DEVELOPMENT OF EQUATIONS TO PREDICT DRY MATTER INTAKE OF DAIRY HEIFERS

by

J. D. Quigley, III

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APPROVED:

R. E. James, Chairman

M. L. McGilliard

D. M. Kohl

C. C. Stallings

C. E. Polan

J. M. White

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Committee Chairman: R. E. James

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(ABSTRACT)

Equations to predict daily dry matter intake (DMI) of individual animals were developed with 118 Holstein heifers fed totally mixed rations (TMR). Animals grouped according to body weight (136, 227, 317 kg) were fed TMR (corn silage, ground hay, high moisture corn, soybean meal) once daily for 28 days. Rations were balanced to mean body weight according to National Research Council (NRC) recommendations for protein, vitamins and minerals, and to 85, 95, 105, and 115% of recommendation for energy. Independent variables were body weight (BWT, kg/day) daily body weight gain (GAIN, kg), environmental temperature (AMBT, ^{o}C), ration acid detergent fiber (ADF, percent of dry matter), neutral detergent fiber (NDF, percent of dry matter), net energy for maintenance and gain (NEM, NEG, megacalories), total digestible nutrients (TDN, percent of dry matter), and bulk density (BULK, g/ml as fed). Squared terms, appropriate interaction terms, and metabolic body weight (MBWT, $kg^{.75}$) were included in the model. Stepwise regression was utilized to generate two

models, simplified and expanded. Simplified model was: DMI (kg/day) = -29.86 + (-.54E-05 * BWT^2) + (.157 * MBWT) + (2.090 * GAIN) + (-.118 * $GAIN^2$) + (.730 * TDN) + (-.005 * TDN^2) + (-.001 * BWT * GAIN) + (-.019 * TDN * GAIN); n = 4797, r^2 = .59, $s_{y.x}$ = 1.18. Expanded model was: DMI (kg/day) = -1906.91 + (-0.04 * BWT) + (0.37 * MBWT) + (32.36 * ADF) + (2305.51 * NEM) + (-664.06 * NEG) + (-0.08 * AMBT) + (-0.13 * ADFSQ) + (-637.68 * NEMSQ) + (42.31 * NEGSQ) + (-5.35 * BULKSQ) + (0.001 * AMBTSQ) + (-1.56E-04 * BWT * ADF) + (8.873E-05 * BWT * AMBT) + (246.30 * NEM * NEG) + (-21.30 * NEM * ADF) + (7.83 * NEG * ADF) + (0.04 * NEG * AMBT) + (0.01 * GAIN * ADF) + (-0.01 * GAIN * AMBT); n = 4429, r^2 = .65, $s_{y.x}$ = 1.09. Predicted intakes by simplified equation agree with those of NRC at TDN recommended by NRC and .7 kg/day. Computerized ration formulation systems were developed using simplified model. Expanded model requires further refinement prior to incorporation into a ration formulation system.

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INTRODUCTION

The development and application of computer technology has changed fundamentally methods of feeding dairy cattle. Today, computers have been programmed to feed high producing cows in various ways: 1) identifying individual animals and metering grain at a predetermined rate to meet nutrient needs, 2) calculating nutrient requirements for energy, protein, minerals, and additives, based on body weights, condition, performance, and age, and 3) formulating rations based on nutrient requirements, predicted intake, and nutrient content of available feeds. Future applications of computer technology will be limited only by software development.

Successful applications of computerized feeding of dairy cattle are well documented. Continued improvements in computer applications directed toward all aspects of dairy nutrition are dependent upon incorporation of accurate data from which realistic estimates of nutrient requirements, nutrient content of feeds, and their interactions can be made. Present estimates of nutrient requirements are the most accurate available, but in many cases are based on research conducted with only small numbers of animals under less than ideal conditions. Similarly, nutrient content of feeds used in ration formulation are often based on published data, not on accurate chemical analyses. Consequently, ration formulations are only estimates of actual rations required by the animal for its productive function. Continued improvement of assumptions underlying ration formulation will further improve the economic return of dairy farmers using these systems. An assumption critical to precision of ration formulation is intake of dry matter. Intake of feed dry matter sets the input of all other nutrients, and therefore, determines animal response and function. Considerable research has been conducted to improve the accuracy of dry matter intake equations for lactating cows by identifying factors not elucidated previously. Formulation of rations for dairy heifers are based on equations that predict intake of dry matter for animals of various body weights. These equations, developed from research conducted between 1943 and 1964, are likely obsolete due to improvements in genetics, management, and systems of feeding. Objectives of this study are to determine factors that significantly affect intake of dry matter of growing dairy heifers, and to develop equations to predict intake of dry matter of growing dairy heifers from 100 to 400 kg.

REVIEW OF LITERATURE

A. Nutritional Management of Dairy Heifers

Productive and economical rearing of dairy replacements is important to maintaining a profitable dairy enterprise. Management of dairy replacements should promote rapid growth, early conception, and maximize performance in first and subsequent lactations. Sexual maturity is dependent more on body size than age (175); this suggests plane of nutrition to be most important in determining age at first calving. Physiological and economic effects of manipulating plane of nutrition on age at first calving are of interest.

1. Feeding recommendations for dairy heifers

Increasing proportion of grain in the ration can reduce age at first calving below approximately 20 mo of age. These rations result in overconditioning (175), low conception rates and reproductive disorders (146), decreased milk production (78, 146, 174, 175, 201) and lowered longevity (146). Depressed milk production has been attributed to decreased deposition of mammary tissue and increased deposition of adipose tissue in mammary gland from 3 to 9 mo of age (160). It is also probable that excess condition results in decreased dry matter (DM) intake, (203) thereby reducing milk production. Reductions in productive performance have been shown in studies using identical twins to minimize genetic influences (56, 175).

Feeding rations high in grain results in changes in rumen fermentation including diminished rumination, altered microbial populations, and decreased acetate to propionate ratio (124). Higher propionate ratios have been correlated with increased energy output to fat tissue (52). Thus, energy deposited at higher intakes is composed of a greater proportion of fat and lesser proportion of protein (131). Additionally, it is possible to supply energy in such a form to induce fattening in preference to protein deposition. Protein deficient diets shift deposition from protein to fat (52). Little or no data are available from feeding trials using rations containing higher amounts of protein, vitamins and minerals in addition to energy for growing heifers.

Heifers fed at levels slightly below current recommendations until 2 to 3 mo prepartum, at which time supplemental concentrates are offered, frequently produce more milk than heifers raised on a normal plane of nutrition (175). Thus, it is more desirable to have heifers in lean than in fat condition at midgestation. Compensatory growth can occur during the first lactation and smaller heifers will reach normal size rapidly if properly fed and managed (78). Underfeeding heifers at levels less than 70% of requirement delays first estrus, increases calving difficulties, and reduces milk production during first lactation (78, 175).

It is important to note, however, that feeding high forage diets does not necessarily imply underfeeding. High quality forage may contain sufficient nutrients to promote adequate growth and milk production. Hof and Lenaers (80) fed high and low roughage rations to growing dairy heifers to determine performance during first lactation. Both treatments contained sufficient energy and protein to meet heifers' requirements for growth. No effect of high roughage versus high concentrate was observed in the rearing period, nor during subsequent lactation.

2. Recommended body weights at time of first breeding

Current recommendations for weight of breeding age heifers are 340 to 393 kg for Holstein and Brown Swiss, 280 to 330 kg for Ayrshire and Guernsey, and 250 to 280 kg for Jersey breeds (44). Canadian standards for all breeds (43), and Ragsdale and Beltsville standards for Holstein heifers are similar (78). Recommendations for age at first breeding are 14 to 17 mo of age (43, 61, 89). Studies have reported maximum economic return (75, 78, 123) and longevity (75) in dairy cattle bred to calve at 23 to 25 mo of age. Increasing age at first calving beyond this range has been estimated to increase costs from $10 to $30 /heifer/month (61) to $60 to $70 /heifer/month (6, 77). Body weights at various ages that result in acceptable size at breeding and calving ages for Holstein heifers are presented in Table 1.

Rates of recommended daily gain range from .64 kg to .75 kg (Table 1). Although these growth rates are less than maximum growth rates possible, they are reported to allow early calving and acceptable mature weight (139, 146).

Average age of first calving on Virginia dairy farms is 29 mo (94). This figure has declined by only 1 mo since 1972 (94), and suggests management factors promoting efficient growth of heifers have not been implemented in Virginia. James et al. (91) reported that dairymen cited poor rates of growth resulting in increased age at first calving. Inadequate nutrition and poor growth rates may result from neglect of the heifer-raising operation due to more obvious demands for labor and resources (154).

B. Factors Affecting Intake of DM and Energy in Ruminants

1. Introduction

Fundamental to the concept of a ration formulation system is accurate prediction of DM and energy intake (30, 31). It follows that factors controlling or limiting DM intake should be included in a ration system. Control of feed intake by ruminants is a component of homeostatic regulation of energy balance (18). Energy balance is determined by difference between dietary energy inputs and energy outputs in the form of feces, urine, methane, and heat increment, plus energy expended for maintenance, growth, production,

TABLE 1. Recommended body weights of Holstein heifers at various ages.

