	80	373.898	.96373	604.55	7.67683	7.9657
2	90	383.445	.94568	681.47	7.70682	8.1495
2	100	392.813	.92796	758.69	7.73681	8.3375
2	110	402.005	.91057	836.20	7.76681	8.5296
2	120	411.025	.89351	914.02	7.79630	8.7260
2	130	419.877	.87677	992.14	7.82679	8.9268
2	140	428.562	.86035	1070.56	7.85678	9.1321
2	150	437.085	.84423	1149.28	7.88677	9.3420
2	160	445.448	.82841	1228.29	7.91676	9.5565
2	170	453.654	.81289	1307.61	7.94675	9.7759
2	180	461.706	.79766	1387.23	7.97674	10.0001
2	190	469.608	.78272	1467.15	8.00674	10.2294
2	200	477.362	.76806	1547.36	8.03673	10.4637
2	210	484.970	.75367	1627.88	8.06672	10.7033
2	220	492.436	.73955	1708.70	8.09671	10.9482
2	230	499.762	.72569	1789.81	8.12670	11.1986

2	240	506.951	.71209	1871.23	8.15669	11.4545
2	250	514.005	.69875	1952.95	8.18668	11.7161
2	260	520.927	.68566	2034.96	8.21667	11.9835
2	270	527.719	.67282	2117.28	8.24667	12.2569
2	280	534.384	.66021	2199.90	8.27666	12.5364
2	290	540.924	.64784	2282.81	8.30665	12.8220
2	300	547.341	.63571	2366.03	8.33664	13.1140
2	310	553.639	0.6238	2449.55	8.36663	13.4125
2	320	559.818	.61211	2533.36	8.39662	13.7175
3	0	290.662	1.2723	0.00	7.88218	6.1954
3	10	303.249	1.2452	78.89	7.89613	6.3410
3	20	315.568	1.2188	157.92	7.91007	6.4900
3	30	327.627	1.1929	237.09	7.92402	6.6425
3	40	339.429	1.1676	316.40	7.93797	6.7985
3	50	350.980	1.1428	395.85	7.95191	6.9582
3	60	362.287	1.1185	475.44	7.96586	7.1216
3	70	373.353	1.0948	555.17	7.97980	7.2889
3	80	384.184	1.0715	635.04	7.99375	7.4600
3	90	394.786	1.0488	715.04	8.00770	7.6351
3	100	405.162	1.0265	795.19	8.02164	7.8144
3	110	415.318	1.0047	875.48	8.03559	7.9978
3	120	425.258	0.9834	955.90	8.04953	8.1855
3	130	434.987	.96251	1036.47	8.06348	8.3775
3	140	444.510	.94208	1117.17	8.07743	8.5741
3	150	453.830	.92207	1198.02	8.09137	8.7752
3	160	462.953	0.9025	1279.00	8.10532	8.9810
3	170	471.881	.88333	1360.12	8.11926	9.1916
3	180	480.621	.86458	1441.39	8.13321	9.4071
3	190	489.174	.84622	1522.79	8.14716	9.6277
3	200	497.546	.82825	1604.33	8.16110	9.8534
3	210	505.741	.81067	1686.01	8.17505	10.0844
3	220	513.761	.79345	1767.83	8.18900	10.3207
3	230	521.611	.77661	1849.79	8.20294	10.5625
3	240	529.294	.76012	1931.89	8.21689	10.8100
3	250	536.814	.74398	2014.13	8.23083	11.0633
3	260	544.175	.72818	2096.50	8.24478	11.3224
3	270	551.379	.71272	2179.02	8.25873	11.5876
3	280	558.430	.69759	2261.68	8.27267	11.8590
3	290	565.332	.68277	2344.48	8.28662	12.1367
3	300	572.087	.66828	2427.41	8.30056	12.4208
3	310	578.698	.65409	2510.49	8.31451	12.7116
3	320	585.170	0.6402	2593.70	8.32846	13.0092
4	0	290.662	1.3636	0.00	8.34628	6.1207
4	10	304.142	1.3326	83.47	8.34845	6.2647
4	20	317.316	1.3023	166.97	8.35061	6.4121
4	30	330.191	1.2727	250.49	8.35277	6.5630
4	40	342.773	1.2438	334.02	8.35493	6.7175
4	50	355.068	1.2155	417.58	8.35710	6.8756
4	60	367.084	1.1878	501.17	8.35926	7.0374
4	70	378.827	1.1608	584.77	8.36142	7.2030
4	80	390.303	1.1344	668.39	8.36358	7.3725
4	90	401.517	1.1086	752.04	8.36574	7.5460
4	100	412.477	1.0834	835.71	8.36791	7.7236
4	110	423.188	1.0588	919.40	8.37007	7.9054
4	120	433.655	1.0347	1003.11	8.37223	8.0914
4	130	443.883	1.0112	1086.84	8.37439	8.2819
4	140	453.880	.98818	1170.60	8.37656	8.4768
4	150	463.649	.96571	1254.38	8.37872	8.6763

4	160	473.196	.94375	1338.17	8.38088	8.8804
4	170	482.525	.92229	1421.99	8.38304	9.0894
4	180	491.643	.90131	1505.83	8.38520	9.3033
4	190	500.553	.88082	1589.70	8.38737	9.5223
4	200	509.261	.86079	1673.58	8.38953	9.7464
4	210	517.770	.84121	1757.49	8.39169	9.9757
4	220	526.087	.82208	1841.42	8.39385	10.2105
4	230	534.214	.80339	1925.36	8.39602	10.4558
4	240	542.156	.78512	2009.34	8.39818	10.6967
4	250	549.917	.76726	2093.33	8.40034	10.9484
4	260	557.502	.74982	2177.34	8.40250	11.2061
4	270	564.915	.73277	2261.38	8.40466	11.4698
4	280	572.159	0.7161	2345.44	8.40683	11.7397
4	290	579.238	.69982	2429.51	8.40899	12.0160
4	300	586.157	0.6839	2513.62	8.41115	12.2987
4	310	592.918	.66835	2597.74	8.41331	12.5881
4	320	599.525	.65315	2681.88	8.41548	12.8844
5	0	290.662	1.455	0.00	8.74047	6.0072
5	10	305.034	1.4197	87.38	8.73511	6.1527
5	20	319.059	1.3853	174.70	8.72975	6.3017
5	30	332.743	1.3517	261.97	8.72439	6.4543
5	40	346.096	1.3189	349.19	8.71903	6.6107
5	50	359.124	1.287	436.35	8.71367	6.7708
5	60	371.837	1.2558	523.46	8.70831	6.9347
5	70	384.242	1.2253	610.52	8.70295	7.1027
5	80	396.346	1.1956	697.52	8.69759	7.2747
5	90	408.156	1.1666	784.47	8.69223	7.4508
5	100	419.681	1.1383	871.37	8.68687	7.6313
5	110	430.925	1.1107	958.21	8.68151	7.8161
5	120	441.897	1.0838	1045.00	8.67615	8.0053
5	130	452.603	1.0575	1131.73	8.67079	8.1992
5	140	463.050	1.0319	1218.41	8.66543	8.3977
5	150	473.243	1.0069	1305.04	8.66007	8.6010
5	160	483.189	.98245	1391.61	8.65470	8.8093
5	170	492.894	.95863	1478.13	8.64934	9.0226
5	180	502.364	.93539	1564.60	8.64398	9.2411
5	190	511.604	.91271	1651.01	8.63862	9.4648
5	200	520.620	.89058	1737.37	8.63326	9.6940
5	210	529.417	.86899	1823.68	8.62790	9.9287
5	220	538.001	.84792	1909.93	8.62254	10.1691
5	230	546.377	.82736	1996.13	8.61718	10.4153
5	240	554.550	0.8073	2082.28	8.61182	10.6674
5	250	562.525	.78773	2168.37	8.60646	10.9257
5	260	570.306	.76863	2254.40	8.60110	11.1902
5	270	577.899	.74999	2340.39	8.59574	11.4611
5	280	585.308	.73181	2426.32	8.59038	11.7385
5	290	592.537	.71407	2512.20	8.58502	12.0227
5	300	599.591	.69676	2598.02	8.57966	12.3137
5	310	606.473	.67986	2683.79	8.57430	12.6118
5	320	613.189	.66338	2769.51	8.56894	12.9171
6	0	290.662	1.5464	0.00	8.97600	5.8046
6	10	305.925	1.5065	89.72	8.96738	5.9523
6	20	320.796	1.4678	179.35	8.95875	6.1037
6	30	335.284	1.43	268.89	8.95013	6.2590
6	40	349.398	1.3931	358.35	8.94151	6.4182
6	50	363.150	1.3573	447.72	8.93289	6.5815
6	60	376.547	1.3223	537.01	8.92427	6.7489
6	70	389.599	1.2883	626.21	8.91565	6.9206

6	80	402.315	1.2551	715.32	8.90703	7.0966
6	90	414.704	1.2228	804.35	8.89840	7.2771
6	100	426.774	1.1913	893.29	8.88978	7.4622
6	110	438.533	1.1606	982.14	8.88116	7.6520
6	120	449.989	1.1307	1070.91	8.87254	7.8466
6	130	461.150	1.1016	1159.59	8.86392	8.0462
6	140	472.024	1.0733	1248.19	8.85530	8.2508
6	150	482.618	1.0456	1336.70	8.84668	8.4606
6	160	492.939	1.0187	1425.12	8.83805	8.6757
6	170	502.995	.99248	1513.46	8.82943	8.8963
6	180	512.791	.96693	1601.71	8.82081	9.1225
6	190	522.335	.94203	1689.88	8.81219	9.3545
6	200	531.634	.91777	1777.96	8.80357	9.5923
6	210	540.693	.89414	1865.95	8.79495	9.8362
6	220	549.519	.87112	1953.86	8.78633	10.0862
6	230	558.117	.84869	2041.68	8.77770	10.3426
6	240	566.495	.82684	2129.41	8.76908	10.6055
6	250	574.656	.80555	2217.06	8.76046	10.8751
6	260	582.607	.78481	2304.62	8.75184	11.1516
6	270	590.354	0.7646	2392.09	8.74322	11.4350
6	280	597.901	.74491	2479.48	8.73460	11.7256
6	290	605.254	.72573	2566.79	8.72598	12.0236
6	300	612.418	.70705	2654.00	8.71735	12.3292
6	310	619.397	.68884	2741.13	8.70873	12.6425
6	320	626.196	.67111	2828.18	8.70011	12.9638
7	0	290.662	1.6377	0.00	8.96413	5.4735
7	10	306.815	1.5931	89.60	8.95651	5.6221
7	20	322.528	1.5497	179.13	8.94888	5.7746
7	30	337.812	1.5075	268.58	8.94126	5.9313
7	40	352.681	1.4664	357.96	8.93364	6.0923
7	50	367.144	1.4264	447.25	8.92602	6.2576
7	60	381.213	1.3876	536.48	8.91840	6.4274
7	70	394.899	1.3498	625.62	8.91078	6.6018
7	80	408.211	1.313	714.69	8.90316	6.7809
7	90	421.161	1.2772	803.68	8.89554	6.9649
7	100	433.759	1.2424	892.60	8.88791	7.1538
7	110	446.013	1.2085	981.44	8.88029	7.3479
7	120	457.933	1.1756	1070.21	8.87267	7.5473
7	130	469.528	1.1436	1158.90	8.86505	7.7520
7	140	480.807	1.1124	1247.51	8.85743	7.9623
7	150	491.779	1.0821	1336.05	8.84981	8.1783
7	160	502.452	1.0526	1424.51	8.84219	8.4002
7	170	512.834	1.0239	1512.89	8.83457	8.6280
7	180	522.933	.99604	1601.20	8.82695	8.8621
7	190	532.757	0.9689	1689.43	8.81932	9.1024
7	200	542.314	0.9425	1777.58	8.81170	9.3493
7	210	551.610	.91681	1865.66	8.80408	9.6029
7	220	560.652	.89183	1953.66	8.79646	9.8633
7	230	569.449	.86753	2041.59	8.78884	10.1309
7	240	578.005	.84389	2129.44	8.78122	10.4056
7	250	586.329	0.8209	2217.22	8.77360	10.6878
7	260	594.425	.79853	2304.91	8.76598	10.9776
7	270	602.301	.77677	2392.53	8.75835	11.2753
7	280	609.963	.75561	2480.08	8.75073	11.5811
7	290	617.415	.73502	2567.55	8.74311	11.8951
7	300	624.665	.71499	2654.94	8.73549	12.2177
7	310	631.717	.69551	2742.26	8.72787	12.5489
7	320	638.577	.67655	2829.50	8.72025	12.8892

8	0	290.662	1.7291	0.00	8.61612	4.9830
8	10	307.703	1.6794	86.15	8.61376	5.1291
8	20	324.254	1.6311	172.28	8.61140	5.2795
8	30	340.330	1.5842	258.38	8.60904	5.4342
8	40	355.943	1.5387	344.46	8.60668	5.5936
8	50	371.108	1.4944	430.51	8.60432	5.7575
8	60	385.836	1.4515	516.54	8.60196	5.9263
8	70	400.141	1.4098	602.55	8.59960	6.1000
8	80	414.035	1.3692	688.53	8.59724	6.2789
8	90	427.530	1.3299	774.50	8.59488	6.4629
8	100	440.637	1.2916	860.43	8.59252	6.6524
8	110	453.367	1.2545	946.35	8.59016	6.8474
8	120	465.731	1.2185	1032.24	8.58780	7.0481
8	130	477.739	1.1834	1118.10	8.58544	7.2547
8	140	489.402	1.1494	1203.94	8.58308	7.4674
8	150	500.730	1.1164	1289.76	8.58072	7.6863
8	160	511.733	1.0843	1375.56	8.57836	7.9116
8	170	522.419	1.0531	1461.33	8.57601	8.1435
8	180	532.798	1.0228	1547.08	8.57365	8.3823
8	190	542.879	.99343	1632.80	8.57129	8.6280
8	200	552.669	.96487	1718.50	8.56893	8.8809
8	210	562.179	.93713	1804.18	8.56657	9.1412
8	220	571.415	0.9102	1889.84	8.56421	9.4092
8	230	580.385	.88403	1975.47	8.56185	9.6850
8	240	589.098	.85862	2061.07	8.55949	9.9689
8	250	597.560	.83394	2146.66	8.55713	10.2611
8	260	605.779	.80996	2232.22	8.55477	10.5619
8	270	613.762	.78668	2317.75	8.55241	10.8715
8	280	621.515	.76407	2403.26	8.55005	11.1902
8	290	629.045	0.7421	2488.75	8.54769	11.5182
8	300	636.359	.72077	2574.22	8.54533	11.8559
8	310	643.462	.70005	2659.66	8.54297	12.2034
8	320	650.362	.67992	2745.08	8.54061	12.5611
9	0	290.662	1.6978	0.00	7.84323	4.6196
9	10	307.399	1.6499	78.47	7.85040	4.7581
9	20	323.664	1.6033	157.01	7.85756	4.9008
9	30	339.470	1.558	235.62	7.86472	5.0478
9	40	354.829	1.5141	314.30	7.87189	5.1992
9	50	369.755	1.4713	393.06	7.87905	5.3551
9	60	384.259	1.4298	471.88	7.88621	5.5158
9	70	398.354	1.3894	550.78	7.89338	5.6812
9	80	412.051	1.3502	629.75	7.90054	5.8515
9	90	425.361	1.312	708.79	7.90770	6.0270
9	100	438.295	1.275	787.90	7.91487	6.2077
9	110	450.864	1.239	867.09	7.92203	6.3939
9	120	463.079	1.204	946.35	7.92919	6.5856
9	130	474.948	1.17	1025.67	7.93636	6.7831
9	140	486.482	1.137	1105.07	7.94352	6.9864
9	150	497.691	1.1049	1184.54	7.95068	7.1959
9	160	508.583	1.0737	1264.09	7.95785	7.4117
9	170	519.168	1.0434	1343.70	7.96501	7.6339
9	180	529.454	1.0139	1423.39	7.97217	7.8627
9	190	539.449	.98529	1503.14	7.97934	8.0985
9	200	549.162	.95747	1582.97	7.98650	8.3412
9	210	558.601	.93044	1662.87	7.99366	8.5913
9	220	567.774	.90417	1742.85	8.00083	8.8488
9	230	576.687	.87864	1822.89	8.00799	9.1141
9	240	585.349	.85383	1903.01	8.01515	9.3873
9	250	593.766	.82973	1983.19	8.02232	9.6686

9	260	601.946	0.8063	2063.45	8.02948	9.9584
9	270	609.894	.78353	2143.78	8.03664	10.2569
9	280	617.618	.76141	2224.19	8.04381	10.5643
9	290	625.124	.73991	2304.66	8.05097	10.8810
9	300	632.419	.71902	2385.20	8.05813	11.2071
9	310	639.507	.69872	2465.82	8.06530	11.5429
9	320	646.395	.67899	2546.51	8.07246	11.8889
10	0	290.662	1.7053	0.00	6.55673	3.8448
10	10	307.472	1.657	65.67	6.57768	3.9697
10	20	323.806	1.61	131.55	6.59862	4.0985
10	30	339.677	1.5643	197.64	6.61957	4.2315
10	40	355.097	1.52	263.94	6.64052	4.3688
10	50	370.081	1.4769	330.45	6.66147	4.5105
10	60	384.639	1.435	397.17	6.68241	4.6567
10	70	398.785	1.3943	464.10	6.70336	4.8077
10	80	412.529	1.3548	531.24	6.72431	4.9634
10	90	425.884	1.3164	598.59	6.74526	5.1242
10	100	438.860	1.279	666.15	6.76620	5.2901
10	110	451.468	1.2428	733.91	6.78715	5.4614
10	120	463.718	1.2075	801.89	6.80810	5.6381
10	130	475.621	1.1733	870.08	6.82905	5.8205
10	140	487.137	1.14	938.47	6.84999	6.0088
10	150	498.424	1.1077	1007.08	6.87094	6.2030
10	160	509.343	1.0763	1075.89	6.89189	6.4035
10	170	519.953	1.0457	1144.91	6.91284	6.6105
10	180	530.261	1.0161	1214.15	6.93378	6.8240
10	190	540.277	.98727	1283.59	6.95473	7.0444
10	200	550.009	.95928	1353.24	6.97568	7.2718
10	210	559.465	.93207	1423.10	6.99663	7.5065
10	220	568.653	.90564	1493.17	7.01758	7.7487
10	230	577.581	.87996	1563.45	7.03852	7.9987
10	240	586.255	.85501	1633.94	7.05947	8.2566
10	250	594.683	.83076	1704.64	7.08042	8.5228
10	260	602.872	0.8072	1775.55	7.10137	8.7975
10	270	610.829	.78431	1846.67	7.12231	9.0810
10	280	618.561	.76207	1918.00	7.14326	9.3735
10	290	626.073	.74046	1989.54	7.16421	9.6753
10	300	633.372	.71946	2061.28	7.18516	9.9868
10	310	640.464	.69906	2133.24	7.20610	10.3083
10	320	647.355	.67924	2205.40	7.22705	10.6399

Table 4. Analysis of Variance of the Predicted Weight Model (PWT)

Source	df	Residual sum of squares	mean sum of squares	f test
Regression[a]	3	634,932.6462	211,644.2151	
Ration[b]	27	523,752.0119	19,398.2227	6.392[g]
Lack of fit[c]	25	83,626.0445	3,345.0418	1.102[h]
Model[d]	2	440,125.9674	220,062.9837	
Animal/Ration[e]	30	91,039.4174	3,034.6472	
Residual[f]	529	20,141.2168	38.0741	

[a] $Wt = A(1 - Be^{-kt})$ fitted to pooled data of 20 steers (Appendix I Table 1)

[b] Regression - [$Wt = A(1 - Be^{-kt})$ fitted to data pooled by ration] (Appendix I Table 1 & 2)

[c] PWT - [$Wt = A(1 - Be^{-kt})$ fitted to data pooled by ration] (Appendix I Table 4 & 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 I Tables 2 & 3)

[f] $Wt = A(1-Be^{-kt})$ fitted to data by animal (Appendix I Table 3)

[g] $(P<.001)$ Ration MS ÷ Animal/Ration MS

[h] $(P>.396)$ Lack of fit MS ÷ Animal/Ration MS

Table 5. Analysis of Variance of the Accumulative Dry Matter Intake Model (PDM).

Source	df	residual sum of squares	mean sum of squares	f test
Regression[a]	2	6,465,918.2575	3,232,959.1288	
Ration[b]	18	5,806,425.0390	2,903,212.5195	94.787[g]
Lack of fit[c]	13	492,953.8606	37,919.5377	1.238[h]
Model[d]	5	5,313,471.1784	1,062,694.2356	
Animal/Ration[e]	20	612,577.5164	30,628.8758	
Residual[f]	549	46,915.7017	85.4567	

[a] $DM = \beta_1 t + \beta_2 t^2$ fitted to pooled data of 20 steers (Appendix I Table 5)

[b] Regression - [$DM = \beta_1 t + \beta_2 t^2$ fitted to data pooled by ration] (Appendix I Tables 5 & 6)

[c] PDM - [$DM = \beta_1 t + \beta_2 t^2$ fitted to data pooled by ration] (Appendix I Tables 8 & 6)

[d] Ration - Lack of fit

[e] [$DM = \beta_1 t + \beta_2 t^2$ fitted to data pooled by ration] - [$DM = \beta_1 t + \beta_2 t^2$ fitted to data pooled by animal] (Appendix I Tables 6 & 7)

[f] $DM = \beta_1 t + \beta_2 t^2$ fitted to data by animal (Appendix I Table 7)

[g] ($P<.001$) Ration MS ÷ Animal/Ration MS

[h] ($P>.324$) Lack of fit MS ÷ Animal/Ration MS

component was further partitioned into the Model and Lack of Fit. The Model effect for PWT was the amount of variation accounted for by describing k as a linear function of ME and DM. The Model effect for PDM was the amount of variation accounted for by describing B_1 as a cubic function of ME and B_2 as a quadratic function of ME. Comparing Ration mean square to Animal within Ration mean square in an F-test showed cumulative weight gain and DM intake are both significantly effected by the ration ($P<.001$). An F-test comparing Model mean square to Animal within Ration mean square shows inclusion of ME and DM terms in k produces a model with adequate representation ($P>.396$). Inclusion of ME in describing B_1 and B_2 also gives an adequate representation at ($P>.324$). Values and residual sums of squares of components used to calculate the analysis of variance are given in Appendix I.

The analysis of variance tables are some what different from the usual linear model table. For example, the nonlinear model involves three parameters and does not include the mean. First the degrees of freedom add to n, not n-1, since there is no effect due to the mean corresponding to the usual correction factor. Secondly, each model involves three parameters and thus there are 9 degrees of freedom for comparing rations from each parameter, yielding 27 degrees of freedom for ration comparisons. But, as in the usual linear model case, an animal is the experimental unit for rations and thus we use differences between animals within rations to test hypothesis concerning ration effects.

Weight Gain and Rate of Gain

PWT and RWT increased with increasing ME through ration 8, but there was little difference between rations 8, 9 and 10 (Fig. 2-5). This indicates a ration must contain more than 2.98 Kcal ME/Kg or less than 30% corn silage on a DM basis to maximize rate of gain. RWT decreased for all rations as time on feed increased. However, the decrease in RWT was greater as the ME of the ration increased. The 320 day modeled feeding period showed RWT of ration 1 to drop from .97 to .57 Kg gain/day or a 41% decline while ration 10 dropped from 1.71 to .68 Kg gain/day or 60%. The reason of the greater rate of decline on the higher concentrate rations may be because faster gaining animals approach their mature weight sooner.

As rate of gain increases the time required to reach market weight is reduced, which means a savings in fixed costs. Table 6 shows by ration the time needed to reach 500 Kg from a starting weight of 290 Kg.

Dry Matter and Rate of Dry Matter Intake

PDM intake increased as ME increased from rations 1 to 7 but decreased drastically as ME continued to increase from rations 8 to 10 (Fig. 6 and 7). RDM intakes also indicate that maximum DM intake was on rations 6 and 7 (Fig. 8 and 9). The decline in DM intake on rations with 20% or less corn silage may be due to ruminal acidosis. Vance et al. (1972) found steers fed an all concentrate diet had significant clumping of papillae and lower pH readings compared to steers fed 2.3 Kg/day or more

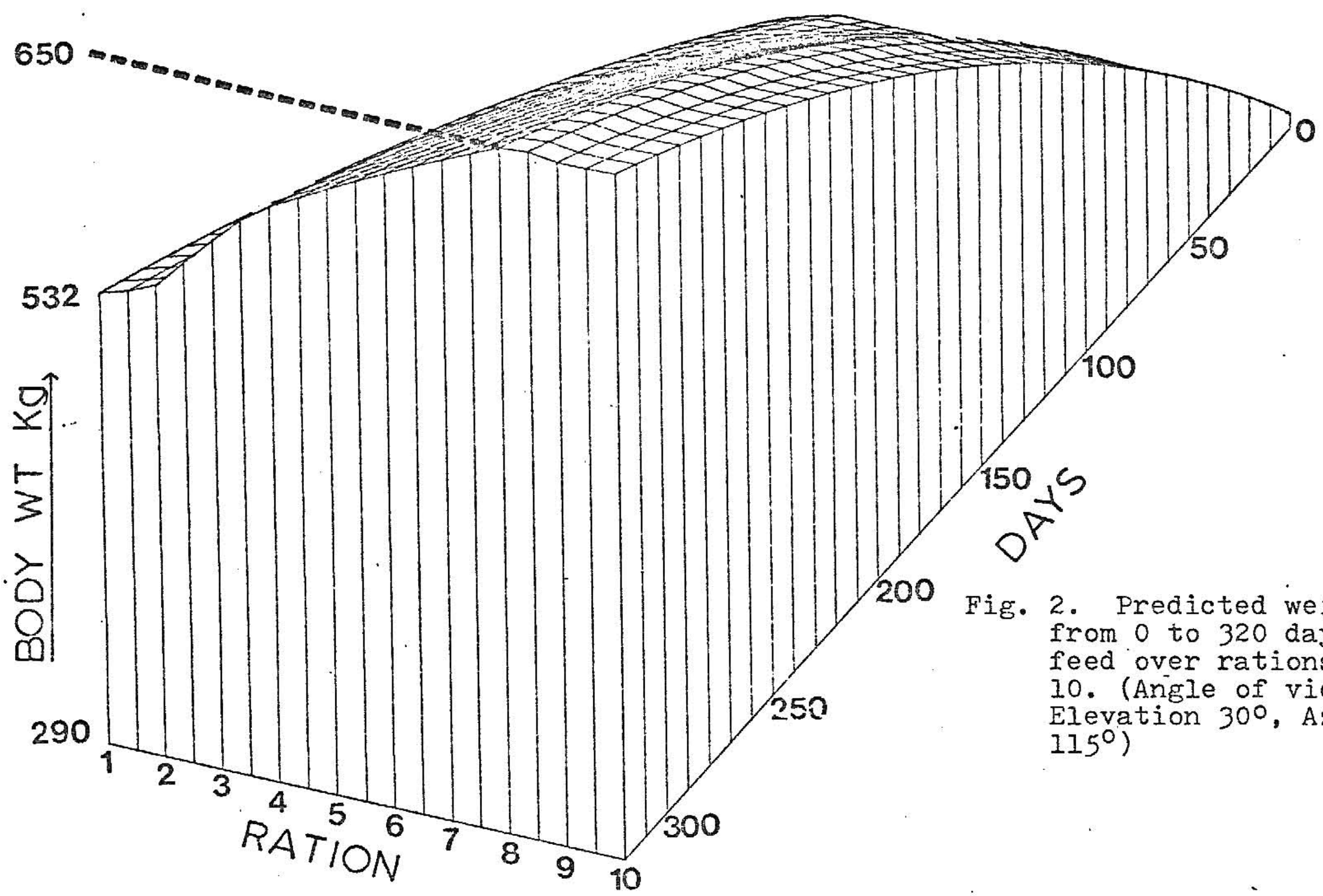

Fig. 2. Predicted weights from 0 to 320 days on feed over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth 115°)

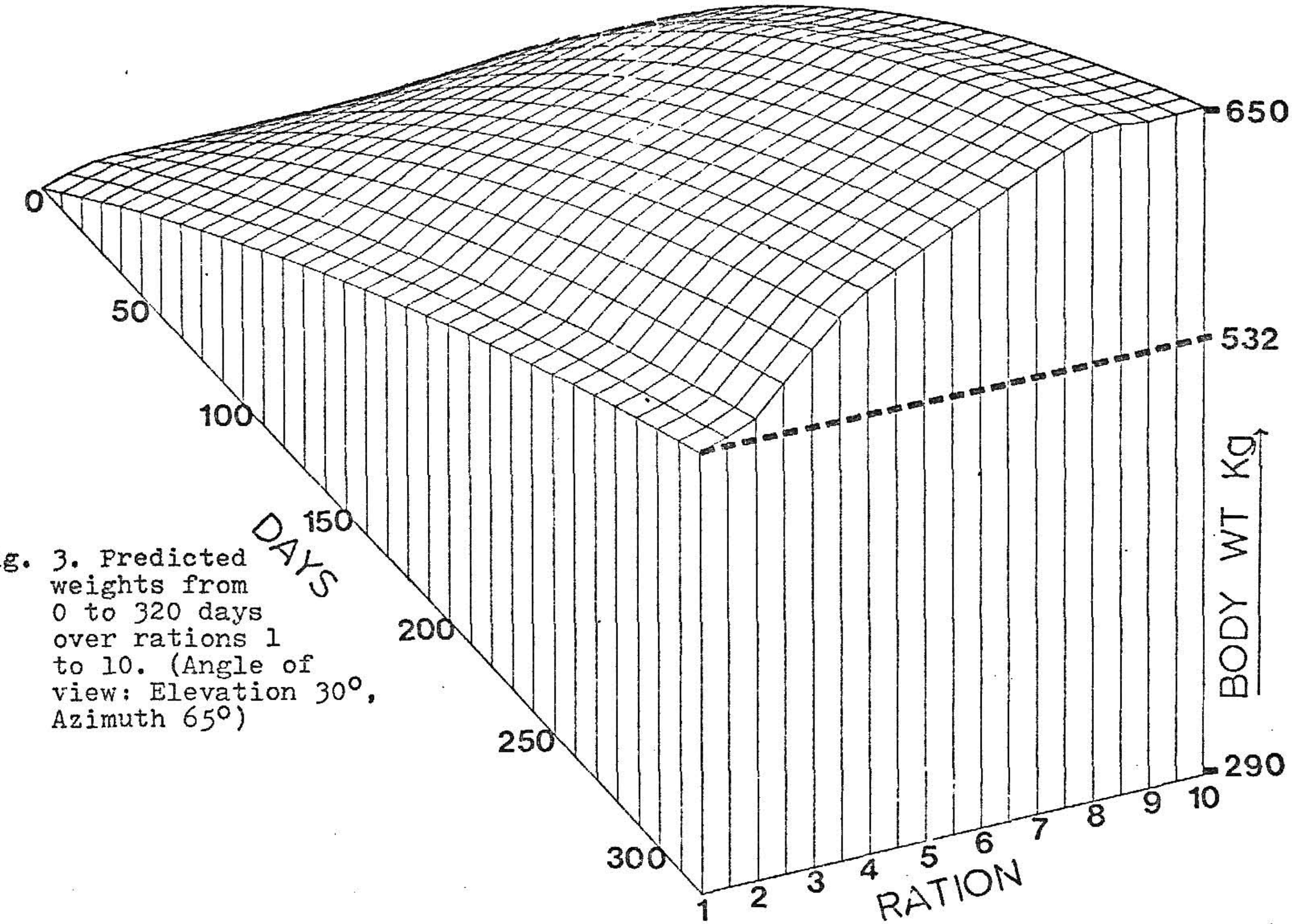

Fig. 3. Predicted weights from 0 to 320 days over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth 65°)