Age	Clapp	Clapp	Etgen	Swanson*	James*	NRC*
(mo)	---------------------(kg)-----------------------					
0	44	42	42	45	28	30
1	-	54	52	65	49	49
2	68	73	73	86	70	68
4	127	127	122	127	110	106
6	179	182	177	167	152	144
8	227	235	231	208	193	183
10	306	280	277	249	234	221
12	336	323	318	290	275	259
14	376	366	354	331	316	297
16	399	388	386	372	358	336
18	456	456	413	412	399	374
20	479	488	445	453	440	412
22	485	525	476	494	481	450
24	572	575	513	535	522	489

Regression equations:
Clapp (44) : bwt(kg) = 44.07 + 22.15 * age(mo)
Clapp (43) : bwt(kg) = 42.15 + 22.41 * age(mo)
Etgen (61) : bwt(kg) = 51.12 + 20.15 * age(mo)
James (89) : bwt(kg) = 28.47 + 20.57 * age(mo) r = .9998
NRC (139) : bwt(kg) = 29.57 + 19.13 * age(mo) r = .9999
Swanson (175): bwt(kg) = 45.35 + 20.41 * age(mo) r = 1.0

*Values were obtained by linear regression of actual values at ages other than those listed.

reproduction, and physical activity. Positive energy balance and thereby energy retention can result from increased feed energy input above energy output, decreased energy output, or a combination of the two (18). Domestic ruminants have the ability to control energy balance (9, 11, 12, 18, 106, 133, 134). Until the early 1970's there was doubt that ruminants actually could regulate intake of energy (18). When fed all forage or predominantly forage rations, energy intake appears to be controlled by factors inherent in the forage (12, 18). As rations of higher caloric density are consumed, ruminants adjust intake to balance energy requirements (12, 18) when energy outputs such as body heat flux, exercise, growth, and lactation are changed (12). Mechanisms whereby feed intake is regulated are highly complex and relations among various proposed machanisms are not well defined (93). Maintenance of energy balance is not apparent in some situations. Because nutrient intake is dependent on feeding behavior and associated drives, various factors such as sensory cues can override apparent inhibitors, resulting in excess fat deposition, inefficient production, or emaciation (9, 11). A vast majority of data from ruminants supports the concept of regulation of energy balance (11).

2. Physical and metabolic regulation of intake

Conrad et al. (48) determined digestibility of DM and voluntary DM intake in 114 trials with lactating dairy cows fed rations ranging between 52 and 80% digestibility. They concluded that physical and metabolic factors regulating feed intake change in importance with increasing ration digestibility. Further, they reported that below approximately 67% ration digestibility, digestible DM intake was related to body weight to the one power, whereas above 67% ration digestibility, digestible DM intake was related to body weight to the .73 power. This classic experiment along with those of Montgomery and Baumgardt (133, 134) have formed the basis for the concept of physical and metabolic regulation of feed intake. Montgomery and Baumgardt (133) proposed a general relation to describe physiological and metabolic regulation of feed intake (Figure 1). Below approximately 67% DM digestibility, DM consumption increases with nutritive value (including energy concentration, particle size, rate of passage, etc.) (133). When nutritive value is increased above 67% DM digestiblity (Figure 1) rate of DM intake decreases, and energy intake remains essentially constant (133). The point at which control of feed intake changes from physical to metabolic has been reported to be 56 (133) or 66% (48) DM digestibility, 2.5 kcal DE/g feed (18), or a crude fiber content of approximately 16% of DM (98). Jahn et al. (88) found that at levels above 23% ADF (70% DM digestibility), physical factors limited diges-

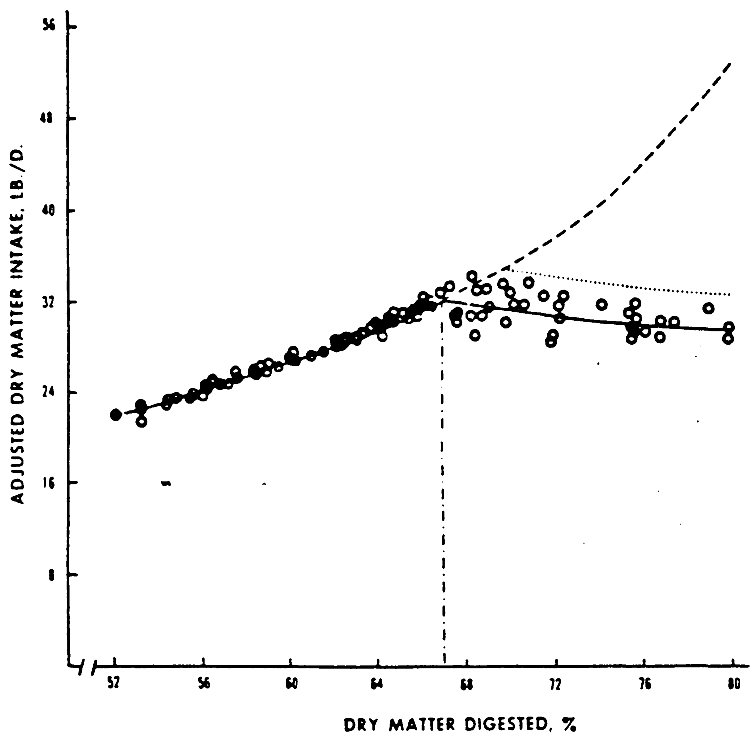

Figure 1. Effect of dry matter digestibility on dry matter intake (lb/day) adjusted for milk production (133).

tible DM intake of calves 8 to 20 wk of age. Intake of DM was greatest at 23% ADF in these animals, then declined with increasing ADF. In lactating dairy cows this point is not reached until ration digestibility is approximately 60 (149) to 66% (48, 93), or approximately 2.95 kcal DE/g (93). Gill and coworkers (74) reported maximal DM intake at 3.0 Mcal ME/kg DM in finishing steers fed diets containing 3.0 to 3.6 Mcal ME/kg DM. Ward and Kelley (197) measured ad libitum consumption of lactating dairy cows fed various roughage to concentrate ratios in total mixed rations. Consumption increased as concentrate in ration DM increased from 0 to 60%. In studies with sheep, adjustment of intake to caloric dilution was not evident (9, 72), and may have been due to physical form of ration.

Physical regulation of DM intake. Evidence that voluntary intake of DM is limited by physical conditions within the gut and amount of digesta in the reticulorumen has been shown by: 1) intraruminal additions or removals of feed and other materials, 2) relationship between rumen fill and voluntary intake, and 3) rate of digesta disappearance and voluntary intake (34).

Addition of recently consumed hay (12, 34, 35), water in bladders (12, 34, 35), or gas filled bladders (12, 34) into the rumen decreased intake of hay in cattle. Stretch receptors in the reticulorumen responding to physical distention have been proposed (12), but have not been identified histologically. Hay removed from the rumen induced cows to eat for much longer periods (34, 35, 169), suggesting physical control of intake. It is assumed that size of animal is critical in determining volume of the abdominal cavity which in turn limits volumetric expansion of the rumen during eating (23), when diets are of low digestibility.

When ruminants are offered feeds such as hay and dried grass, there is evidence that cattle and sheep eat to a constant rumen fill and/or rate of disappearance from the reticulorumen (11, 12, 34). Further, this "critical level" of rumen contents (12) is adaptable under certain conditions according to physiological or nutritional status of the animal (12). Reduction of forage intake in cattle that are obese or are in the last few months of gestation has been attributed to decreased ability for rumen expansion (12). Increased consumption during early lactation has been attributed, in part, to increased size of the reticulorumen after expulsion of the fetus (12, 98). Tulloh and Hughes (cf. 57) showed the rumen to be 32 to 40% larger in lactating animals than when dry.

Limitation of intake through gastrointestinal fill assumes some limit or equilibrium between degree of fill and stretch of gastrointestinal organs and rate at which contents can be disposed of through digestion or passage (191). Greater tolerance to a high bulk diet would be provided by increased rumination or chewing, increased particle size passed, or increased stretch of the organs.

Evidence exists to suggest that ruminants do not eat to a constant rumen fill (34). Campling et al. (36) showed animals consumed more hay than when the same animals were offered oat straw. Similarly, hay was consumed in preference to silage in other experiments (34). It is possible that different degrees of digestibility and rates of passage from the reticulorumen may have confounded these results.

Metabolic regulation of intake. Metabolic regulation associated with control of intake, as well as factors controlling the point at which metabolic factors begin to exert an influence on voluntary DM intake of ruminants has been the subject of considerable research. Some factors that possibly affect metabolic regulation of intake and their modes of action are presented.

Dry matter and energy intakes by mature sheep and dairy heifers appear to increase until ration digestibility reaches 55 to 56% (93, 133) or 2.4 to 2.5 kcal DE/g (18, 93), (Figure 1). After this threshold is reached, intake of DM declines and DE intake remains constant. It is of interest that current recommendations for DE content of rations for growing heifers range from 2.8 to 3.2 kcal/g DM

(139) (Table 2). Addition of high energy substances such as tallow or vegetable oils reduced ME intake even though estimated NE_m and NE_g were increased in the ration by 15 and 30%, respectively (72). Cowsert and Montgomery (52) concluded that decreased feed intake with increasing proportions of corn in rations fed to heifers was due to increased energy concentration rather than decreased crude protein content of experimental rations. Consistent with the theory of energy balance regulation, it seems reasonable that absolute level of energy intake at which metabolic control of intake begins to play a role would vary with physiological demands of the animal (18, 191). The transition point is probably different in lactating cows and growing heifers because of a lower metabolic requirement in the latter (195). Higher energy demand requires a greater rumen fill or a faster rate of passage such that fill becomes limiting at higher densities of dietary energy (191). Baumgardt (18) suggested levels of 200 to 300 and 350 to 500 kcal DE/kg body wt$^{.75}$ for growing and lactating animals, respectively. Variation is to allow for varying degrees of growth, fattening and intensity of lactation. In a synthesis utilizing mathematical relationships, Brokken (28) concluded that animals with a higher genetic potential for gain differ from animals with lower potential in slope and intercept of DM and DE intake curves.

3. Digestibility and rate of passage

The preceeding discussion has assumed that digestibility and intake are related directly. Although they are somewhat interdependent, intake and digestibility are separate parameters of quality (191). Intake appears to be dependent upon structural volume, and, therefore cell wall content, while digestibility is dependent upon both cell wall and its availability to digestion as determined by lignification and other factors (20, 191). Although intake appears to be more important than digestibility in causing differences in digestible DM intake from forages (195), both affect animal performance. Crampton et al. (cf. 195) calculated that intake and digestibility accounted for 70 and 30% of digestible DM intake of both legumes and grasses. Others (4) have also found differences attributable to intake.