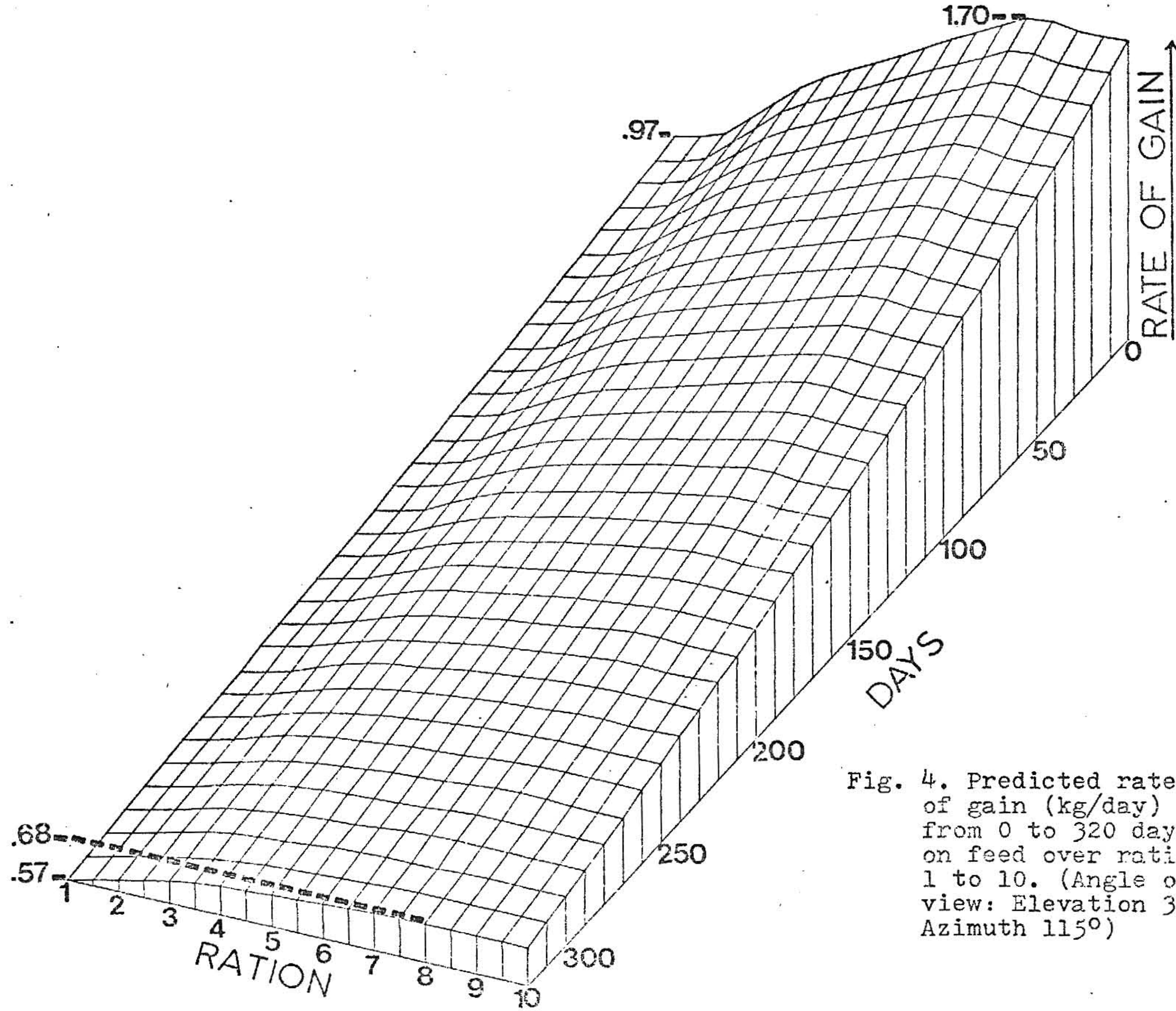

Fig. 4. Predicted rate of gain (kg/day) from 0 to 320 days on feed over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth 115°)

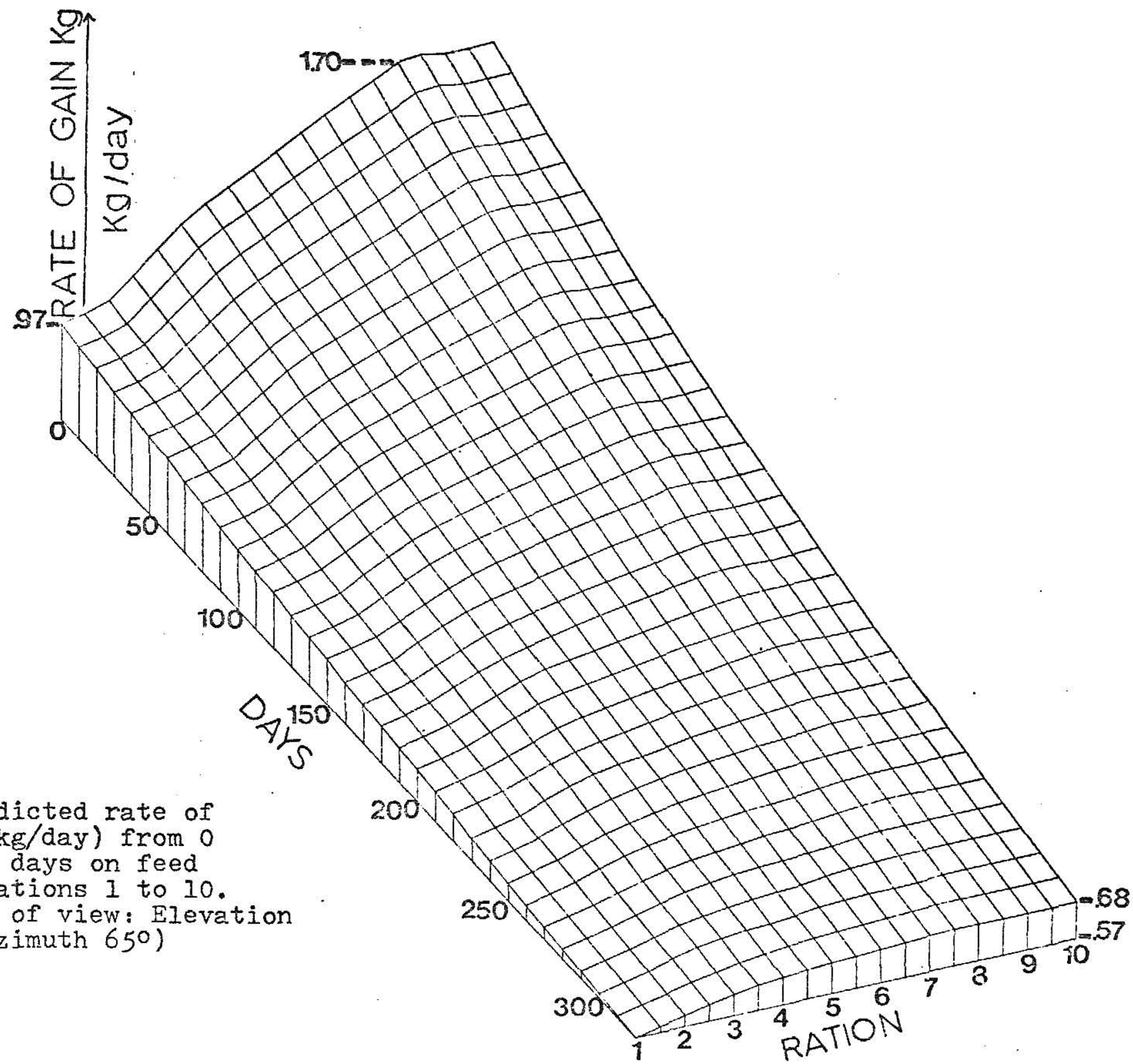

Fig. 5. Predicted rate of gain (kg/day) from 0 to 320 days on feed over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth 65°)

Table 6. Performance at 500 kg

Ration	1	2	3	4	5	6	7	8	9	10
Days from 290-500 kg	267.0	230.3	203.0	189.4	177.5	167.0	157.7	149.3	152.1	151.4
Rate of Gain (kg/day)	.63	.73	.82	.88	.95	1.01	1.07	1.11	1.09	1.10
DM/Gain	13.50	11.20	9.92	9.52	9.17	8.82	8.33	7.68	7.24	6.24

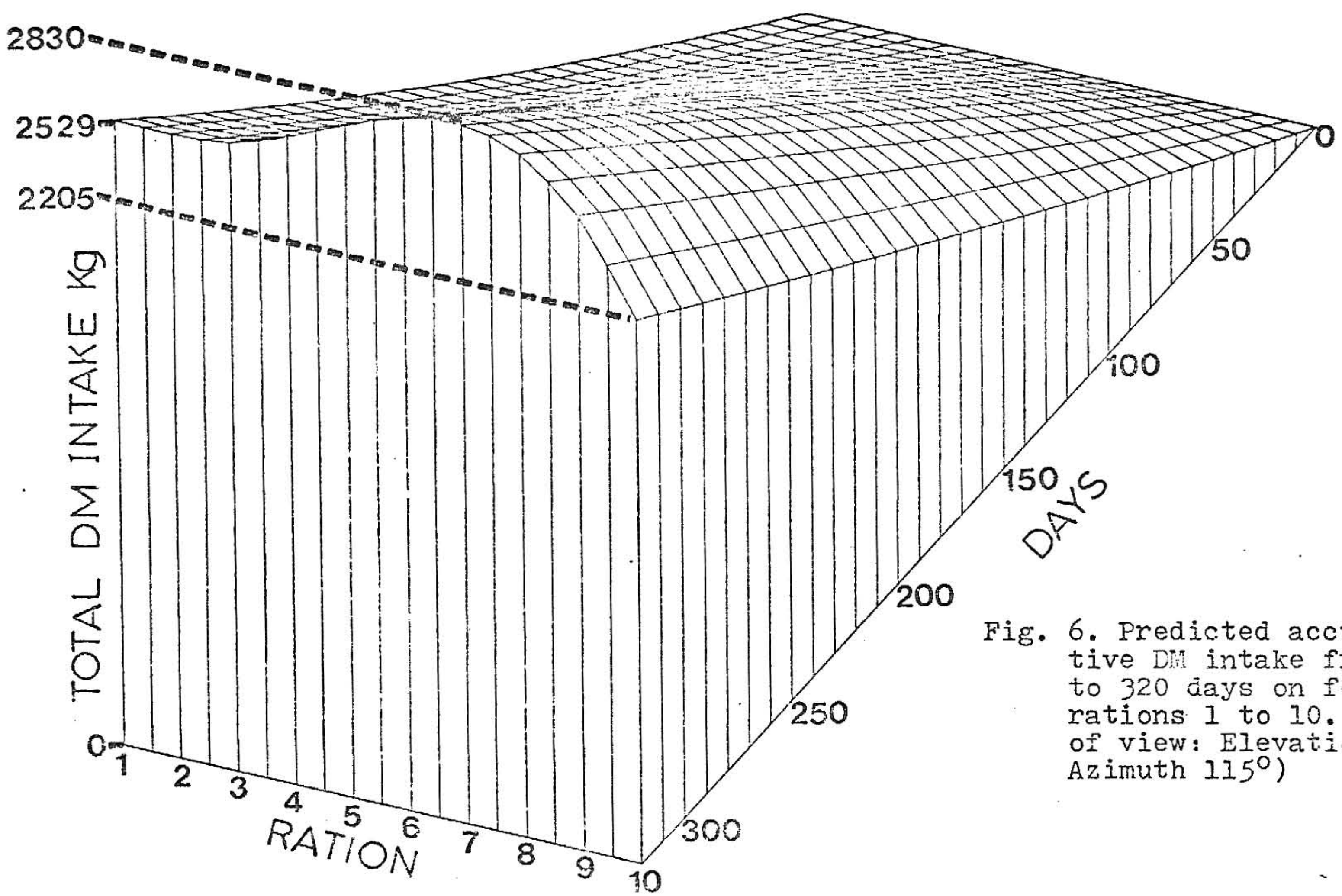

Fig. 6. Predicted accumulative DM intake from 0 to 320 days on feed over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth 115°)

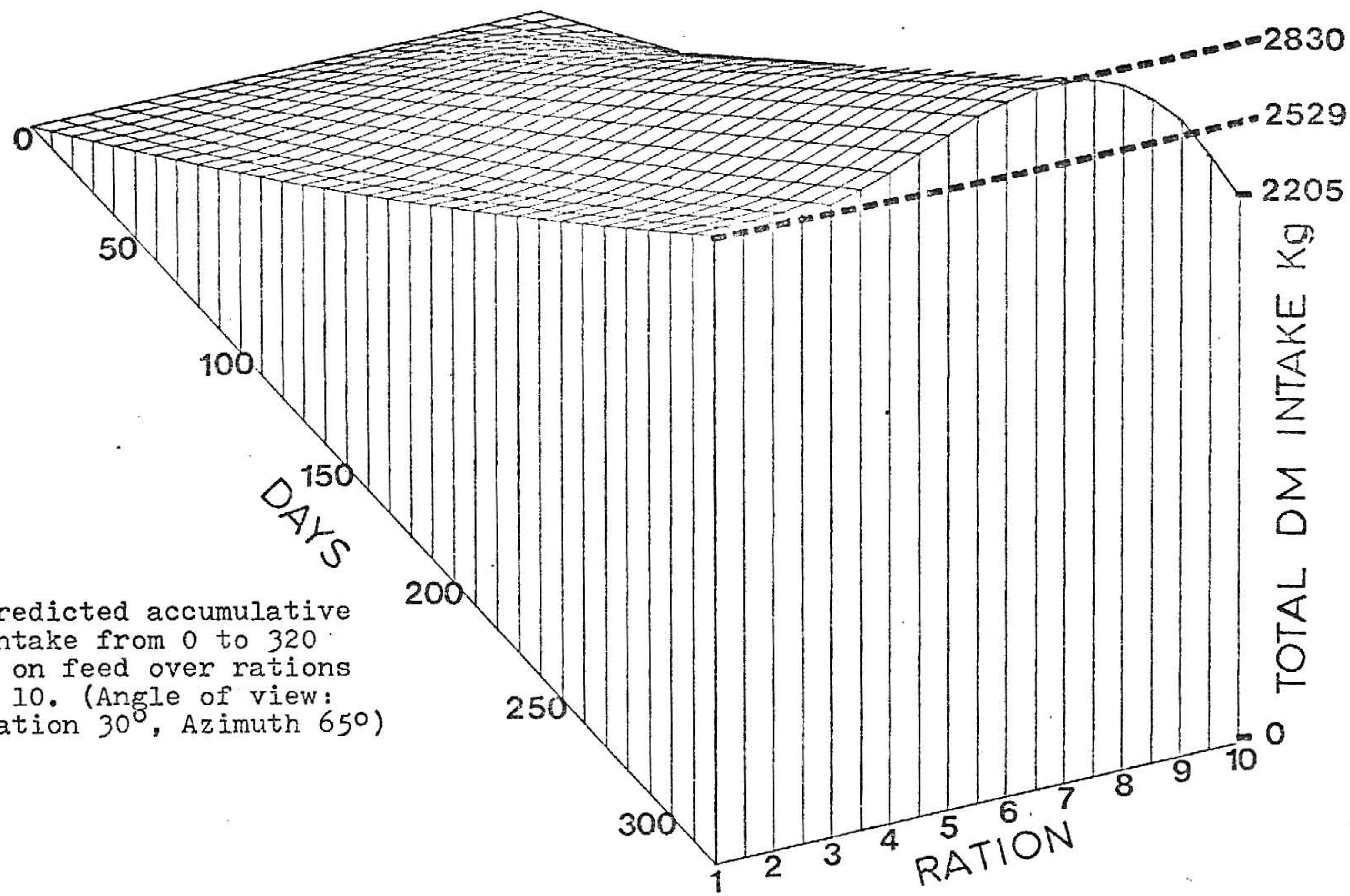

Fig. 7. Predicted accumulative DM intake from 0 to 320 days on feed over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth 65°)