Digestibility. Feed DM consumed by the animal travels through the gastrointestinal tract and leaves by digestion and absorption or passage. Rate of disappearance, therefore, is the sum of absorption plus passage (191). Passage and digestion are competitive processes. Comparison of rate of passage to the fractional rate of digestion gives extent of digestion (191), which can in turn give digestibility of a feed or feed component.

Rate of digestion, the quantity of a given feed component digested per unit time, is a function mainly of diet.

Two factors appear to affect rate of digestion: amount of component and its intrinsic properties that determine magnitude of rate constant of digestion (191). Van Soest (190) concluded that soluble portions of plant cells are completely available to digestion and, therefore digestibility of a feed (or feed component) is dependent upon characteristics of the plant cell wall. These observations appear to refute the theory of incrustation whereby lignified walls were thought to entrap protein and other cellular contents (120). In contrast, Rust and Owens (157) reported a depression of organic matter digestibility with increasing feed intake in finishing steers fed rations containing 10 or 50% roughage. Depression of digestibility was attributed to starch and hemicellulose with little effect on ADF digestibility (149), suggesting incrustation of cellular contents. Digestion of cell walls is dependent upon several factors, including chemical composition, plant morphology, crystallinity (121) and amount of lignification (120, 189). The tendency of digestibility of forage cell walls to decrease with increasing age is compensated partially by increasing amounts of cell wall with increasing age (120). Thus, amounts of cell wall digested under some conditions remains essentially constant. Digestible plant cell wall components will be the major fractions subject to digestive escape, since their rates of digestion are in competition with rates of passage.

Rate of passage. Flow of undigested residues through the gastrointestinal tract is rate of passage. Passage is a consequential function of intake because consumption of more feed appears to pressure the flow of undigested residues (191). Passage is affected also by particle size, with the major factor in forages being particle breakdown rate through rumination and microbial action (191). It appears, however, that particle breakdown is influenced more by rumen movements and rumination than by microbial action per se; combined action of both probably exceeds the effectiveness of each alone (137). Also affecting passage is rumination differences among animals (121, 200). It appears that rate of passage is more important than rate of digestion in accounting for intake of animals (191), emphasizing importance of particle size reduction as a means of improving intake.

Intake at low ration digestibility is governed by physical factors (Figure 1), including rumen volume, rate of digestion, and rate of passage from the rumen; which are in turn related to digestibility and particle size (12). If digestiblity is a consequence of extent of cell wall digestion, then a measure of cells walls should relate closely to intake. Content of plant cell walls is estimable from neutral detergent fiber (NDF) of feeds, and appears to be highly correlated with voluntary feed intake (20, 42, 187, 191).

Relationships between forage intake and cell wall content appear to exhibit quadratic effects (120, 191). Depression of intake of forages with low cell wall content result from partial metabolic effects, while rumen fill depresses intake of forages with high cell wall content (191). Maximum intake of forages occurs with cell wall content between 50 and 60% (191). Amount of NDF in rations is proported to measure feed components with the slowest rate of disappearance (both passage and digestion) from the tract (120). Also, NDF is related to rate of particle size reduction that must occur before feed can escape the rumen. Thus, for low quality diets, intake of DM decreases as NDF content of feed increases due to restriction associated with gut fill (104, 120). Krabill et al. (104) suggested that total mixed rations (42.3 and 47.5% NDF) consisting of chopped alfalfa or orchardgrass hay fed to lactating Holstein cows limited intake due to physical effects of the ration. When feeding high quality rations, intake is regulated by metabolic demands of the animal. The primary feed characteristic affecting this relationship is its digestibility (120). Relationship between ration NDF content and intake of high quality diets is opposite that of low quality diets (120). Because NDF is inversely related to digestibility, the relationship between NDF and DM intake over the total range of feed qualities should be curvilinear (120). Experiments by Varga et al. (194, 193) have shown that NDF may be digested at different rates in the rumen, causing varying effects of NDF on voluntary intake. Recent evidence (60) suggests also that fiber components of feeds, including NDF, may be affected by methods of laboratory analysis. Care is required to assure proper determination of feedstuff components.

While digestibility is an important factor affecting intake, it does not measure the space filling, or volume characteristics of a ration. If volume of the rumen limits intake on low quality diets, then measurement of nutritive value of a ration should reflect differences in density of feeds (119).

Baumgardt et al. (20), Bull et al. (33), and Baile and Pfander (14) stated that bulk density of rations was an important component of both physical and metabolic control mechanisms of voluntary intake in ruminants and should be included in any equation to predict feed intake. Baumgardt et al. (20) reported that NDF and bulk density of literature values correlated highly with DM intake (r = -.91 and .93, respectively). Content of NDF is related closely to gut fill and perhaps rate of passage (20), and may be preferable to density in relating digestibility to intake (18). Density coupled with a measure of digestibility may provide a more accurate index of fill-producing characteristics of a ration than either factor separately (19). Baile and Pfander (14) predicted the volume of feed consumption as:

$$V = 73 * D^{-1.20},$$

where: V = volume of feed consumed (ml/bwt$^{.75}$), and D = density (g/ml). Baumgardt (134) combined digestibility and density into a single index called caloric density. Caloric density (expressed as kcal DE/ml) has been proported to be superior to energy concentration or digestibility of rations in predicting DM intake (18, 19, 20, 33). At a given digestibility, processed feeds with higher caloric density (e.g., ground vs. long hay), result in more rapid rate of passage, more rapid rate of digestion, and occupy less space in the digestive tract per unit weight (19, 119). Since rate of passage and digestibility are related to physical form of a diet, ration density may also reflect differences in characteristics of the ration associated with passage (119). It follows that higher density (caloric or bulk) feeds should promote greater intake of digestible energy while physical factors regulate energy intake (Figure 2). At present, bulk and caloric density have limited practical application because techniques have not been standardized and optimum ration densities have not been determined (119).

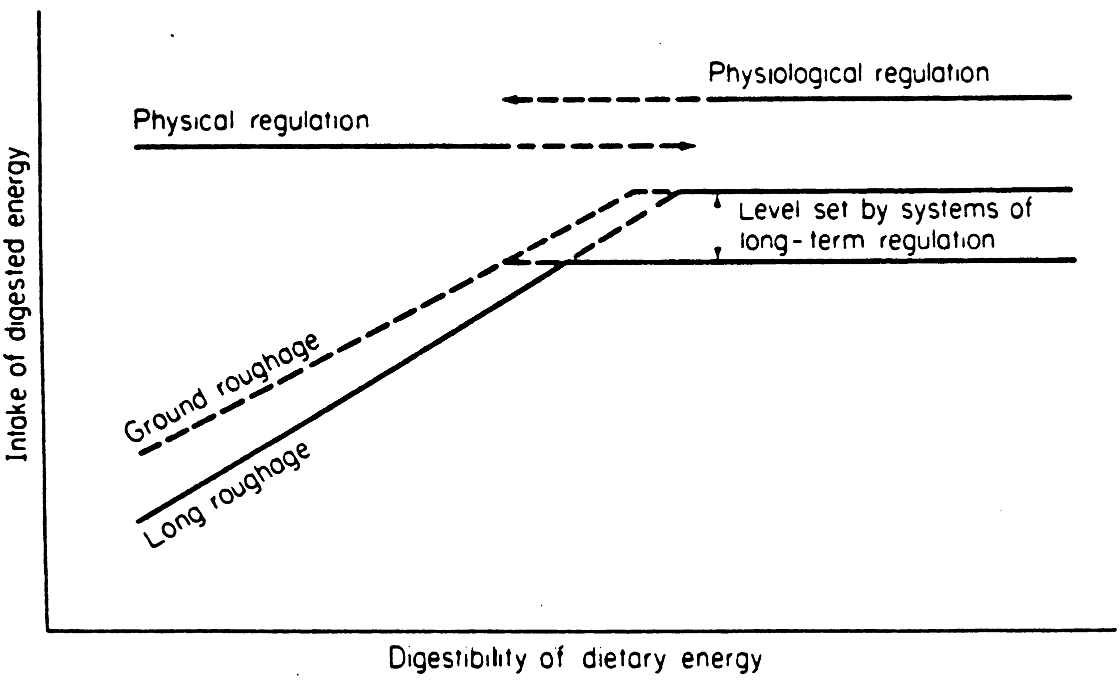

Figure 2. Effect of digestibility of dietary energy, roughage type, and energy balance on intake of digested energy (146).

4. Feed processing

Feed processing may be defined as chemical or mechanical manipulation of feedstuffs prior to feeding. Processing is conducted to facilitate storage and handling of roughages. Effects of three types of processing and inclusion of lower quality feed by-products on voluntary feed intake will be discussed.

Reduction of particle size. Mechanical reduction of feed particle size through grinding, milling, pelleting, cobbing, or other methods are performed often to facilitate handling of the feed. Reduction of forage particle size is associated generally with increased voluntary intake (34, 92, 191), dependent upon digestibility of the forage (23, 34, 92). At low digestibilities and physical regulation of intake (Figure 2), intake of forage is improved considerably by grinding (23, 34, 92, 147), whereas little or no response is observed by grinding good quality forages (23, 34). Reduction in digestibility as a result of processing appears to be offset by increased intake so that intake of digestible energy increases with processing. Pelleted diets containing mixtures of cereals and roughages offered to growing ruminants do not limit voluntary intake solely by physical means (100). Grinding roughage results in a more rapid rate of digestion and increased rate of passage, effecting an increased voluntary intake and decreased digestibility (20, 92, 147, 191). As stated by Baumgardt et al. (20), physical characteristics of the diet, including effects of grinding and pelleting on particle size, must be considered important in prediction of feed intake from diet characteristics.

Van Soest (191) has proposed that effects of grinding and pelleting are in response to collapsing of the cell wall structure as well as reduction of particle size. Therefore, bulky forages of good digestibility (e.g. grass hays) offer greatest improvement in intake upon pelleting (191). Increased intake and decreased digestibility is dependent on the plant cell wall, which is the slowest digesting fraction (191).

Ensiling. Harvesting hay crops as silage has been recommended in areas of the U.S. that face significant weather risk and/or short growing season, and in the incorporation of hay into total mixed ration feeding programs (82). However, most comparisons of haycrop silage vs. cured hay have found voluntary intake of haycrop silage to be less than cured hay (18, 20, 82). Lower DM content (108) and chemical compounds resultant from ensiling have been proposed as factors depressing intake (18, 20, 178). However, effects of lowered DM may be confounded with ensiling effects (108, 195). Thomas et al. (178) suggested that reduction of intake and lower DM of alfalfa silage fed in their study was a relationship secondary to fermentation during ensiling. Chase (39) predicted DM intake would be reduced by .02 kg / 100 kg body weight for each percent increase in dietary water content of a ration. As noted by Demarquilly and Jarrige (58), fresh material of higher moisture content is generally consumed in greater quantities than fermented or dried materials. Buffers added to silage diets (161, 168) have resulted in increased DM intake over unbuffered diets. Shaver et al. (162) fed corn silage to Holstein heifers with sodium bicarbonate added at 0, 2, 4, or 6% of DM to determine effects of pH on silage intake. Corresponding silage pH's were 3.72, 4.46, 5.62, and 8.05. Organic matter intake was increased 1.0 and 1.2 kg/day by addition of 2 and 4% sodium bicarbonate. Intake was reduced by .7 kg at 6% sodium bicarbonate. The researchers concluded that pH affects consumption of silage DM and that pH 5 to 6 is optimum.

Chemical treatments. Many treatments have been developed to improve nutritive value of forages, especially low quality forages such as straw and crop residues. Examples include treatment of roughages with sodium hydroxide, calcium hydroxide, potassium hydroxide, or by ammoniation. All chemical treatments effectively solubilize portions of hemicellulose fractions of plant cell walls and increase rate and extent of cellulose and hemicellulose digestion (25) resulting generally in an increase in digestibility and efficiency of ME utilization (156). Ammoniation of crop residues also improves nitrogen content of residues by providing nonprotein nitrogen (NPN) (25), possibly improving digestibility by modification of physical structure of the plant and providing NPN for rumen microbes.

Effects of chemical treatment on intake and digestibility should be incorporated into feed recommendations as more information becomes available. Present data appear to be insufficient for incorporation into feed tables.

Lower quality feed by-products. Feedstuffs with lower energy and protein content have been used traditionally for dairy animals with lower nutrient requirements such as dry cows and heifers. Unfortunately, low quality feeds and by-products have too often served as a staple for these animals, resulting in nutrient imbalance and reduced performance. Research by Keys and Smith (80, 101, 102, 103) has investigated potential uses of corn stover and poultry excreta as feed sources for dairy heifers. They have shown intakes of high stover diets may limit DE intake and restrict rate of gain due to rumen fill. Stover in diets may need to be limited to 15 to 20% of DM to ensure adequate DM intake.

5. Feed management.

Factors classified as feed management affecting intake of DM include form of ration, feeding frequency, group competition, and palatability.

Feeding frequency. Limitation of food amount reduces time spent eating and increases eating rate in cattle (59). Nocek and Braund (143) found no effects of feeding frequency on DM intake of lactating heifers fed 1, 2, 4, or 8 times per day. It is probable that heifers are not sufficiently stressed nutritionally to result in significant effects of feeding frequency when animals are fed under ad libitum conditions.

Form of ration. The usual or conventional method of feeding dairy animals is to offer animals forage (hay and/or silage) free-choice and concentrate fed individually or amounts added to the forage at certain times of the day. Lactating dairy cows will often receive additional concentrate in the milking parlor. With the advent of free stall housing system and improved milking efficiency, cows are often unable to meet their nutrient requirements by grain consumption during milking alone.

Recent advances in feed management and computer technology have resulted in two divergent systems of feeding designed to be more efficient than conventional feeding systems; total mixed rations (TMR) and individually controlled computerized feeders.

A TMR may be defined as a quantitative mixture of all dietary ingredients, blended sufficiently to prevent separation and sorting, formulated to specific nutrient content and offered ad libitum (51). Advantages of a TMR for lactating cows [as stated by Coppock (51)] include: 1) no expression of choice among feed ingredients is allowed, 2) fewer digestive upsets and wastage of protein on lower lactation cows, 3) better utilization of substances that are degraded rapidly in the rumen, 4) allows for dilution of unpalatable ingredients, 5) changes in individual ingredients can be made without digestive upset, 6) quantitative ration formulation is possible. Disadvantages of a TMR feeding system for lactating cows as stated by Coppock (51) include: 1) hay stored in bales must be ground before incorporation into a ration, 2) mechanical devices for weighing, mixing, and delivery of a TMR are expensive, 3) grouping cows and feeding a TMR implies that higher producing cows in each group will be underfed and lower producers overfed. Comparison of systems of group feeding (165, 202) indicated little or no increase in milk production by feeding in two groups vs. feeding in one group. These studies have been criticized for using too few groups (51, 170) to adequately express advantages of TMR feeding. Owen (148) reported higher daily DM intake when ingredients are fed as a TMR, and concluded that mixing feed ingredients into a TMR does allow a significant nutritional advantage.

As dairymen invest further in equipment to formulate, blend and deliver a TMR, increased interest will be expressed toward using this equipment in heifer feeding systems. Unfortunately, development of TMR feeding systems for growing dairy heifers has lagged behind those of lactating cows due to the lower priority placed on heifer feeding and management (154). Clifton and Fowler (46) fed Holstein and Jersey heifers a complete ration consisting of a grain mixture of ground shelled corn, soybean meal, and vitamins, minerals, and salt with forage consisting of citrus pulp, soy and cottonseed hulls. Holsteins gained .99 kg/day from 2 to 6 mo of age. Other reports (136, 152) indicate successful rearing of heifers using TMR systems. It is possible to control rate of growth with TMR by adding fiber to the formulation to control intake (152).

Control of intake. Restricting intake by addition of fiber to a ration is an effective means for controlling gain of dairy replacements and to avoid overconditioning. Workers have shown that weight gains and DM intake of ruminants fed all concentrate diets are lower than when some roughage is included (99). Addition of roughage (wheat or barley straw, chaff, etc.) to high concentrate rations increases body fill (88, 114, 172), and decreases DM digestibility (88, 112). Swann and Lamming (109, 150, 173) found that substitution of corn by barley straw up to 30% of the ration did not depress live weight gain, but 30% straw did appear to restrict intake of heifers below 380 kg body weight. Lister et al. (112) reported that diets containing 40% ground hay depressed body weight below that of diets containing 0 and 20% hay, but DM intake was increased when rations contained 40% ground hay. When concentrate and forage are offered separately, generally forage intake is decreased as concentrate supplementation is increased (110, 117). Addition of concentrate to high forage rations generally increases live weight gain (110), DM content of digesta (100), and DM intake (110) of heifers.

Group competition. Group competition appears to be most important under conditions where resources (feed) are scarce. Social order of animals begins to exert an influence, and high ranking individuals take precedence over lower ranking individuals (51). Such conditions would be apparent when forages and concentrates are fed separately. Under ad libitum TMR feeding conditions, group competition is less of a factor in determining intake. Coppock et al. (50) determined that lactating cows fed under group feeding conditions consumed 7% more DM than animals fed individually. Increased activity was proposed as most effecting increased consumption.

Effects of amount of feed bunk space available for consumption of a TMR has been investigated (67, 68). Generally, if feed is available ad libitum, there is no need for sufficient bulk space for each cow to eat simultaneously (51). Experiments designed to determine feed bunk space requirements for growing dairy heifers have not been reported. Reports of grouping heifers by age and body size (90) rely on common practical experience and not results of scientific study.

Palatability. Palatability is defined as dietary characteristics which stimulate intake in animals (41). Sensory factors in ruminants have been reported to include gustatory, olfactory and tactile stimuli, but not vision (12, 41). Cattle generally prefer sucrose and molasses tastes, and reject tastes of acetic and other acids (41). Others (137) have concluded that sight is a primary stimulus during grazing. Sensory cues appear to interact with the state of energy balance to cause animals feeding at or near satiety to become more fastidious, and at lower levels of energy balance to become less so (9). Unpalatability as a result of any stimuli can depress intake. However, it should be noted that ruminants exhibit an "acceptance complex" (18) - the ability to become accustomed to a particular stimuli. Ruminants will consume rations containing feces when accustomed to the smell (18). Huber and Kung (86) noted the need to adapt cattle to diets containing urea.

There is a large and consistent variation among cows in their preference for excellent forages (49). Some animals prefer fermented feeds, while others appear to prefer hay. Factors influencing individual preference have not been determined. Spahr (170) has suggested that blending concentrates with forage will decrease appetite variations among individual cows.

6. Environmental Temperature

Nutrient requirements for all classes of farm livestock have been estimated under tightly controlled experimental conditions, including a thermoneutral environment. In areas of the United States where environmental conditions leave the thermoneutral zone, domestic livestock may be stressed sufficiently to cause changes in requirements for nutrients.

Heat balance. Homeotherms maintain a relatively constant core temperature by balancing heat gained from metabolism against that gained from or given up to the environment (heat demand) (140). Heat demand may be defined as the rate of heat flow from an animal to a particular environment (140), and is contingent upon several environmental factors: 1) thermal radiation, 2) humidity, and 3) air movement, all of which embody effective ambient temperature (140). In this context, thermoneutral environments may be considered as the effective ambient temperature within which heat from normal maintenance and production in nonstressful situations offsets heat loss to the environment (140). Ranges of thermoneutral environments under various management conditions have been reported (140). Ranges for cattle and calves are 0 to 16°C and 12 to 25°C, respectively (140). Low ranges for mature cattle on full feed are due to heat produced from microbial fermentation.