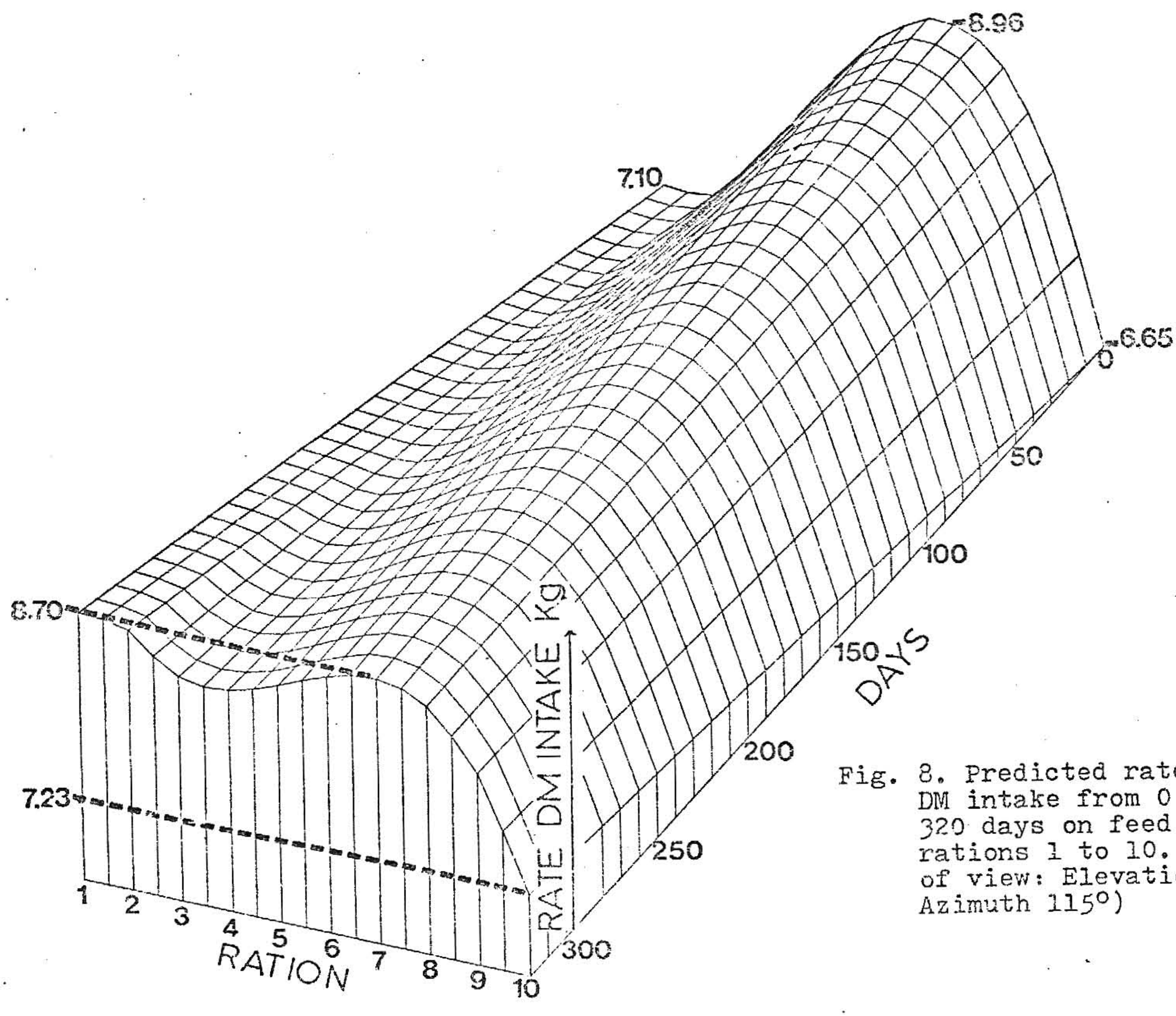

Fig. 8. Predicted rate of DM intake from 0 to 320 days on feed over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth 115°)

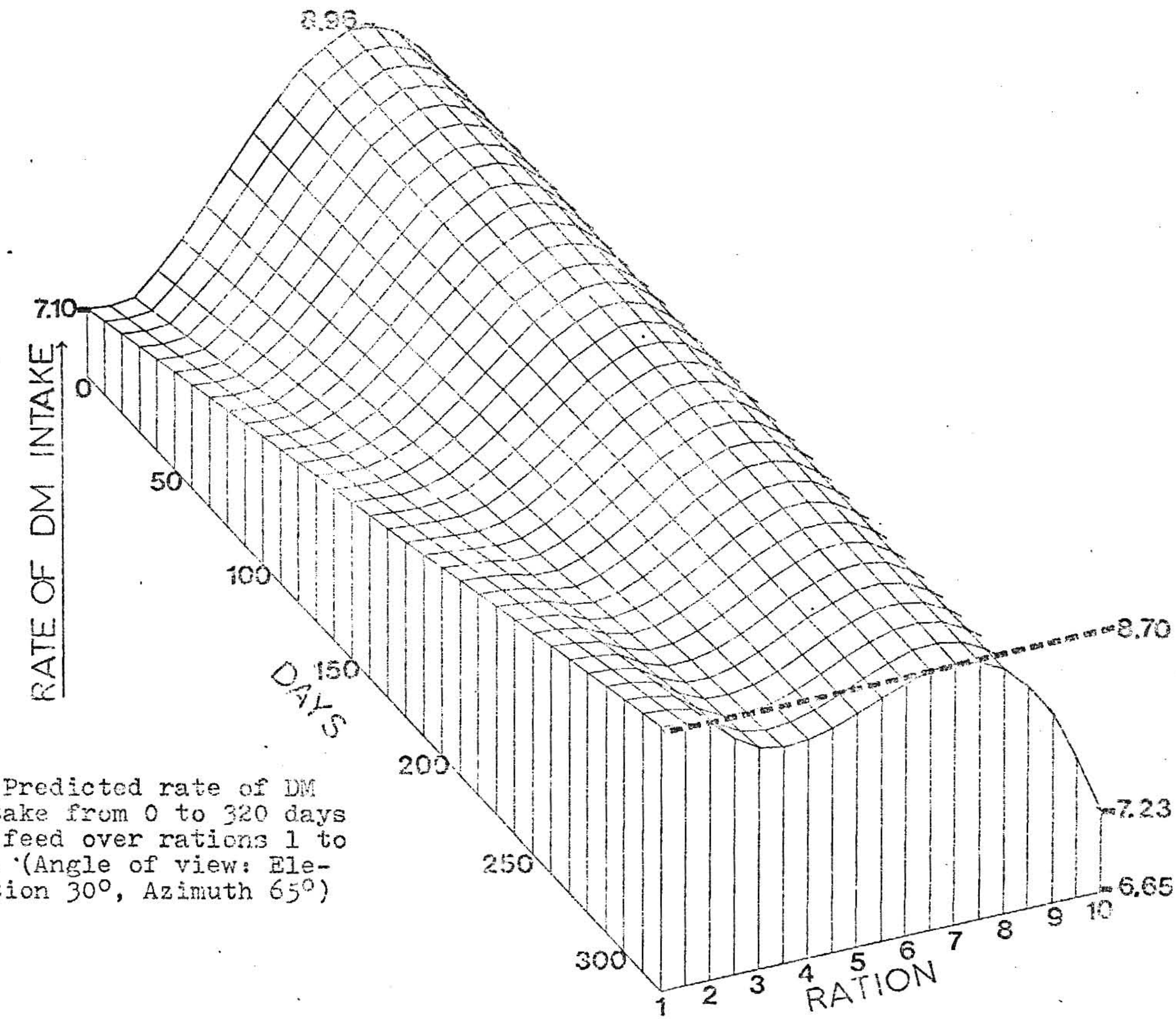

Fig. 9. Predicted rate of DM intake from 0 to 320 days on feed over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth 65°)

corn silage (40% DM). Both he and Jesse et al. (1976) noted depressed DM intake on high concentrate rations.

Except for rations 6, 7 and 8, RDM intake increased over time. RDM intake on rations 1 and 2, however, increased at a faster rate than the others, indicating that these steers' intake may be limited by physical capacity and as they grew their capacity increased. The percentage increase in RDM intake over time is very small compared to approximately 100% increase in body weight over the same time. There seems to be little relationship between body weight or metabolic size and DM intake for these steers above 290 Kg, indicating there is a fallacy in using general 'thumb rules' which calculate feed intake as a percentage of body weight. The RDM intake model shows DM intake is more dependent on the energy concentration of the ration rather than body weight.

Feed Efficiency

Dry matter conversion became less efficient as both time and proportion of corn silage increased (Fig. 10 and 11). Over time, the higher concentrate rations had a faster rate of deterioration in PFE. During the 320 day modeled period the amount of DM required for gain increased 206.8% to 277.1% from rations 1 to 10 respectively. Comparing rations on an equal weight basis from 290.7 to 500 Kg, PFE increased 183.9 and 162.5% for rations 1 and 10 respectively (Table 6).

Despite the decreased DM intake on the high concentrate rations they produced the greatest weight gains and thus feed

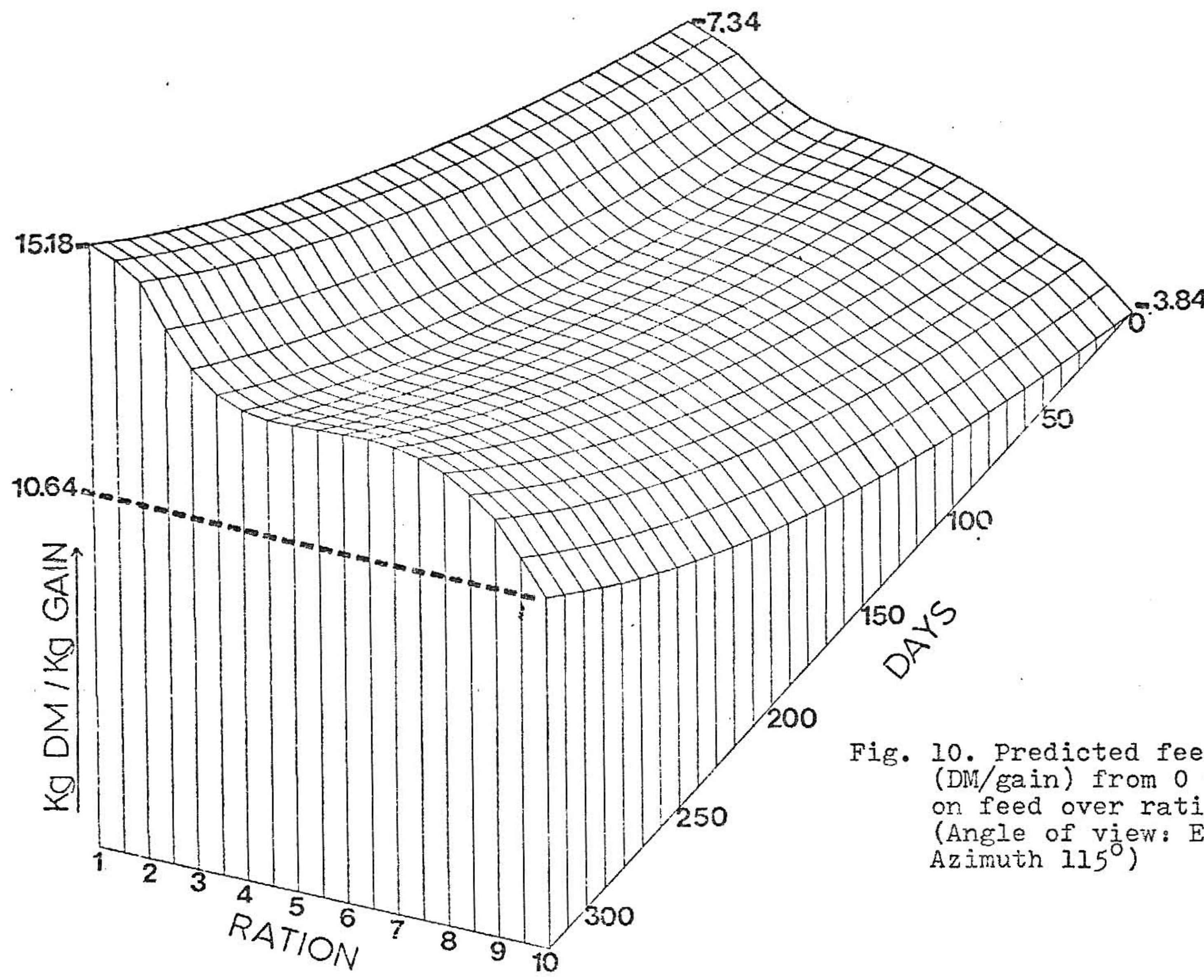

Fig. 10. Predicted feed efficiency (DM/gain) from 0 to 320 days on feed over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth 115°)