Changes in ruminant metabolism involved with changing temperature outside the thermoneutral zone can be grouped into 2 categories: 1) affecting voluntary intake of feed DM, and 2) affecting utilization of ingested nutrients.

Feed intake. When lactating dairy cows were fed free choice a diet of 60 to 65% high quality roughage and 35 to 40% concentrate and exposed to constant temperature conditions, feed intake increased approximately 15% at -20°C over the level at 10 to 20°C (Figure 3) (140). Marx (115) housed heifers in a cold (unheated) loafing barn and warm (heated) confinement barn. Intake was increased by 5.1% by heifers housed in the cold barn. Animals were raised in Minnesota. At high temperatures, feed intake is reduced. Continuous heat stress may reduce feed intake to such an extent that negative energy balance results, and cows may not eat at all if temperature remains above 40°C (9). Decreases in rumen motility due to heat stress have been reported (204) and may function to depress feed intake.

Thermal stress may only contribute to depression of intake. Frequently, lowering of forage quality due to temp-

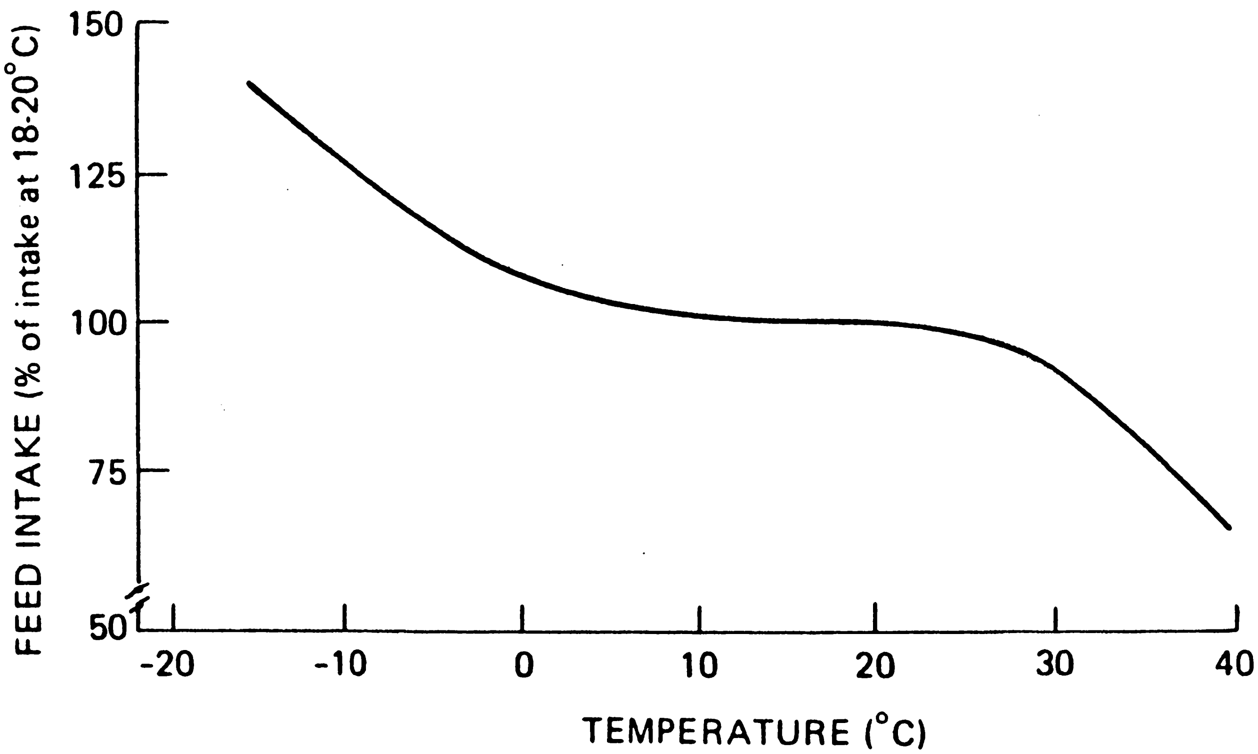

Figure 3. Effect of temperature on feed intake (as a percent of intake at 18-20°C) (141).

erature effects on forage composition (secondary fermentation), or decreased pasture quality may affect intake (140).

Effects of ambient temperature on feed intake and growth of growing dairy heifers can be mild to marked. However, compensatory growth and increased feed intake during periods of temperature moderation result in poor correlation between growth and temperature (140). It is probable that although temperature can affect voluntary DM intake of dairy heifers, long term effects are minimized by compensatory growth.

Nutrient utilization. Reduction of ME values of feeds when fed to cold-stressed sheep and cattle has been documented (140, 204). Apparently, increased fecal and urinary losses account for the lowered ME values independent of changes in feeding level (140, 204). Similarly, increases in digestibility are associated with warmer environmental temperatures. Digestibility factors may be related to changes in rumen motility associated with thermal stress. Ames (3) suggested that protein level of rations fed during cold weather be reduced in proportion to the expected reduction in average daily gain resultant from thermal stress.

Effects of thermal stress on NE_m and NE_g and intake are shown in Figure 4. At extremely low effective temperatures, large amounts of lipid are oxidized (21) to provide energy

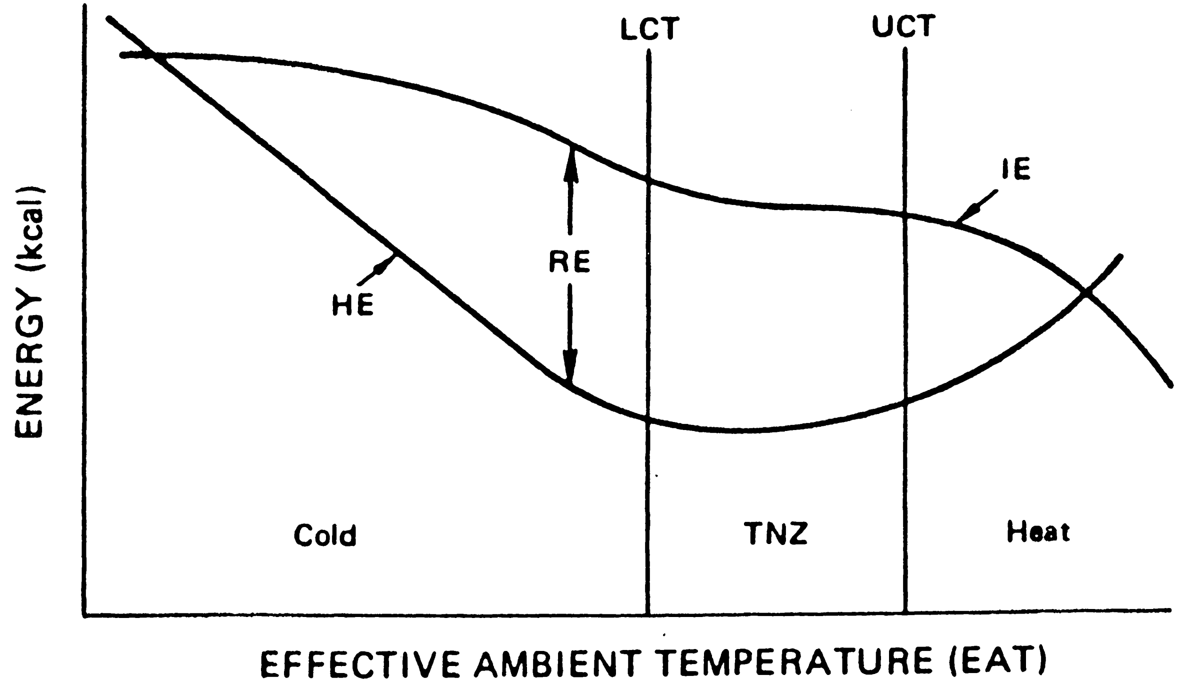

Figure 4. Effect of effective ambient temperature (EAT) on intake of energy (IE), heat production (HE), and retained energy (RE) through three zones of EAT: cold, thermoneutral (TNZ), and heat (141).

for thermal regulation. As effective temperature increases, proportionally more energy is made available to the tissues for gain and less energy is used for thermal regulation. Increasing effective temperature above thermoneutral results in utilization of energy to initiate heat dissipation mechanisms. Intake declines gradually with increasing effective temperature, then drops sharply when animals are heat stressed.

C. Energy requirements of growing heifers

1. Introduction

Quantitative energy requirements of growing ruminants are complex and change depending on sex, physiological state, and a variety of environmental factors (141). Although rate of growth and feed intake are closely related, cause and effect are not well established (149). Whether gain is dependent upon intake or intake dependent upon genetic ability for growth is open to debate. This theoretical question must be answered by research using animals of superior genetic ability and diets containing sufficient energy for metabolic factors to control intake. It is certain that energy requirements of growing dairy heifers will influence directly intake of DM, and therefore are of considerable importance to those modelling intake functions.

Energy requirements can be divided into two separate units; energy required for maintenance of body tissue, and that required for growth. The partial efficiency, and therefore, energy costs of maintenance are higher than for growth (105, 113). Energy required for growth can be further separated into two components; energy required for substrates from which new tissue is formed, and extra energy required for production of tissue (125). As the animal ages, composition of new tissue deposition changes from higher protein deposition to increasing levels of fat (125, 139).

2. Efficiency of ME utilization.

Metabolizable energy available to body tissues is utilized for several processes: maintenance of body tissues and/or deposition of new body tissues as protein or fat. Efficiency of use of ME for various functions has been studied in both sheep and cattle under many different physiological and management conditions. Such efficiencies are the basis for the net energy systems used in the U.S. (113, 139). Determination of efficiency of ME utilization for both maintenance and gain requires more than one level of feeding. Net energy for maintenance or partial efficiency of ME use for maintenance is determined with incremental changes in feeding between fasting and maintenance (71). Measurement of NE values for a productive function (growth) is conducted with both levels of feeding above maintenance (71). Changes in efficiency of ME use for maintenance and/or gain during growth may result in an increase or decrease of ME value of feeds, and thus intake.

Efficiency of ME utilization for maintenance (k_m) is used to predict NE_m of growing ruminants and content of feedstuffs: $NE_m = k_m * ME$ (Mcal/kg DM), and ranges from 58 to 70% (141). Estimates made in Europe range from 66 to 75% under similar conditions (70, 141). Differences between estimates may be due to varying techniques for determining k_m (73, 141). As body weight increases in growing cattle, k_m appears to decline due to protein turnover, physical activity, and other work or growth (71, 73, 184).

Tyrrell and Moe (184) have calculated that maintenance requirement on similar diets declines by 54 to 75 kJ/kg body $wt^{.75}$ for each 100 kg increase in body weight. Additionally, apparent maintenance requirement increased .21 kcal/kg body $wt^{.75}$ for each increase in ME intake of 1 kcal/kg body $wt^{.75}$ above maintenance (180).

Efficiency of ME utilization for growth (k_g) varies depending upon composition of animal gain (141), and to some extent on breed, body size, growth rate, and sex (73, 141). Net energy for gain may be calculated as $k_g * ME$ for animal requirements and feedstuffs, and ranges from 25 to 50% (141). However, NE_g may be factored into major components of energy required for deposition of fat (k_f) and protein (k_p) (141). Because $k_f > k_p$ (71, 141, 155), the relationship between NE_g (and k_g) and body gain is not constant, but varies according to the proportion of fat and protein deposited. Deposition of body weight as fat or protein is dependent upon many factors, including sex, rate of gain, breed, age, body weight and genetic potential. In general, however, k_p has been estimated to be from 20% (73) to 33% (177) and k_f to be 75% (73) to 77% (177), but varies according to diet (179). Because k_f and k_p do change, potential effects on energy intake must be anticipated. Theriez et al. (177) showed that concentration of ME in the diet had an effect on efficiency of ME use for fattenning. When ruminants consume ME above maintenance, resulting heat increment of feeding is proportional to amount of fiber in the diet, and molar proportions of VFA produced in the rumen (199). Heat increment of feeding is dependent on energy cost of eating and ruminating, heat of fermentation, work of digestion, and work of nutrient metabolism (199). Heat increment of feeding above maintenance is affected most by work of nutrient utilization, which accounts for 65 to 70% of total heat increment of feeding (199).

If intake of food by dairy heifers fed ad libitum is dependent on energy requirements and concentration of energy in the diet, factors affecting energy requirement must be considered when developing DM intake prediction equations.

Current estimates of energy requirements of groups of growing heifers are in Table 2.

TABLE 2. Recommended energy requirements[a] of growing heifers weighing 136, 227, and 317 kg gaining .73 kg/day.

Item	136	227	317
TDN, kg	2.6	3.8	4.8
TDN, % of DM	72.2	66.0	64.0
Digestible energy, Mcal[b]	11.4	16.8	21.0
Digestible energy, Mcal/kg DM	3.18	2.92	2.82
Metabolizable energy, Mcal[c]	9.9	14.3	17.9
Metabolizable energy, Mcal/kg DM	2.76	2.48	2.40
Net energy, maintenance, Mcal[d]	3.1	4.5	5.8
Net energy, maintenance, Mcal/kg DM	.87	.78	.78
Net energy, growth, Mcal[e]	1.7	2.2	2.5
Net energy, growth, Mcal/kg DM	.47	.37	.34

[a]National Research Council, 1978 (139).

[b]Calculated from TDN: 1 kg TDN = 4.409 Mcal DE.

[c]Calculated from NE_m and NE_g.

[d]Calculated as .077 Mcal * kg body $wt^{.75}$.

[e]Calculated as Mcal = -.322286 + 2.986787E-3 * bwt + 1.491215 * gain - 6.3116E-6 * bwt^2 + 6.286167E-3 * (bwt * gain).

Requirements have been calculated in several different terms: total digestible nutrients (TDN), digestible energy (DE), metabolizable energy (ME), and net energy for growth (NE_g) and maintenance (NE_m). A review of these methods of energy expression is in Appendix 1. Because TDN, DE, and ME are used with different efficiencies for maintenance or growth (127, 139) in growing animals, the net energy system as described by Lofgreen and Garrett (113) may be the method of choice. Both NE_m and NE_g are used to estimate the energy requirement for growing heifers. Defined as amount of energy necessary to prevent tissue loss from the animal's body, NE_m is a function of body weight (69). Net energy for gain is energy stored as a result of a given amount of a feedstuff being consumed above that necessary for maintenance (141). It is dependent on proportion of fat and protein in gain (69). Lofgreen and Garrett (113) determined NE_m requirement to be .077 Mcal/kg body wt$^{.75}$ for growing beef heifers and steers. Net energy for gain was estimated as $(56.03G + 12.65G^2) * (\text{kg body wt}^{.75})$, where G = kg gain/day (113), and was based on energy content of body gain. Improvement of this model by Fox and Black (64) included adjustments for breed, environmental conditions, use of growth stimulants in growing bulls, heifers, and steers.

Estimates of requirements for growth and fattenning developed by the Agricultural Research Council (ARC) (1) are based on the ME concept, and opposed to NE systems that account for feeding values, use an iterative approach to estimate animal's ME requirements on a given ration (206). Zulbertt and Reid (206) developed equations to predict the ME requirement of growing cattle that do not require iteration, and estimated accurately ARC ME requirements. Included in this equation were: ME content of ration (Mcal/kg DM), age of animal, kg body wt$^{.73}$, daily gain (kg/day). Metabolizable energy in this equation is calculated as ME for maintenance (ME_m) and growth (ME_g), and both are adjusted for efficiency of utilization of ME for the respective functions (141, 206).

3. Regulation of energy balance

Lactating animals lose weight early in lactation because intake of energy does not keep pace with energy in milk. Later in lactation the animal reaches positive energy balance and begins to replace body fat lost earlier in lactation (11, 12, 18, 93). Montiero (132) proposed a model of energy balance in high producing dairy cows based on demands of milk production. This "closed-loop" system included factors controlling milk production and voluntary feed intake that communicate in both forward and reverse directions. Delayed response of feed intake to milk production early in lactation suggest milk production to be causal of increased feed intake. This observation, along with many similar observations in rodents (12) supports the theory of long-term metabolic regulation of energy balance in animals. A short-term system for metabolic energy regulation that controls day to day frequency, size, and duration of meals has been proposed also.

Short-term regulation of energy balance. Short term regulation of energy balance may be considered as those factors resulting in initiation, continuation, and/or termination of a meal. Meyer (cf. 93) proposed a mechanism by which short-term regulation of energy intake would function: 1) it be integrated with metabolic processes that mediate the relation between energy input and expenditure, 2) be compatible with known metabolic characteristics of the central nervous system and be based on practicable and reversible cellular changes, 3) explain effects of metabolic hormones and disorders on intake, 4) describe why variations in environmental conditions associated with increased energy output influence energy intake (e.g., exercise, cold), and 5) account for existence of the hunger state and give a physiologic framework for hunger behavior.

Rumen factors have been proposed to mediate satiety in ruminant animals. Rumen distention and rate of passage have been mentioned. Baile (9) suggested that rumen distention may serve as a "safety valve" to terminate a meal prior to excessive rumen fill. Receptors in the rumen have been determined (9).

Rumen fluid pH probably does not affect feed intake under physiological conditions, but when rumen pH falls below 5.5 and rumen function is disturbed, pH may inhibit normal feed consumption (9, 11, 12). Jones (93) suggested that rumen pH may play a role in controlling rates of absorption of volatile fatty acids (VFA) (acetate, propionate, and butyrate) from the rumen to blood where they act as a signal of satiety.

Rumen VFA produced as a result of carbohydrate and protein fermentation have been proposed as factors controlling feed intake (8, 11, 12, 13, 62, 93, 163, 164). Reasons for suggesting VFA in control of feed intake were stated by Baile (13, 93): 1) VFA are produced in the forestomachs and absorbed before passage into the abomasum; 2) rates of VFA production and absorption are related to feeding behavior, and 3) intraruminal injections of VFA coincide with decreased feed intake. Simkins et al. (163) reported a relationship between rumen and blood acetate concentrations and satiety in growing calves. Both acetate and propionate have been proposed to control intake; butyrate probably exerts less of an effect (9, 12, 13, 93). Acetate receptors appear to exist in the lumen side of the dorsal rumen (11, 12, 13). Intravenous injections (IV) of acetate had a depressing effect on cattle (12, 83, 164), but not in sheep

(12). Goats were not affected by IV injections, but intraruminal injections depressed intake (12, 93). A local anaesthetic included in acetate injections effectively blocked depression caused by acetate injection, suggesting that acetate response is neurally rather than hormonally transmitted (12). Ruminal propionate also appears to affect meal size. Intraruminal injections of propionate depressed meal size in cattle, sheep, and goats (8, 11, 12, 164). However, IV injections of propionate in the ruminal vein were more effective in depressing intake than injections into carotid, jugular, (11, 12), mesenteric, or portal veins (8, 12). Jones (11) proposed that receptors for propionate are located in either the rumen wall, rumen vein, liver, or all three locations, whereas acetate receptors are present only in the rumen wall. Receptors at these sites may be sensitive to some undetermined metabolite, and a certain concentration in rumen fluid or blood signals the ventromedial hypothalmus, which in turn neurally or hormonally signals the animal to stop eating (11). Insulin stimulated hepatic uptake of propionate has been proposed as an important determinant in satiation (22, 62). Forbes (62) has reported experiments in which sheep were denervated at the hepatic plexus to determine neural effects on ruminal propionate infusion. Completely denervated sheep were not affected by propionate infusion, whereas those less completely denervated consumed less under the influence of propionate infusion.