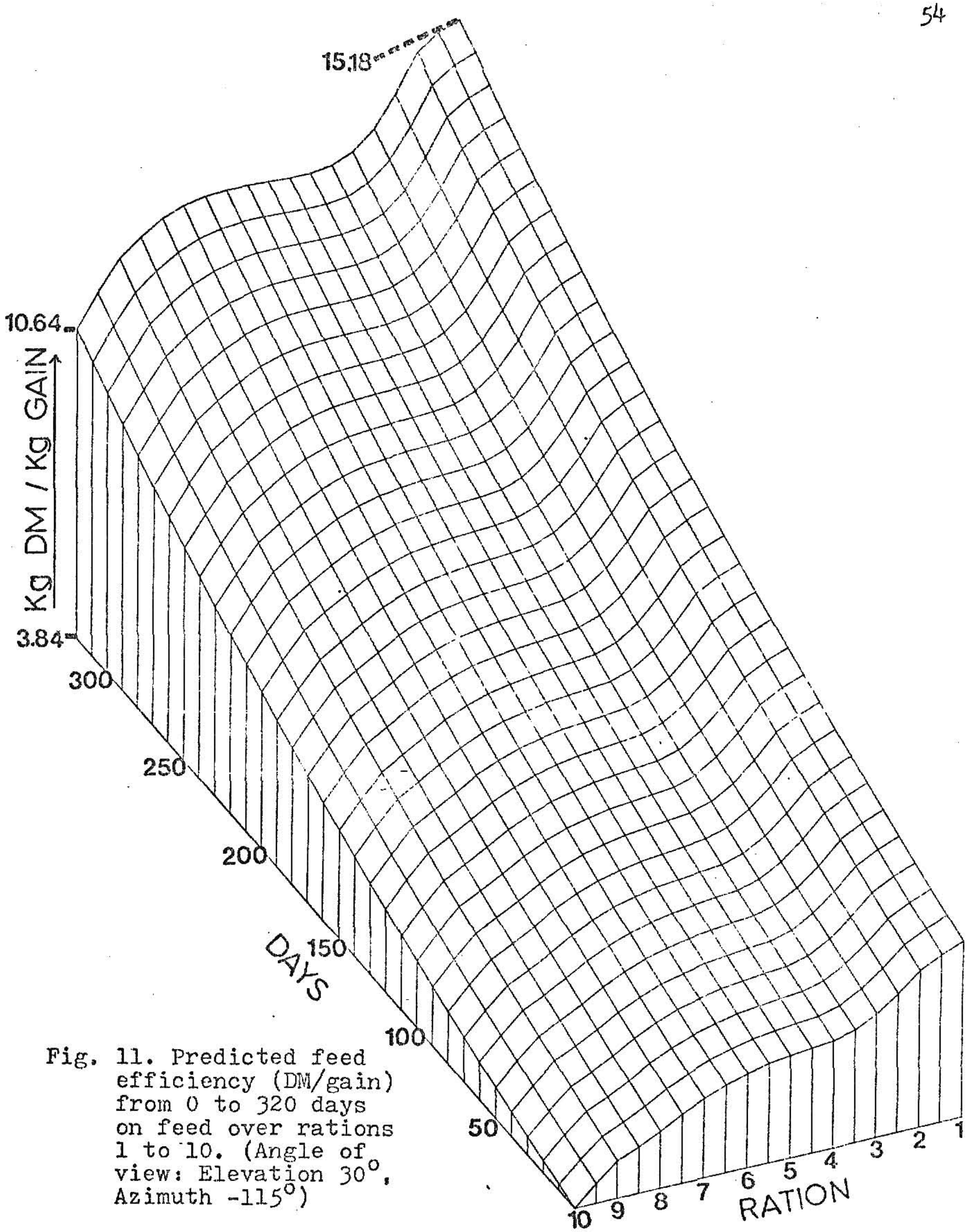

Fig. 11. Predicted feed efficiency (DM/gain) from 0 to 320 days on feed over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth -115°)

efficiency improved as ME increased. This is in agreement with Vance *et al.* (1972) and Jesse *et al.* (1976).

Metabolizable Energy Intake and Efficiency

The model of rate of ME intake, found by the product of ration ME concentration and RDM, shows rate of ME intake to increase as ME content of the ration increases from ration 1 to 7 and 8 but declines sharply for rations 9 and 10 (Fig. 12).

Utilization of ME, found by multiplying ME by PFE, reveals a different picture, however (Fig. 13). Except for rations 1 and 2 ME efficiency improved as the corn silage:corn ratio is adjusted to high or low extremes. The reason for rations 1 and 2 not following the trend may again be due to physical limits not allowing them to maximize intake. Possible associative effects of corn silage and corn may be the reason for detrimental utilization of ME for rations in the middle of the spectrum. Combinations of roughage and concentrates may not allow optimum rumen environment for either cellulolytic or amylolytic microbial populations. Vance *et al.* (1972) discovered the NE_m and NE_p values of corn to decrease as corn silage was increased in the rations. Kromann (1967) used simultaneous equations to show that NE_{m+p} values of both molasses and a low energy basal mix fed by Lofgreen and Otagaki (1960) changed as molasses was added to the basal mix.

Economic Applications

By finding the product of cost/Kg of ration and PFE a model of feed cost/Kg of additional gain can be projected

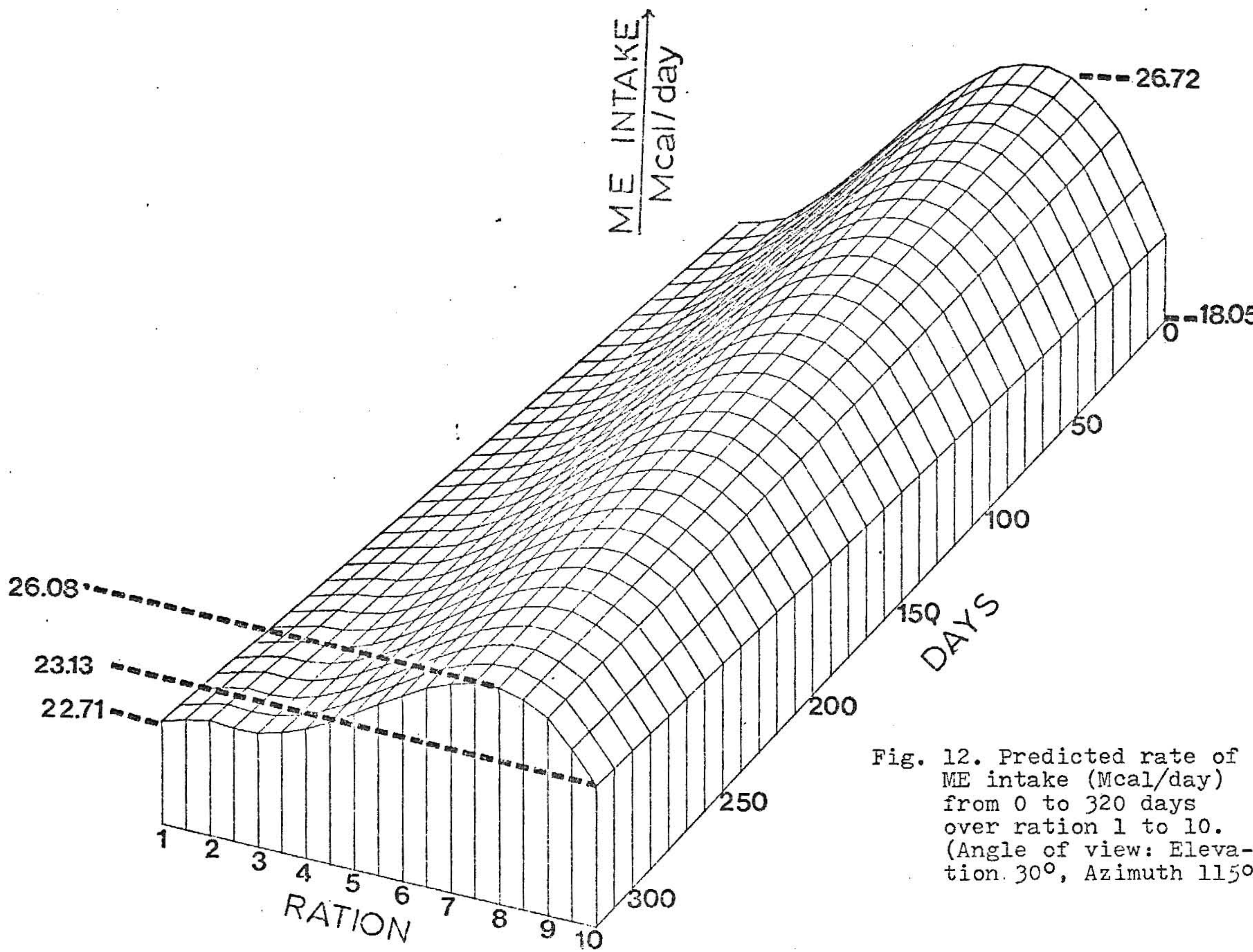

Fig. 12. Predicted rate of ME intake (Mcal/day) from 0 to 320 days over ration 1 to 10. (Angle of view: Elevation 30°, Azimuth 115°)

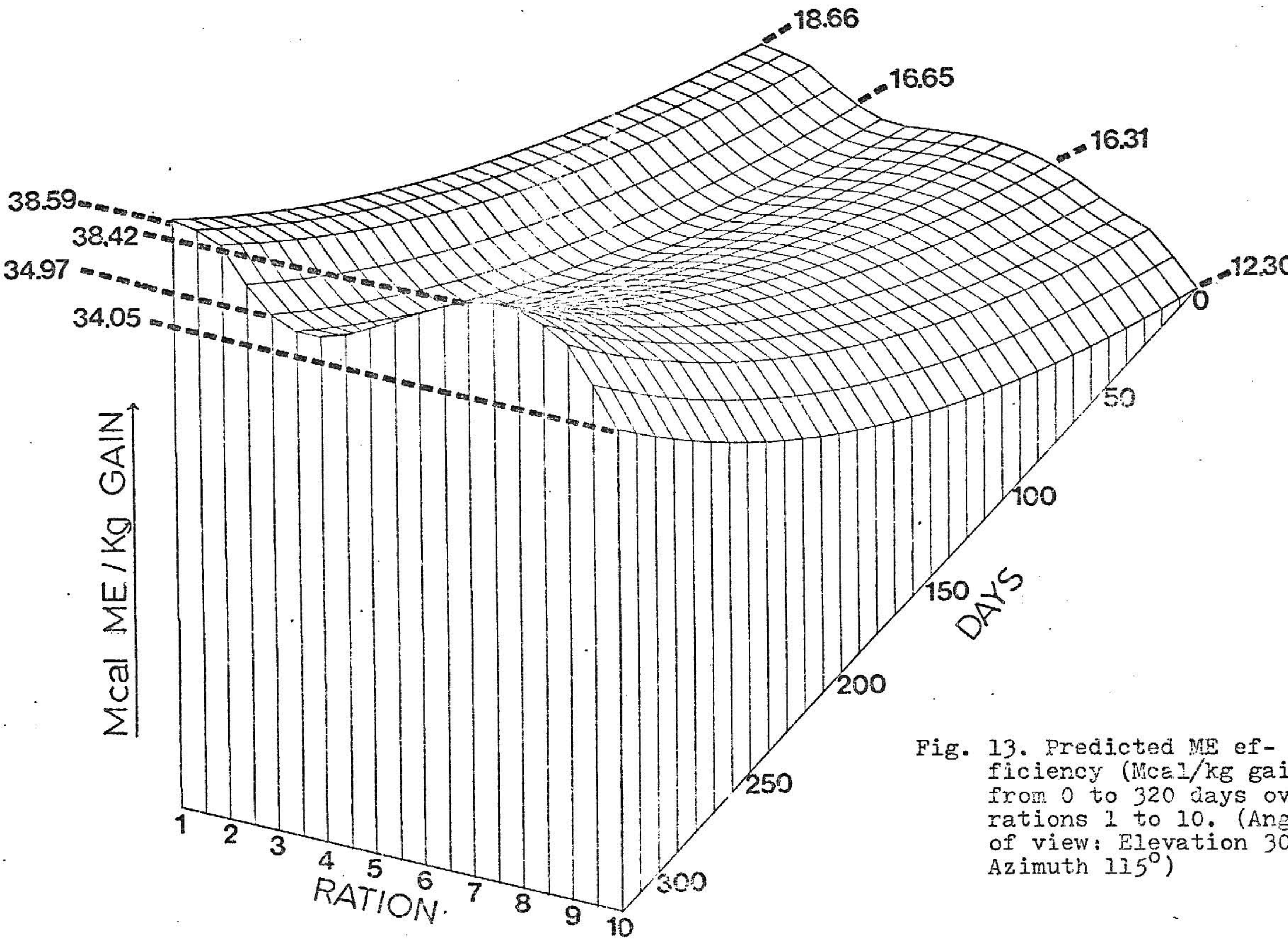

Fig. 13. Predicted ME efficiency (Mcal/kg gain) from 0 to 320 days over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth 115°)

(Fig. 14). Under any given set of corn and corn silage prices this model can estimate the corn silage:corn ratio that will minimize feed costs. Adding to the equation of this model a constant fixed cost figure divided by RWT produces a model of total cost/Kg gain. Models of this type readily lend themselves to practical economic applications.

Table 7 gives the cost/additional pound of gain at 10 day intervals by ration for three different corn silage:corn price ratios. Prices are expressed in relation to pounds because it is easier to compare break even costs to market prices. The three corn silage:corn price ratios, referred to as medium (M), low (L) and high (H) respectively, are \$20.00/ton:\$2.00/bu., \$20.00/ton:\$2.50/bu. and \$25.00/ton:\$2.00/bu. Soybean meal was priced at \$170.00/ton. The value of corn and corn silage are related to each other so even though actual prices may be higher or lower than those used in these tables the ratios will be approximately the same and thus the relative costs per additional gain will be the same. For example if corn silage is \$15.00/ton and corn \$1.50/bu. it has the same price ratio as \$20.00/ton corn silage and \$2.00/bu. corn.

For all three corn silage:corn price ratios the 100% concentrate ration was the most economical in terms of feed costs/gain. The higher concentrate rations have an additional advantage in that fixed costs are less because they reach market weight sooner. The M and L price ratios showed a feed cost/gain advantage for ration 3 over both the lower and some of

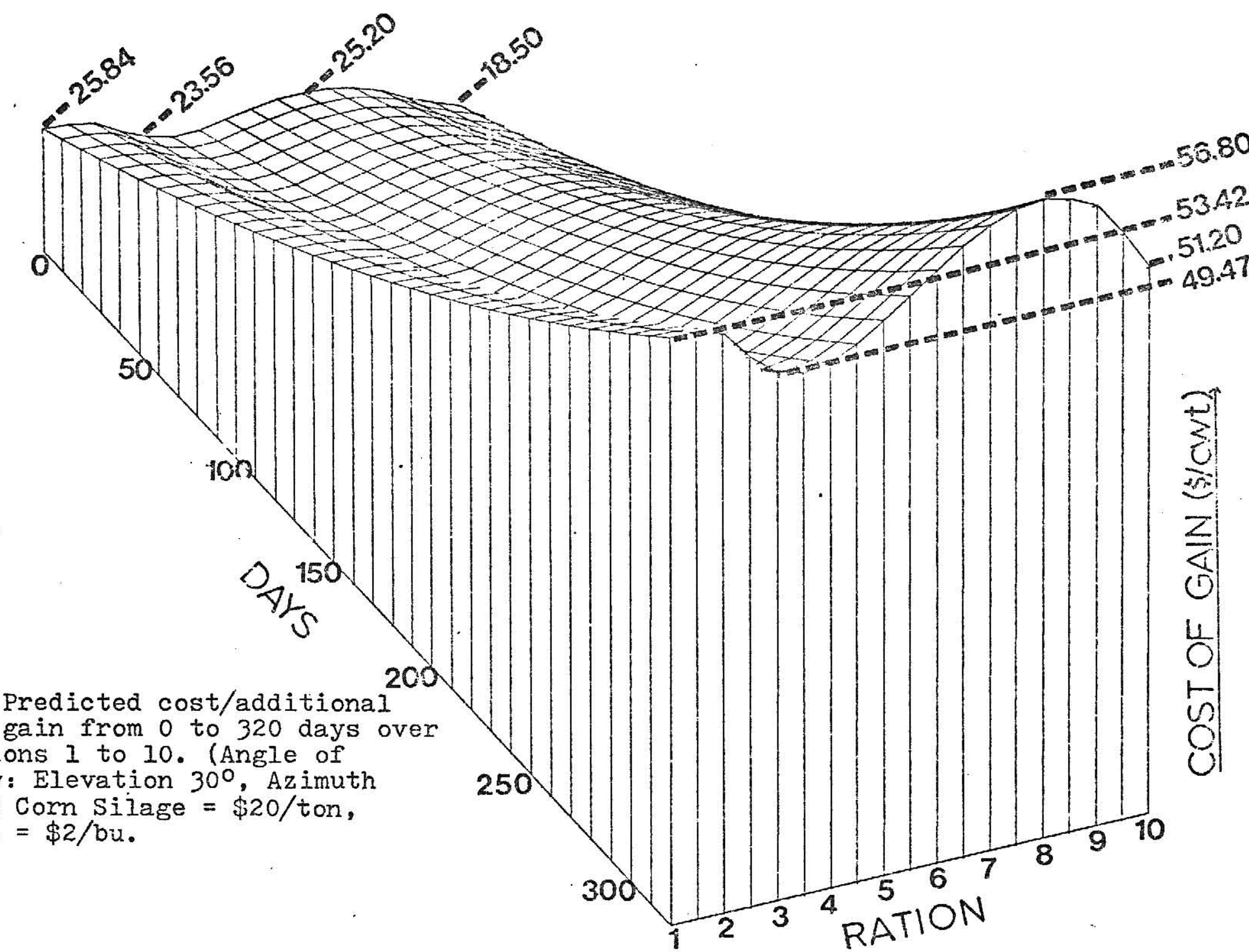

Fig. 14. Predicted cost/additional lb. gain from 0 to 320 days over rations 1 to 10. (Angle of view: Elevation 30°, Azimuth 65°) Corn Silage = $20/ton, Corn = $2/bu.