Chase and Wangness (40) measured portal blood constituents of growing dairy calves immediately before, during, and after initiation of meals. Although rapid physiological changes were observed during the meal, no cause and effect relationships were established. It was suggested that certain blood metabolites can respond rapidly within the length of the meal and may serve as components of a short-term feedback system (40). Support for circulating metabolites serving as satiety signals has been obtained using cross-circulation experiments. Jugular blood of two animals, one fed and one fasted, are exchanged. Such studies in sheep (198) and rats (10) have shown a reduction in feed intake in hungry animals after initiation of cross-circulation.

Other factors that have been proposed to control satiety are plasma glucose (8, 11, 12, 13, 83), other rumen VFA (11, 12, 13, 83, 93), free fatty acids in blood or rumen fluid (11, 12, 93), amino acids (11, 12, 93), hormones (Growth hormone, insulin, glucagon, epinepherine) (8, 11, 12, 62), blood and skin temperature (11, 12), osmolality (9, 11, 12), but none appear to directly affect the control of meal size or frequency under normal physiological conditions in the ruminant.

The role of the ventromedial hypothalmus and lateral hypothalmus in stimulating and depressing intake, respectively, and in control of energy balance in ruminants has been proposed (11, 12, 13). Cholecystokinen octapeptide decreased food intake in wethers in a dose-related manner when injected continuously into the lateral cerebral ventricles (57), This peptide has been proposed to play a role at the small intestine and brain in controlling intake (10), and may be related in some manner with production or expression of entry rates of VFA (191).

In conclusion, it appears that initiation of a meal is stimulated by a combination of the decrease of inhibitory action of areas such as the ventromedial hypothalmus and stimulatory action of sensory inputs, or of gastrointestinal sensations. Meal size is controlled by an overriding action of the energy balance/ maintenance system on a variable threshold at which satiety develops (8). The threshold should be dependent on the metabolic state of the animal, and be controlled by factors regulating energy balance.

Long-term regulation of energy balance. Long-term factors associated with regulation of energy balance in ruminants are poorly defined. Substantial evidence exists that animals do regulate intake in relation to energy requirements over periods of time to maintain constant level of energy stores called "set point" (83). Bines and Morant (24) fed "fat" and "thin" cows 5 kg hay/day and concentrate ad libitum for 5 hours/day. Fat cows consumed 24% less daily DM than their thin counterparts. Proposed as regulating intake in thin cows was increased utilization of VFA and glucose, resulting in lower rumen concentration at similar intakes (24). Others have reported effects of obesity on voluntary DM intake (63, 185). Integration of short- and long-term control of energy balance would suggest that centers of control are located in the hypothalmus (11). Free fatty acids from adipose tissue were thought to serve as a feedback mechanism for energy balance (8, 11, 12, 13, 18, 93, 98). However, as Kennedy (cf. 12) observed, free fatty acids were increased during severe obesity as well as hunger, and therefore may not act to signal the hypothalmus of energy stores. Other researchers have implicated brain peptides, neurotransmitters (11), and corticoids and prostaglandins (12, 93) in control of energy balance.

Due to the large number of interrelated factors conrolling short- and long-term intake, a considerable amount of research is needed before factors controlling energy balance associated with growth and lactation will be defined clearly. It follows from this discussion that prediction of voluntary intake of DM, energy or other nutrient remains difficult. From a practical standpoint prediction of nutrient intake continues to improve as physical and metabolic factors affecting energy balance and intake are included in mathematical models.

4. Partition of nutrient energy

The contribution of a feed toward meeting the requirements for energy depends not only on the amount of energy supplied, but also on the chemical form of that energy and physiological direction of energy to dependent tissues (29).

Chemical form of energy. Fermentation of energy sources in the rumen is responsible largely for the formation of endproducts (VFA, glucose) available for metabolism by the animal. Chemical form of these endproducts; acetic, propionic, butyric, lactic acids, other lesser VFA, and/or glucose can affect partition of nutrients to body tissues (29, 71). Calorimetric evidence (cf. 29) indicates that diet composition or infusion of specific VFA can affect the division of nutrients to tissues. Most clearly understood effect is milk fat depression. Flatt et al. (cf. 29) illustrated clearly the effect of diet composition on distribution of energy to body fat and milk fat synthesis. Recognized generally as influencing energy partition is the ratio of acetate to propionate resulting from rumen fermentation. Acetate to propionate ratio falls with decreasing forage in the diet (29). Increased propionate production in some as yet unexplained manner affects milk fat metabolism, particularly its suppression. It is interesting to note that milk fat depression is associated with increased lipid deposition in adipose tissue (191).

Studies of Armstrong and workers (cf. 71) suggested a relationship between rumen VFA production and efficiency of ME use for maintenance and gain. Provided small amounts of propionate were present in the rumen, the three major VFA were utilized at nearly equal efficiencies for maintenance. When acetate was infused into the rumen, efficiency of ME utilization decreased compared to propionate and butyrate (71). Blaxter and Warner (27) found a significant linear relationship of k_g and molar proportion of acetate in rumen fluid of sheep when various mixtures of hay and corn were fed. However, these observations have not been supported by other research (144, 145).

Physiological control of nutrient flow. Partition of nutrients to various tissues involves two types of regulation: homeostasis and homeorhesis (17). Homeostatic mechanisms involve maintenance of physiological equilibrium or constant conditions in the internal environment (17). Homeorhesis is the coordinated change in metabolism of body tissues to support a physiological state (17). In this scheme, a "hierarchy of tissue demand" is established whereby nervous, circulatory, respiratory, excretory systems and other tissues maintain a high priority for nutrients (45). The priority among other tissues will vary depending on the physiological state of the animal (viz. homeorhesis)

(45). Although considerable research is being conducted presently to clarify homeorhetic mechanisms in high producing dairy cows, little work appears in current literature reporting homeorhetic mechanisms of ruminant growth.

D. Equations to Predict Intake of DM

The importance of accurate and precise equations to predict intake of dairy animals cannot be overemphasized in the present context of ration formulation systems. Most diets formulated for animals are calculated using nutrient requirements expressed on a percentage basis (149). Conversion of requirements from grams per day basis, as determined factorially, to percentages assumes a feed intake value. Variation between assumed and actual feed intake is a major problem in this system.

Prediction of feed intake under various management systems is difficult. As mentioned, control of intake by physical and metabolic effectors are expected to change depending upon ration formulation and physiological state of the animal; thus coefficients describing both systems of intake control must be included in a ration system.

Equations derived to predict intake of DM in lactating dairy cows have developed from a low degree of confidence (18, 54, 55, 106) to those explaining 80 to 83% of variation in DM intake (32, 133, 205). Brown et al. (31) predicted intake of DM and milk yield in lactating dairy cows utilizing 4135 Holstein and 704 Jersey records of 492 cows in 11 cooperating university herds. Found to influence intake of DM were: season, days in milk, ln days in milk, ln milk (kg/day), milk fat (kg/day), body weight (kg), crude fiber (% of DM), and crude fiber squared. Milk yield was most important in determining total intake of DM in the data set, and most accurately reflected physiological state of the animal and its demand for metabolizable energy. Brown et al. (32) in a review of intake equations reported that parameters required in equations to predict intake of DM in lactating cows were: days in milk, milk production, body weight, energy content of the ration; additional parameters suggested were: growth, reproductive status, age, feeding frequency, feed type, and physical form of the ration.

Yungblut and others (205) regressed daily intake of DM on several independent variables and were able to account for 84% of variation. Independent variables were: milk production, days in milk, fat percent, fat yield, fat corrected milk, ADF in ration, wither height, metabolic body weight, change in body weight, and heart girth.

Forbes (63) suggested that models of food intake should be built up from a series of experimentally derived relationships. Two equations must be developed; the first describes energy requirements for maintenance, lactation, pregnancy, and fattening, knowing ME concentrations of feeds and efficiency of ME utilization. This equation predicts food intake when intake should be metabolically controlled. The second equation describes relationships between food intake, gut capacity and other factors to calculate physically limited intake (63). Whichever is smaller is the predicted intake. According to Forbes, (63) such simulation predicts with relative accuracy short term control of meals in sheep. Improvement of assumptions used in the model will improve its predictability.

Literature available on intake of DM by dairy heifers is inadequate. McCullough and Sisk (116) reported similar intakes of estimated net energy (ENE) with rations above 66% DM digestibility. They stated that at high levels of digestibility, bulk density of the total ration may be of considerable importance in total intake, suggested a delicate balance between rate of rumen fermentation, ration composition, and DM digestibility. Song and Dinkel (169) developed equations to predict voluntary food intake regulated by physiological demand (VFI_p) and gastrointestinal distention (VFI_d) in beef steers from weaning to slaughter. Physiological demand for energy (defined as the maximum energy that the animal could consume from feed when gastrointestinal distention did not inhibit energy intake), and amount of metabolizable energy per gram of feed DM were related to VFI_p. Gut fill, rate of excretion, digestibility of DM, and rate of digestion which were in turn estimated by dietary crude fiber, degree of animal maturity, rate of excretion and rate of digestion were related to VFI_d. Simulations conducted with these equations projected maximum dry matter intake to occur at 2.81, 2.76, 2.73, 2.68, 2.58, and 2.54 kcal metabolizable energy per gram dry matter for cattle with .3, .4, .5, .6, .7, and .8 degree of maturity, respectively. Degree of maturity was defined as present weight / expected mature weight. These results suggest that physiological demand for energy decreases with degree of maturity. This decreased physiological demand for energy appears to be due to a decreased demand for NE_g with advancing age (Table 2).