Table 7. Feed Cost Per Additional Lb. of Gain

$ Cost Per Additional Lb. of Gain

(Price Ratio in $/ton Corn Silage : $/bu Corn)

Ration	Days	$20.00:$2.00	$20.00:$2.50	$25.00:$2.(
1	0	0.2584	0.2584	0.3056
1	10	0.2645	0.2645	0.3128
1	20	0.2707	0.2707	0.3202
1	30	0.2771	0.2771	0.3277
1	40	0.2836	0.2836	0.3354
1	50	0.2903	0.2903	0.3433
1	60	0.2971	0.2971	0.3513
1	70	0.3040	0.3040	0.3595
1	80	0.3111	0.3111	0.3679
1	90	0.3183	0.3183	0.3764
1	100	0.3257	0.3257	0.3852
1	110	0.3332	0.3332	0.3941
1	120	0.3410	0.3410	0.4032
1	130	0.3488	0.3488	0.4125
1	140	0.3569	0.3569	0.4220
1	150	0.3651	0.3651	0.4317
1	160	0.3734	0.3734	0.4417
1	170	0.3820	0.3820	0.4518
1	180	0.3907	0.3907	0.4621
1	190	0.3997	0.3997	0.4727
1	200	0.4088	0.4088	0.4834
1	210	0.4181	0.4181	0.4944
1	220	0.4276	0.4276	0.5057
1	230	0.4373	0.4373	0.5171
1	240	0.4472	0.4472	0.5288
1	250	0.4573	0.4573	0.5408
1	260	0.4676	0.4676	0.5530
1	270	0.4781	0.4781	0.5654
1	280	0.4889	0.4889	0.5782
1	290	0.4998	0.4998	0.5911
1	300	0.5111	0.5111	0.6044
1	310	0.5225	0.5225	0.6179
1	320	0.5342	0.5342	0.6317
2	0	0.2429	0.2495	0.2808
2	10	0.2485	0.2553	0.2873
2	20	0.2543	0.2612	0.2940
2	30	0.2602	0.2672	0.3008
2	40	0.2662	0.2734	0.3078
2	50	0.2723	0.2797	0.3149
2	60	0.2786	0.2862	0.3222
2	70	0.2851	0.2928	0.3296
2	80	0.2917	0.2996	0.3372
2	90	0.2984	0.3065	0.3450
2	100	0.3053	0.3136	0.3529
2	110	0.3123	0.3208	0.3611
2	120	0.3195	0.3282	0.3694
2	130	0.3268	0.3357	0.3779
2	140	0.3344	0.3434	0.3866
2	150	0.3420	0.3513	0.3955
2	160	0.3499	0.3594	0.4045

2	170	0.3579	0.3677	0.4133
2	180	0.3661	0.3761	0.4233
2	190	0.3745	0.3847	0.4330
2	200	0.3831	0.3935	0.4429
2	210	0.3919	0.4025	0.4531
2	220	0.4009	0.4118	0.4635
2	230	0.4100	0.4212	0.4741
2	240	0.4194	0.4308	0.4849
2	250	0.4290	0.4406	0.4960
2	260	0.4388	0.4507	0.5073
2	270	0.4488	0.4610	0.5189
2	280	0.4590	0.4715	0.5307
2	290	0.4695	0.4822	0.5428
2	300	0.4802	0.4932	0.5551
2	310	0.4911	0.5044	0.5678
2	320	0.5022	0.5159	0.5807
3	0	0.2356	0.2479	0.2666
3	10	0.2411	0.2538	0.2729
3	20	0.2468	0.2597	0.2793
3	30	0.2526	0.2658	0.2858
3	40	0.2585	0.2721	0.2926
3	50	0.2646	0.2785	0.2994
3	60	0.2708	0.2850	0.3065
3	70	0.2772	0.2917	0.3137
3	80	0.2837	0.2985	0.3210
3	90	0.2903	0.3055	0.3286
3	100	0.2972	0.3127	0.3363
3	110	0.3041	0.3201	0.3442
3	120	0.3113	0.3276	0.3522
3	130	0.3186	0.3353	0.3605
3	140	0.3260	0.3431	0.3690
3	150	0.3337	0.3512	0.3776
3	160	0.3415	0.3594	0.3865
3	170	0.3495	0.3678	0.3955
3	180	0.3577	0.3765	0.4048
3	190	0.3661	0.3853	0.4143
3	200	0.3747	0.3943	0.4240
3	210	0.3835	0.4036	0.4339
3	220	0.3925	0.4130	0.4441
3	230	0.4017	0.4227	0.4545
3	240	0.4111	0.4326	0.4652
3	250	0.4207	0.4427	0.4761
3	260	0.4306	0.4531	0.4872
3	270	0.4406	0.4637	0.4986
3	280	0.4510	0.4746	0.5103
3	290	0.4615	0.4857	0.5223
3	300	0.4723	0.4971	0.5345
3	310	0.4834	0.5087	0.5470
3	320	0.4947	0.5206	0.5598
4	0	0.2415	0.2598	0.2678
4	10	0.2471	0.2659	0.2741
4	20	0.2530	0.2721	0.2805
4	30	0.2589	0.2785	0.2871
4	40	0.2650	0.2851	0.2939
4	50	0.2712	0.2918	0.3008
4	60	0.2776	0.2987	0.3079
4	70	0.2842	0.3057	0.3151
4	80	0.2908	0.3129	0.3225

4	90	0.2977	0.3203	0.3301
4	100	0.3047	0.3278	0.3379
4	110	0.3119	0.3355	0.3458
4	120	0.3192	0.3434	0.3540
4	130	0.3267	0.3515	0.3623
4	140	0.3344	0.3598	0.3708
4	150	0.3423	0.3682	0.3795
4	160	0.3503	0.3769	0.3885
4	170	0.3586	0.3858	0.3976
4	180	0.3670	0.3948	0.4070
4	190	0.3757	0.4041	0.4166
4	200	0.3845	0.4136	0.4264
4	210	0.3935	0.4234	0.4364
4	220	0.4028	0.4333	0.4467
4	230	0.4123	0.4435	0.4572
4	240	0.4220	0.4540	0.4679
4	250	0.4319	0.4647	0.4789
4	260	0.4421	0.4756	0.4902
4	270	0.4525	0.4868	0.5018
4	280	0.4631	0.4982	0.5136
4	290	0.4740	0.5100	0.5256
4	300	0.4852	0.5220	0.5380
4	310	0.4966	0.5343	0.5507
4	320	0.5083	0.5468	0.5636
5	0	0.2456	0.2696	0.2671
5	10	0.2515	0.2761	0.2736
5	20	0.2576	0.2828	0.2802
5	30	0.2639	0.2896	0.2870
5	40	0.2703	0.2966	0.2939
5	50	0.2768	0.3038	0.3011
5	60	0.2835	0.3112	0.3083
5	70	0.2904	0.3187	0.3158
5	80	0.2974	0.3264	0.3235
5	90	0.3046	0.3343	0.3313
5	100	0.3120	0.3424	0.3393
5	110	0.3195	0.3507	0.3475
5	120	0.3273	0.3592	0.3559
5	130	0.3352	0.3679	0.3646
5	140	0.3433	0.3768	0.3734
5	150	0.3516	0.3860	0.3824
5	160	0.3601	0.3953	0.3917
5	170	0.3689	0.4049	0.4012
5	180	0.3778	0.4147	0.4109
5	190	0.3869	0.4247	0.4208
5	200	0.3963	0.4350	0.4310
5	210	0.4059	0.4455	0.4415
5	220	0.4157	0.4563	0.4522
5	230	0.4258	0.4674	0.4631
5	240	0.4361	0.4787	0.4743
5	250	0.4467	0.4903	0.4858
5	260	0.4575	0.5021	0.4976
5	270	0.4685	0.5143	0.5096
5	280	0.4799	0.5267	0.5219
5	290	0.4915	0.5395	0.5346
5	300	0.5034	0.5526	0.5475
5	310	0.5156	0.5659	0.5608
5	320	0.5281	0.5796	0.5743
6	0	0.2457	0.2746	0.2623

6	10	0.2519	0.2816	0.2690
6	20	0.2583	0.2888	0.2758
6	30	0.2649	0.2961	0.2828
6	40	0.2716	0.3037	0.2900
6	50	0.2785	0.3114	0.2974
6	60	0.2856	0.3193	0.3050
6	70	0.2929	0.3274	0.3127
6	80	0.3003	0.3358	0.3207
6	90	0.3080	0.3443	0.3288
6	100	0.3158	0.3531	0.3372
6	110	0.3239	0.3620	0.3458
6	120	0.3321	0.3713	0.3546
6	130	0.3405	0.3807	0.3636
6	140	0.3492	0.3904	0.3728
6	150	0.3581	0.4003	0.3823
6	160	0.3672	0.4105	0.3920
6	170	0.3765	0.4209	0.4020
6	180	0.3861	0.4316	0.4122
6	190	0.3959	0.4426	0.4227
6	200	0.4060	0.4538	0.4334
6	210	0.4163	0.4654	0.4445
6	220	0.4269	0.4772	0.4558
6	230	0.4377	0.4893	0.4673
6	240	0.4489	0.5018	0.4792
6	250	0.4603	0.5145	0.4914
6	260	0.4720	0.5276	0.5039
6	270	0.4840	0.5410	0.5167
6	280	0.4963	0.5548	0.5298
6	290	0.5089	0.5689	0.5433
6	300	0.5218	0.5833	0.5571
6	310	0.5351	0.5982	0.5713
6	320	0.5487	0.6134	0.5858
7	0	0.2396	0.2724	0.2514
7	10	0.2461	0.2798	0.2582
7	20	0.2528	0.2874	0.2652
7	30	0.2596	0.2952	0.2724
7	40	0.2667	0.3032	0.2798
7	50	0.2739	0.3114	0.2874
7	60	0.2813	0.3199	0.2952
7	70	0.2890	0.3285	0.3032
7	80	0.2968	0.3374	0.3114
7	90	0.3049	0.3466	0.3198
7	100	0.3131	0.3560	0.3285
7	110	0.3216	0.3657	0.3374
7	120	0.3304	0.3756	0.3466
7	130	0.3393	0.3858	0.3560
7	140	0.3485	0.3962	0.3657
7	150	0.3580	0.4070	0.3756
7	160	0.3677	0.4180	0.3858
7	170	0.3777	0.4294	0.3962
7	180	0.3879	0.4410	0.4070
7	190	0.3984	0.4530	0.4180
7	200	0.4092	0.4653	0.4293
7	210	0.4203	0.4779	0.4410
7	220	0.4317	0.4908	0.4530
7	230	0.4435	0.5041	0.4652
7	240	0.4555	0.5178	0.4779
7	250	0.4678	0.5319	0.4908
7	260	0.4805	0.5463	0.5041

7	270	0.4936	0.5611	0.5178
7	280	0.5069	0.5763	0.5318
7	290	0.5207	0.5919	0.5463
7	300	0.5348	0.6080	0.5611
7	310	0.5493	0.6245	0.5763
7	320	0.5642	0.6414	0.5919
8	0	0.2253	0.2602	0.2325
8	10	0.2320	0.2678	0.2393
8	20	0.2388	0.2757	0.2463
8	30	0.2458	0.2838	0.2535
8	40	0.2530	0.2921	0.2610
8	50	0.2604	0.3006	0.2686
8	60	0.2680	0.3095	0.2765
8	70	0.2759	0.3185	0.2846
8	80	0.2839	0.3279	0.2929
8	90	0.2923	0.3375	0.3015
8	100	0.3008	0.3474	0.3104
8	110	0.3097	0.3576	0.3195
8	120	0.3187	0.3680	0.3288
8	130	0.3281	0.3788	0.3385
8	140	0.3377	0.3899	0.3484
8	150	0.3476	0.4014	0.3586
8	160	0.3578	0.4131	0.3691
8	170	0.3683	0.4252	0.3799
8	180	0.3791	0.4377	0.3911
8	190	0.3902	0.4505	0.4025
8	200	0.4016	0.4637	0.4143
8	210	0.4134	0.4773	0.4265
8	220	0.4255	0.4913	0.4390
8	230	0.4380	0.5057	0.4518
8	240	0.4508	0.5206	0.4651
8	250	0.4640	0.5358	0.4787
8	260	0.4776	0.5515	0.4928
8	270	0.4916	0.5677	0.5072
8	280	0.5061	0.5843	0.5221
8	290	0.5209	0.6015	0.5374
8	300	0.5362	0.6191	0.5531
8	310	0.5519	0.6372	0.5693
8	320	0.5680	0.6559	0.5860
9	0	0.2155	0.2525	0.2188
9	10	0.2220	0.2601	0.2254
9	20	0.2287	0.2679	0.2322
9	30	0.2355	0.2759	0.2391
9	40	0.2426	0.2842	0.2463
9	50	0.2499	0.2927	0.2537
9	60	0.2574	0.3015	0.2613
9	70	0.2651	0.3105	0.2691
9	80	0.2730	0.3198	0.2772
9	90	0.2812	0.3294	0.2855
9	100	0.2896	0.3393	0.2941
9	110	0.2983	0.3495	0.3029
9	120	0.3073	0.3599	0.3120
9	130	0.3165	0.3707	0.3213
9	140	0.3260	0.3818	0.3310
9	150	0.3358	0.3933	0.3409
9	160	0.3458	0.4051	0.3511
9	170	0.3562	0.4172	0.3616
9	180	0.3669	0.4297	0.3725

9	190	0.3779	0.4426	0.3836
9	200	0.3892	0.4559	0.3951
9	210	0.4009	0.4696	0.4070
9	220	0.4129	0.4836	0.4192
9	230	0.4253	0.4981	0.4318
9	240	0.4380	0.5131	0.4447
9	250	0.4511	0.5284	0.4580
9	260	0.4647	0.5443	0.4718
9	270	0.4786	0.5606	0.4859
9	280	0.4929	0.5774	0.5005
9	290	0.5077	0.5947	0.5155
9	300	0.5229	0.6125	0.5309
9	310	0.5386	0.6309	0.5468
9	320	0.5547	0.6498	0.5632
10	0	0.1850	0.2196	0.1850
10	10	0.1910	0.2267	0.1910
10	20	0.1972	0.2341	0.1972
10	30	0.2036	0.2417	0.2036
10	40	0.2102	0.2495	0.2102
10	50	0.2170	0.2576	0.2170
10	60	0.2240	0.2659	0.2240
10	70	0.2313	0.2746	0.2313
10	80	0.2388	0.2835	0.2388
10	90	0.2465	0.2926	0.2465
10	100	0.2545	0.3021	0.2545
10	110	0.2627	0.3119	0.2627
10	120	0.2712	0.3220	0.2712
10	130	0.2800	0.3324	0.2800
10	140	0.2891	0.3432	0.2891
10	150	0.2984	0.3543	0.2984
10	160	0.3081	0.3657	0.3081
10	170	0.3180	0.3775	0.3180
10	180	0.3283	0.3897	0.3283
10	190	0.3389	0.4023	0.3389
10	200	0.3498	0.4153	0.3498
10	210	0.3611	0.4287	0.3611
10	220	0.3728	0.4425	0.3728
10	230	0.3848	0.4568	0.3848
10	240	0.3972	0.4715	0.3972
10	250	0.4100	0.4867	0.4100
10	260	0.4232	0.5024	0.4232
10	270	0.4369	0.5186	0.4369
10	280	0.4509	0.5353	0.4509
10	290	0.4655	0.5525	0.4655
10	300	0.4805	0.5703	0.4805
10	310	0.4959	0.5887	0.4959
10	320	0.5119	0.6076	0.5119

higher concentrate rations. Whether this cost advantage from the 70% corn silage diet is offset by the fixed costs depends on the magnitude of the fixed costs.

The corn silage:corn price ratios, M, L, and H were selected to represent typical and extreme price ratios. Corn silage prices are closely related to corn prices, but price ratios may be altered by buying feedstuffs at separate times or hedging on the futures market. Although individual situations may justify feeding more corn silage, at the present price ratios the traditional high concentrate rations are still the most economical.

Physical Limitation of Intake

As energy density of a diet decreases a point is reached where intake is restricted by physical limits (Baumgardt, 1965a,b). The discontinuity of the PWT and RWT models over rations 1 and 2 indicate other factors, possibly physical limitation of the rumen, are effecting DM intake that are not influencing the other rations. As energy intake/day increases above maintenance a greater percentage of total energy intake/day will be used for production and thus efficiency of ME utilization improves. The poorer conversion of ME to gain on rations 1 and 2 (Fig. 13) gives even more support that intake on these rations is limited by physical capacity.

Efficiency End Point

Table 8 shows the carcass data of the steers killed at the NE_p efficiency end point of 7.0 Mcal/Kg gain. Steers 1, 2, 4

Table 8. Carcass Composition of Steers Killed at the NE_p Efficiency Point of 7.0 Mcal/kg Gain.

Ration	Steer	Days	Quality Grade	Yield Grade	Fat Thickness	REA	KK	Carcass Weight	% Water	% Fat	% Protein
1	1[a]	322	C^+	3.55	.7	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	C^o	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
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	14.06

Table 8. Continued.

Ration	Steer	Days	Quality Grade	Yield Grade	Fat Thickness	REA	KK	Carcass Weight	% Water	% Fat	% Protein
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	C^o	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	C^o	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.

and 20 did not reach this end point but were killed after 322 days. Although the end point was consistent in most cases in predicting when steers reached the choice grade there was a wide variation in carcass composition and yield grades.

The poor ability of the NE_p efficiency end point to predict composition may be due to assumptions made in using the California Net Energy System. NE_m is calculated only as a function of body weight with no regard to environmental influences. Maintenance may also be effected by body composition. Baldwin and Smith (1974) showed that not all body tissues have the same energy expenditure at basal metabolism on a metabolic size basis. Baldwin et al. (1976) modeled the adipose tissue metabolism of a lactating dairy cow in energy balance with 10% body fat. After accounting for all inputs and outputs 34.5 moles of ATP were left, which accounts for only 5.5% of total maintenance requirement or 3.0% of the cow's total heat production. If it is true that adipose tissue has a lower maintenance requirement than other body tissues then body composition does effect maintenance requirements and a fatter animal will have a lower requirement on a metabolic weight basis.

Other errors may result from assuming actual ration energy values from book values. Particularly with forages there can be a wide variation in quality. Interactional influences of one feedstuff upon another when fed in combination may change energy values of the ration too (Vance, 1972 and Kroman, 1973).

Measuring the NE_p efficiency does not appear to be a good method of determining physiological maturity at the present.

When NE_m requirements can be more closely predicted, then NE_p can be also and NE_p efficiency will be a more valuable measurement.

SUMMARY

Mathematical models were developed to adequately describe growth and dry matter (DM) consumption of feedlot steers fed various ratios of corn silage:corn. These models and their first derivatives allow gain, rate of gain, total DM intake, rate of DM intake and feed efficiency to be evaluated continuously over time.

Rations with 20% or less roughage had the best rates of gain and feed efficiency. Rates of gain decreased as corn silage was added above the 20% level and also with increasing time on feed. DM intake was greatest for rations with 30-40% corn silage. DM/gain increased two to three fold over all rations during the 320 day modeled period. Also DM/gain increased with increasing proportion of corn silage.

Behavior of the rate of gain and rate of DM intake models indicate physical capacity may limit consumption of rations containing more than 80% corn silage. A model of metabolizable energy utilization shows energy is used more efficiently when the ration is predominately either corn or corn silage (except when physical capacity limits intake). Poorer energy utilization of corn silage:corn combinations is evidence of associative effects between the two feedstuffs.

Using an NE_p efficiency end point to determine equivalent body compositions did not prove accurate, probably because of inaccuracies in predicting maintenance requirements.

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APPENDICES 1 AND 2

Appendix I Table 1. Value of $A(1 - Be^{-kt})$ All animals pooled.

A	B	k*	Residual Sum of Squares	df
771.5841	.620936	.020942	634,932.6462	589

*time expressed in weeks

Appendix I Table 2. Value of $A(1 - Be^{-kt})$ Fitted by Ration

Ration	A	B	k*	Residual Sum of Squares	df
1	2,455.2726	.879596	.002755	9,402.1166	94
2	1,680.4103	.836859	.005081	13,155.9344	65
3	571.3936	.494570	.041913	1,581.3171	43
4	1,021.5159	.725866	.011918	7,825.7749	82
5	521.2670	.421284	.073710	37,107.3356	43
6	1,006.6764	.711060	.016239	11,909.7595	35
7	611.6525	.526942	.045439	4,375.7472	39
8	866.8517	.672038	.022534	2,592.7529	68
9	718.7646	.612608	.028354	2,839.9692	34
10	949.7501	.684527	.016757	20,389.9268	86
	Total			111,180.6342	589

*time expressed in weeks

Appendix I Table 3. Value of $A(1 - Be^{-kt})$ Fitted by Animal

Animal	A	B	k*	Residual Sum of Squares	df
1	2,156.74127	.856622	.002939	2,932.2903	47
2	2,769.82795	.898181	.002601	1,673.0561	47
3	543.03723	.483594	.038277	160.9452	18
4	1,530.16960	.833175	.006166	4,018.7839	47
5	493.43015	.404361	.063795	277.6226	18
6	567.01161	.505509	.044983	601.6632	25
7	1,005.62436	.722493	.012759	2,122.5499	47
8	613.17359	.557936	.032610	290.2250	35
9	731.01874	.538129	.032293	139.2927	18
10	643.35096	.570584	.034713	328.9183	25
11	941.24222	.676969	.019384	225.6140	18
12	592.02743	.536418	.040571	343.1469	17
13	654.31721	.548785	.041713	284.9552	18
14	728.7859	.606943	.028319	452.4233	21
15	613.44926	.546906	.046292	330.6414	21
16	842.32564	.661539	.024142	1,289.8903	47
17	776.18441	.625324	.023444	421.9906	17
18	681.34131	.609506	.032752	614.3457	17
19	807.54832	.612635	.023993	1,905.4836	39
20	1,203.19930	.762810	.011125	1,727.3786	47
	Total			20,141.2168	589

*time expressed in weeks

Appendix I Table 4. Value of model $PWT = 983.47 (1-.671e^{-t^*(-.00508986 + .0021084(ME) + .00001768(DM))})$ fitted by ration.

Ration	ME Mcal/kg	DM kg/day	Residual Sum of Squares	df
1	2.5420	7.70	14,763.8275	94
2	2.6151	8.30	30,789.4119	65
3	2.6882	8.87	4,951.6935	43
4	2.7613	8.87	24,940.7080	82
5	2.8344	8.87	63,637.2951	43
6	2.9075	8.87	14,332.4500	35
7	2.9806	8.87	7,517.2009	39
8	3.0537	8.87	5,030.0993	68
9	3.1268	7.70	7,515.8935	34
10	3.1999	6.90	21,328.2872	86
	Total		194,806.8670	589

*time expressed in days

Appendix I Table 5. Value of DM = $\beta_1 t^1 \beta_2 t^2$ all animals pooled.*

β_1	β_2	Residual Sum of Squares	df
7.9791	-0.00057996	6,465,918.2575	589

*Time expressed days.

Appendix I Table 6. Value of DM = $\beta_1 t + \beta_2 t^2$ Fitted by Ration*

Ration	β_1	β_2	Residual Sum of Squares	df
1	7.0299	0.00277432	205,848.0905	94
2	7.2128	0.00232839	63,988.7791	65
3	8.5533	0.00175573	2,811.6796	43
4	7.6937	0.00248642	25,777.7481	82
5	9.5756	-0.00530523	60,705.3600	43
6	7.7016	0.01080618	85,295.9219	35
7	8.5245	0.00279629	21,785.4292	39
8	9.1308	-0.00194755	21,497.8535	68
9	6.2062	0.01086743	6,874.4984	34
10	6.7044	0.00043084	164,907.8578	86
	Total		659,493.1687	589

*time expressed in days

Appendix I Table 7. Value of DM = $\beta_1 t + \beta_2 t^2$ Fitted by Animal.

Animal	β_1	β_2	Residual Sum of Squares	df
1	7.1216	0.00145049	4,432.8896	47
2	6.9381	0.00409815	2,758.0499	47
3	6.8578	0.01364059	160.0145	18
4	6.8562	0.00364008	3,323.7682	47
5	8.2429	0.00622067	155.8618	18
6	8.4678	0.00213961	461.8207	25
7	7.8758	0.00195455	4,143.9798	47
8	7.8059	0.00115930	1,725.9222	35
9	8.8760	0.00889281	561.3394	18
10	8.7483	-0.00058123	892.1059	25
11	8.4741	0.00955228	298.2944	18
12	7.4893	0.00419535	424.4496	17
13	8.0718	0.01135865	244.1154	18
14	8.2769	0.00317120	2,181.2444	21
15	7.9143	0.00910669	1,441.8600	21
16	9.1977	-0.00221195	6,272.7100	47
17	6.3648	0.01098252	1,344.2380	17
18	6.0475	0.01075234	1,359.5995	17
19	6.8984	0.0009621	13,674.2266	39
20	6.1419	0.00203423	1,059.2115	47
	Total		46,915.7010	589

*time expressed in days

Appendix I Table 8. Value of Model $DM = (738.8768 - 823.89183979(ME) + 307.1124619(ME^2) - 37.86315756(ME^3))t + (.17035293 - .11670502(ME) + .01993668(ME^2))t^2$ Fitted by Ration*

Ration	ME	Residual Sum of Squares	df
1	2.5420	206,843.3475	94
2	2.6151	71,195.7219	65
3	2.6882	211,254.0950	43
4	2.7613	112,492.4558	82
5	2.8344	89,241.1720	43
6	2.9075	107,909.3244	35
7	2.9806	26,632.6109	39
8	3.0537	65,497.7483	68
9	3.1268	92,523.5713	34
10	3.1999	168,858.0918	86
	Total	1,152,448.1390	589

*time expressed in days

Appendix II Table 1. Observed Weekly Steer Weights and Dry Matter Consumption.

RATION NO	ANIMAL NO	WEEK	WEIGHT (KG)	ACCUMULATIVE DM INTAKE(KG)
1	1	0	296	0
1	1	1	306	46
1	1	2	319	98
1	1	3	326	155
1	1	4	336	204
1	1	5	343	253
1	1	6	348	301
1	1	7	356	353
1	1	8	361	404
1	1	9	359	452
1	1	10	368	505
1	1	11	369	555
1	1	12	372	596
1	1	13	379	643
1	1	14	380	702
1	1	15	386	752
1	1	16	390	807
1	1	17	396	856
1	1	18	407	914
1	1	19	416	963
1	1	20	413	1018
1	1	21	422	1076
1	1	22	427	1134
1	1	23	428	1190
1	1	24	434	1247
1	1	25	433	1300
1	1	26	436	1346
1	1	27	441	1394
1	1	28	454	1453
1	1	29	459	1507
1	1	30	458	1563
1	1	31	467	1617
1	1	32	475	1673
1	1	33	482	1721
1	1	34	480	1780
1	1	35	489	1840
1	1	36	497	1899
1	1	37	502	1963
1	1	38	506	2016
1	1	39	547	2069
1	1	40	519	2121
1	1	41	520	2174
1	1	42	524	2217
1	1	43	530	2258
1	1	44	512	2315
1	1	45	537	2370
1	1	46	542	2421
1	2	0	270	0
1	2	1	274	46
1	2	2	301	99
1	2	3	306	152
1	2	4	310	207
1	2	5	316	255
1	2	6	320	303
1	2	7	335	356
1	2	8	338	409
1	2	9	349	462

1	2	10	353	510
1	2	11	355	560
1	2	12	361	609
1	2	13	366	658
1	2	14	375	717
1	2	15	375	771
1	2	16	377	832
1	2	17	383	885
1	2	18	391	932
1	2	19	404	985
1	2	20	398	1041
1	2	21	413	1104
1	2	22	419	1165
1	2	23	432	1224
1	2	24	439	1283
1	2	25	442	1350
1	2	26	446	1400
1	2	27	449	1453
1	2	28	456	1512
1	2	29	458	1572
1	2	30	466	1631
1	2	31	472	1687
1	2	32	477	1750
1	2	33	484	1817
1	2	34	487	1881
1	2	35	490	1954
1	2	36	507	2018
1	2	37	515	2088
1	2	38	519	2149
1	2	39	529	2211
1	2	40	535	2277
1	2	41	534	2338
1	2	42	544	2394
1	2	43	553	2456
1	2	44	533	2524
1	2	45	559	2574
1	2	46	565	2648
2	3	0	278	0
2	3	1	290	46
2	3	2	305	100
2	3	3	310	150
2	3	4	317	205
2	3	5	327	259
2	3	6	328	312
2	3	7	342	369
2	3	8	350	428
2	3	9	356	486
2	3	10	365	546
2	3	11	376	611
2	3	12	377	671
2	3	13	383	727
2	3	14	384	803
2	3	15	400	872
2	3	16	400	945
2	3	17	406	1008
2	4	0	249	0
2	4	1	261	43
2	4	2	272	89
2	4	3	284	141
2	4	4	288	194

2	4	5	302	241
2	4	6	303	290
2	4	7	313	341
2	4	8	318	397
2	4	9	323	449
2	4	10	336	501
2	4	11	342	555
2	4	12	346	605
2	4	13	359	645
2	4	14	357	695
2	4	15	362	753
2	4	16	369	816
2	4	17	372	870
2	4	18	386	919
2	4	19	386	969
2	4	20	401	1021
2	4	21	406	1081
2	4	22	415	1140
2	4	23	424	1198
2	4	24	436	1258
2	4	25	436	1316
2	4	26	444	1365
2	4	27	451	1424
2	4	28	463	1483
2	4	29	463	1541
2	4	30	470	1600
2	4	31	481	1655
2	4	32	485	1720
2	4	33	464	1780
2	4	34	497	1839
2	4	35	503	1903
2	4	36	514	1968
2	4	37	529	2032
2	4	38	529	2092
2	4	39	538	2152
2	4	40	545	2222
2	4	41	552	2284
2	4	42	558	2340
2	4	43	566	2396
2	4	44	564	2448
2	4	45	544	2502
2	4	46	535	2553
3	5	0	293	0
3	5	1	308	53
3	5	2	316	114
3	5	3	329	171
3	5	4	338	231
3	5	5	352	293
3	5	6	357	357
3	5	7	365	420
3	5	8	371	482
3	5	9	382	547
3	5	10	387	611
3	5	11	394	675
3	5	12	396	738
3	5	13	415	801
3	5	14	406	864
3	5	15	427	936
3	5	16	419	1003
3	5	17	422	1065

3	6	0	276	0
3	6	1	293	53
3	6	2	302	118
3	6	3	319	167
3	6	4	322	231
3	6	5	353	297
3	6	6	346	363
3	6	7	354	424
3	6	8	363	485
3	6	9	376	548
3	6	10	384	609
3	6	11	395	666
3	6	12	394	725
3	6	13	406	784
3	6	14	413	847
3	6	15	416	911
3	6	16	429	979
3	6	17	433	1042
3	6	18	437	1101
3	6	19	450	1161
3	6	20	455	1223
3	6	21	466	1292
3	6	22	462	1357
3	6	23	456	1419
3	6	24	468	1483
4	7	0	264	0
4	7	1	278	46
4	7	2	298	98
4	7	3	308	155
4	7	4	316	202
4	7	5	326	259
4	7	6	336	315
4	7	7	346	377
4	7	8	346	435
4	7	9	366	494
4	7	10	373	553
4	7	11	377	608
4	7	12	389	662
4	7	13	396	719
4	7	14	409	783
4	7	15	412	847
4	7	16	418	910
4	7	17	422	969
4	7	18	432	1028
4	7	19	440	1083
4	7	20	443	1143
4	7	21	452	1209
4	7	22	459	1272
4	7	23	464	1330
4	7	24	461	1388
4	7	25	480	1452
4	7	26	478	1506
4	7	27	487	1561
4	7	28	493	1618
4	7	29	496	1680
4	7	30	501	1742
4	7	31	516	1801
4	7	32	523	1864
4	7	33	500	1924
4	7	34	529	1981

4	7	35	538	2042
4	7	36	543	2108
4	7	37	557	2175
4	7	38	561	2238
4	7	39	566	2301
4	7	40	575	2366
4	7	41	579	2430
4	7	42	586	2489
4	7	43	595	2547
4	7	44	597	2609
4	7	45	578	2663
4	7	46	585	2718
4	8	0	273	0
4	8	1	279	51
4	8	2	291	101
4	8	3	306	157
4	8	4	314	207
4	8	5	323	262
4	8	6	330	318
4	8	7	343	375
4	8	8	347	434
4	8	9	356	491
4	8	10	368	553
4	8	11	376	611
4	8	12	381	665
4	8	13	394	714
4	8	14	393	780
4	8	15	407	835
4	8	16	409	894
4	8	17	414	949
4	8	18	423	1003
4	8	19	431	1057
4	8	20	432	1112
4	8	21	438	1170
4	8	22	445	1227
4	8	23	453	1291
4	8	24	455	1356
4	8	25	465	1417
4	8	26	465	1468
4	8	27	474	1524
4	8	28	480	1577
4	8	29	477	1635
4	8	30	487	1690
4	8	31	494	1740
4	8	32	497	1802
4	8	33	490	1855
4	8	34	497	1918
5	9	0	333	0
5	9	1	352	63
5	9	2	366	132
5	9	3	375	196
5	9	4	387	258
5	9	5	399	327
5	9	6	406	396
5	9	7	416	464
5	9	8	425	525
5	9	9	434	592
5	9	10	448	659
5	9	11	453	730
5	9	12	461	797

5	9	13	477	875
5	9	14	480	952
5	9	15	492	1034
5	9	16	498	1113
5	9	17	501	1187
5	10	0	276	0
5	10	1	291	61
5	10	2	302	119
5	10	3	313	177
5	10	4	325	233
5	10	5	337	296
5	10	6	346	360
5	10	7	354	423
5	10	8	358	486
5	10	9	372	548
5	10	10	386	611
5	10	11	390	672
5	10	12	401	733
5	10	13	409	787
5	10	14	418	850
5	10	15	428	913
5	10	16	426	981
5	10	17	443	1042
5	10	18	452	1102
5	10	19	462	1159
5	10	20	463	1216
5	10	21	470	1277
5	10	22	471	1336
5	10	23	471	1385
5	10	24	480	1441
6	11	0	306	0
6	11	1	316	62
6	11	2	330	124
6	11	3	343	186
6	11	4	344	247
6	11	5	364	309
6	11	6	376	377
6	11	7	384	444
6	11	8	392	505
6	11	9	405	571
6	11	10	417	638
6	11	11	426	707
6	11	12	437	777
6	11	13	452	842
6	11	14	459	916
6	11	15	470	993
6	11	16	469	1075
6	11	17	478	1151
6	12	0	278	0
6	12	1	282	48
6	12	2	303	105
6	12	3	315	158
6	12	4	317	206
6	12	5	327	263
6	12	6	345	319
6	12	7	355	376
6	12	8	359	432
6	12	9	367	494
6	12	10	386	552
6	12	11	390	611

6	12	12	403	662
6	12	13	412	714
6	12	14	405	764
6	12	15	416	830
6	12	16	426	895
7	13	0	297	0
7	13	1	307	57
7	13	2	326	118
7	13	3	340	177
7	13	4	350	232
7	13	5	359	294
7	13	6	374	358
7	13	7	385	422
7	13	8	395	485
7	13	9	404	548
7	13	10	427	620
7	13	11	426	692
7	13	12	435	764
7	13	13	451	826
7	13	14	456	904
7	13	15	461	979
7	13	16	476	1048
7	13	17	478	1113
7	14	0	281	0
7	14	1	299	60
7	14	2	313	120
7	14	3	326	186
7	14	4	335	248
7	14	5	352	316
7	14	6	360	370
7	14	7	366	421
7	14	8	363	469
7	14	9	386	532
7	14	10	392	589
7	14	11	401	652
7	14	12	415	713
7	14	13	427	761
7	14	14	426	825
7	14	15	443	893
7	14	16	455	965
7	14	17	454	1034
7	14	18	466	1103
7	14	19	471	1162
7	14	20	474	1229
8	15	0	271	0
8	15	1	298	48
8	15	2	308	97
8	15	3	328	154
8	15	4	340	216
8	15	5	344	282
8	15	6	357	342
8	15	7	367	405
8	15	8	378	470
8	15	9	387	536
8	15	10	404	602
8	15	11	414	667
8	15	12	424	735
8	15	13	434	803
8	15	14	435	871
8	15	15	446	936

8	15	16	459	1009
8	15	17	456	1077
8	15	18	470	1144
8	15	19	471	1207
8	15	20	482	1270
8	16	0	268	0
8	16	1	300	53
8	16	2	309	102
8	16	3	326	166
8	16	4	338	226
8	16	5	356	295
8	16	6	368	365
8	16	7	376	433
8	16	8	385	503
8	16	9	397	567
8	16	10	403	631
8	16	11	414	698
8	16	12	428	757
8	16	13	441	817
8	16	14	448	886
8	16	15	453	949
8	16	16	457	1010
8	16	17	472	1068
8	16	18	479	1122
8	16	19	491	1179
8	16	20	496	1243
8	16	21	507	1307
8	16	22	516	1370
8	16	23	518	1429
8	16	24	537	1491
8	16	25	537	1550
8	16	26	541	1610
8	16	27	552	1671
8	16	28	556	1727
8	16	29	568	1788
8	16	30	566	1849
8	16	31	573	1895
8	16	32	592	1949
8	16	33	595	2001
8	16	34	583	2064
8	16	35	607	2095
8	16	36	599	2152
8	16	37	616	2221
8	16	38	619	2284
8	16	39	622	2341
8	16	40	628	2399
8	16	41	641	2462
8	16	42	646	2517
8	16	43	652	2572
8	16	44	653	2629
8	16	45	658	2679
8	16	46	655	2736
9	17	0	299	0
9	17	1	304	40
9	17	2	308	81
9	17	3	313	121
9	17	4	334	175
9	17	5	344	226
9	17	6	359	281
9	17	7	362	339

9	17	8	367	394
9	17	9	391	451
9	17	10	396	508
9	17	11	405	565
9	17	12	413	622
9	17	13	421	677
9	17	14	422	731
9	17	15	433	783
9	17	16	441	836
9	18	0	276	0
9	18	1	279	37
9	18	2	286	78
9	18	3	302	117
9	18	4	306	161
9	18	5	327	213
9	18	6	345	268
9	18	7	354	323
9	18	8	359	380
9	18	9	373	438
9	18	10	388	483
9	18	11	396	539
9	18	12	408	588
9	18	13	414	644
9	18	14	406	697
9	18	15	427	747
9	18	16	435	801
10	19	0	309	0
10	19	1	325	44
10	19	2	342	90
10	19	3	353	133
10	19	4	367	175
10	19	5	377	222
10	19	6	384	269
10	19	7	366	304
10	19	8	385	351
10	19	9	401	400
10	19	10	416	452
10	19	11	428	509
10	19	12	442	570
10	19	13	455	626
10	19	14	452	681
10	19	15	466	735
10	19	16	475	790
10	19	17	476	842
10	19	18	482	897
10	19	19	490	954
10	19	20	497	999
10	19	21	512	1048
10	19	22	518	1100
10	19	23	530	1155
10	19	24	536	1212
10	19	25	535	1260
10	19	26	542	1309
10	19	27	542	1354
10	19	28	558	1405
10	19	29	566	1451
10	19	30	570	1499
10	19	31	583	1547
10	19	32	582	1595
10	19	33	578	1633

10	19	34	577	1681
10	19	35	587	1728
10	19	36	597	1781
10	19	37	600	1837
10	19	38	615	1894
10	20	0	281	0
10	20	1	297	40
10	20	2	315	83
10	20	3	317	123
10	20	4	327	170
10	20	5	336	221
10	20	6	335	263
10	20	7	344	294
10	20	8	358	341
10	20	9	370	390
10	20	10	377	437
10	20	11	396	487
10	20	12	407	529
10	20	13	410	570
10	20	14	421	613
10	20	15	429	660
10	20	16	444	709
10	20	17	443	758
10	20	18	455	803
10	20	19	464	850
10	20	20	472	900
10	20	21	478	949
10	20	22	488	994
10	20	23	486	1041
10	20	24	496	1091
10	20	25	508	1141
10	20	26	514	1189
10	20	27	523	1239
10	20	28	529	1288
10	20	29	536	1337
10	20	30	546	1387
10	20	31	564	1431
10	20	32	572	1481
10	20	33	555	1530
10	20	34	567	1580
10	20	35	578	1629
10	20	36	580	1679
10	20	37	587	1729
10	20	38	604	1779
10	20	39	604	1829
10	20	40	612	1878
10	20	41	628	1925
10	20	42	634	1982
10	20	43	650	2036
10	20	44	646	2090
10	20	45	641	2128
10	20	46	648	2176

USING MATHMATICAL MODELS TO EVALUATE FEEDLOT PERFORMANCE OF BEEF CATTLE FED DIFFERING CORN SILAGE:CORN RATIOS

by

ALLAN BRUCE CHESTNUT

B.S., Kansas State University, 1975

AN ABSTRACT OF A MASTER'S THESIS

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Mathmatical models of weight (PWT) and accumulative dry matter intake (PDM) as functions of two independent variables, time and energy concentration of the ration, were developed for Hereford steers. Twenty Hereford steers averaging 283.1 Kg were alloted to ten rations varing in their corn silage:corn ratios from 1:0 to 0:1. Steers were individually fed _ad libitum_ and weekly weights and dry matter (DM) intakes recorded. In an attempt to kill all animals at the same physiological maturity each steer was slaughtered when his NE_p efficiency reached 7.0 Mcal/Kg gain.

A nonlinear equation was used to describe PWT and a polynomial equation for PDM. Significance levels for PWT ($P>.396$) and PDM ($p>.324$) were determined by analysis of variance in which mean squares attributed to incorporation of metabolizable energy into the equation was compared to mean squares due to animal within ration effect.

First derivatives of PWT and PDM equations provide rate of gain (RWT) and rate of dry matter intake (RDM) equations respectively. The quotient of RWT and RDM gives instantaneous feed efficiency (PFE). Values for PWT, RWT, PDM, RDM and PFE are given in Eq. 1-5. These models can be easily applied to minimize cost of gain with changing economic conditions.

(eq. 1) Predicted Weight (PWT) $= A(1-Be^{-kt})$

(eq. 2) Predicted Rate of Gain (RWT) $= AB(-k)e^{-kt}$

A = Mature Weight = 883.47 kg

B = Intergration constant = .671

e = Base of the natural log

k = Relative rate of growth

$= -.00508986 + .0021084(ME) + .0001768\ (DM)$

ME = Metabolizable energy Mcal/kg

DM = Kg dry matter intake/day

t = time in days

(eq. 3) Predicted Accumulative Dry Matter Intake (PDM) = $B_1t + B_2t^2$

(eq. 4) Predicted Rate of Dry Matter Intake/Day (RDM) = $B_1 + 2B_2t$

$$B_1 = 738.8768 - 823.89183979(ME) + 307.1124619(ME)^2 - 37.86315756(ME)^3$$

$$B_2 = .17035293 - .11670502(ME) + .01993668(ME)^2$$

ME = Metabolizable energy Mcal/kg

t = time in days

(eq. 5) Predicted Feed Efficiency (PFE) = $\dfrac{B_1 + 2B_2t}{AB(-k)e^{-kt}}$

Rations with 20% or less roughage had the best rates of gain and feed efficiency. Rates of gain decreased as corn silage was added above the 20% level and also with increasing time on feed. DM intake was greatest for rations with 30-40% corn silage. DM/gain increased two to three fold over all rations during the 320 day modeled period. Also DM/gain increased with increasing proportion of corn silage.

Behavior of the rate of gain and rate of DM intake models indicate physical capacity may limit consumption of rations containing more than 80% corn silage. A model of metabolizable energy utilization shows energy is used more efficiently when the ration is predominately either corn or corn silage (except when physical capacity limits intake). Poorer energy utilization of corn silage:corn combinations is evidence of associative effects between the two feedstuffs.

Three demensional perspective graphs were plotted for PWT, RWT, PDM, RDM and PFE using the Surface II Graphics program on a 370 IBM and line plotter.