Multiple regression analysis conducted by Baumgardt et al. (20) identified percent DM, bulk density (BD), solid density (SD), in vitro DM digestibility (IVDDM), percent NDF and a digestion coefficient for NDF (DNDF) as important variables in predicting DM intake in growing whethers. Including a parameter to describe the rate of NDF digestion in vitro (RTNDF) increased variance explained from 79 to 83% (20). Equation to predict DMI when fill was thought to be limiting was: $DMI\ (g/kg\ bwt^{.75}) = (-3.60 * DM) + (2.41 * DM * SD) - (13.33 * DNDF * BD) - (.07 * DNDF * IVDDM) - (6.31 * BD * IVDDM) - (4.56 * SD * NDF) + (.11 * NDF * IVDDM) + 216.47$; $r^2 = .84$ (20). When rations where fill was not limiting were added to the data set, the equation was: DMI (g/kg bwt$^{.75}$) = (354.52 * BD * SD) + (8.72 * IVDDM) - (23.76 * BD * IVDDM) + (65.29 * BD * RTNDF) + (.009 * DNDF^2) - (4.78 * RTNDF^2) + (1150.08 * BD^2) - 294.35; r^2 = .80 (20). Quadratic terms in the second equation illustrate curvilinear relationships between NDF and DMI, and BD and DMI.

Fox and Black (64) devised adjustments for animals' body weights to account for frame size and degree of fatness (designated by USDA feeder calf grades). This adjusted body weight was in turn used to predict daily DM intake, with further adjustments for other factors assumed to affect intake including age, breed, feed additives, dietary energy concentration, temperature, and presence of mud in feedlot (64).

Present equations in use for predicting DM intake of heifers (139, 166, 171) are crude estimates unsuitable for development of a practical ration system. Those derived by the NRC (139) and Virginia (171) (DMI = .918 + .0332 * BWT(lbs) + -1.210 * BWT(lbs)^2) are based on data obtained from 1943 to 1964, and may be outdated. Cornell equations (166) [under 600 lbs, DMI(lbs) = .6 + .024 * BWT(lbs); over 600 lbs, DMI(lbs) = 9.7 + .0102 * BWT(lbs)] are based on NRC data, and simply divide heifers into two groups. No equation accomodates adequately rate of gain as affecting DM intake. If metabolic factors contribute to regulation of intake in heifers, then body weight is inadequate as sole estimate of voluntary intake. As pointed out by Baumgardt et al. (20), ration digestibility, density, and NDF content of the ration have been identified consistently as important factors affecting intake.

E. Ration Formulation Systems

Heifer feeding and management could be improved if a system of feed formulation were available to rapidly and accurately recommend rate of gain, feeding levels and programs for growing heifers. Adequate growth utilizing economical rations to optimize age at first calving could be realized. Systems of dairy cattle ration formulation are of two general types: those providing an optimal solution or strategy, and those providing an acceptable, but not necessarily optimal strategy. Of techniques designed to provide optimal solutions, linear programming is by far most widely used.

Linear programming. Linear programming involves selection of a set of decision variables and their quantities (e.g., kg of haylage fed per cow per day) that maximize or minimize a linear objective function subject to specified constraints (25). Minimization of feed costs and maximization of income over feed costs are examples of linear objective functions.

The simplex method (linear programming solution technique) requires four assumptions to be implemented properly, that in a ration balancing context, can give rise to considerable complications (25, 87). These assumptions are: 1) additivity, 2) certainty, 3) divisibility, and 4) linearity (proportionality) (87). Activities of a linear program must be additive in the sense that when two or more are used, the total must equal the sum of the individuals (87). This assumption precludes inclusion of interaction in a linear programming model. Certainty requires that parameters of the model - resources, contribution of activities, etc. - are all known with a degree of confidence. Divisibility requires each activity to be infinitely divisible. Linearity (or proportionality) requires that relationships between variables (e.g., milk production and dry matter intake) are linear throughout solution space.

Linear programming has the advantage of allowing the single maximum or minimum strategy to be obtained. In many cases this involves maximizing income over feed costs or minimizing cost of rations. However, several problems unique to ration formulation must be addressed to properly estimate a maximum profit or least cost ration. The major problems involved are uncertainty and linearity.

Uncertainty of dry matter intake equations. Previous discussions have illustrated effects of energy density and other factors on voluntary feed intake of dairy cows. This manifests the need for incorporation of corrections into the linear programming algorithm to correct for changing caloric density and form of diet. Several techniques have been developed to estimate more accurately intake of dry matter (7, 25, 30). These include assigning a "balance equation" that reduces dry matter intake in combination with the DM intake equation; when ration energy density is less than a set constant defined as the point at which physical and physiological mechanisms begin to control intake (25). A second method involves assigning an "intake adjustment" factor to accomodate the impact of energy density and fermented feeds on DM intake (25). As an example, if 2 kg of excellent quality alfalfa hay A_1 were substituted for poor quality hay, A_2, total alfalfa consumption would increase to 2.2 kg, suggesting a substitution of 1.1:1. Thus, A_1 is assigned 1.0 in the DM intake equation compared to 1.1 for A_2 (25). In maximum profit routines (30), required DM intake per unit of milk is defined up to a point of estimated maximum DM intake as defined by an intake equation (30, 38). The maximum ratio of milk production per unit of milk produced is then chosen by the linear programming algorithm.

Uncertainty of nutrient requirements. Dairy animals under conditions of intense productive management exhibit considerable variation in requirements for nutrients during growth and lactation. As an example, energy required for maintenance of cows of similar size and breed can vary as much as 10%, dependent on physical activity (139). Energy requirements vary during lactation, depending on stage of lactation and production. Further compounding uncertainty of nutrient requirement estimates is necessary grouping of animals by production. Requirements for groups are estimated based on production, age, etc., with "safety factors" of 1 to 2 standard deviations above the mean incorporated. It is apparent that estimation of nutrient requirements is complex and requires consideration before incorporation into a ration formulation system.

Protein and energy requirements (118, 139) have been estimated by a factorial method - ie., energy required for productive and maintenance functions are summed together and are expressed as a percent of the total ration, or on an absolute basis (kg DM). Menke (118) proposed that the nutrient requirement for a given productive process can be described by:

$ME = RE/k$, where ME = requirement in metabolizable energy; RE = energy retained, and k = partial efficiency of ME utilization. If a total nutrient requirement is the sum of factorial requirements, then the equation may be rewritten as:

$\Sigma ME_i = RE_i/k_i$, where i = productive functions 1, 2,

..., n. Continued research is required to delineate RE_i and k_i under various conditions of management to improve the error involved with estimating nutrient requirements.

Uncertainty of nutrient composition. Providing the proper amount of a given nutrient to a dairy animal assumes knowledge of the amount of nutrient in each component consumed by that animal. The knowledge is provided by chemical analyses; tables of nutrient composition (e.g., 139) are average values that serve only as guides to feed composition. Applicability of a formulated ration depends intrinsically on accurate determination of nutrient specifications. In the present context of management, error associated with estimation of nutrient composition, especially of forages, is the single largest readily correctable error in a least cost ration system. Nutrient content of forages can vary considerably due to age, stage of maturity, method of storage, year, variety, processing, and many other factors. Recent reports of equations to predict storage losses of fermented feeds (81) may improve predictability of nutrient content of forages.

Nonlinearity of biological functions (e.g., milk production or DM intake) can be incorporated into a linear programming algorithm by utilizing separable programming procedures. Separable programming involves estimating a nonlinear function by a series of linear subfunctions that can be described separately (79). Incorporation of this type of programming into ration formulation systems integrates concepts of: 1) milk vs. energy intake response function, and 2) minimization of cost (25) or maximization of return (30) for a particular rate of performance. Milk vs. energy intake response may be defined as Mcal of NE_l required per day above maintenance. As milk production increases toward genetic potential, amount of NE_l required per kg milk increases. As an example, NE_l required for a cow with a genetic potential of 27.3 kg/day of 3.5% milk to produce 0 to 22.7 kg is .68 Mcal NE_l/kg above maintenance (25). From 22.7 to 23.2 kg milk, 1.23 Mcal NE_l/kg is required. Each discrete activity (e.g., produce 22.7 kg milk/day) is listed in a linear programming matrix to determine the greatest profit for all activities. The system will choose an activity or a weighted average of two activities (e.g., produce 22.7 kg milk; produce 23.2 kg milk; or produce .3(22.7 kg milk) + .7(23.2 kg milk), or 23.05 kg milk).

Development, acceptance, and use of computerized ration formulation systems for lactating dairy cows have been well documented (16, 38, 56, 75, 85, 95, 96, 97). Results from surveys of dairymen in Virginia and Wisconsin using such systems indicate improved production of milk (85, 96, 97), milk fat (85), increased use of feed and forage testing services (85) and improved economic decision analysis (95). These data indicate that an increased level of management results from availability of ration formulation systems. Recent reports (65, 66, 167, 192) suggest management and ration formulation systems written for micro and main frame computers will soon incorporate extensive biological models for both nitrogen and energy, thus improving predictability of animal requirements and response.

Comparisons between types of ration formulation systems (maximum profit, least cost, and "simplified") are incomplete. Wisconsin reports (84) of comparison of two types [least cost (LCR) and simplified (BRB)] suggest that simplified ration balancing programs are preferred. Reasons given were: 1) BRB is less expensive to run than LCR, 2) BRB requires less time on part of the field worker, 3) dairymen can initiate BRB without help from extension staff after 1 or 2 times through BRB, 4) extension staff understands BRB better than LRC, 5) BRB fills a need in ration balancing for dairymen who need to purchase only protein and minerals (84). Many Wisconsin dairymen do not have technology to implement with precision LCR formulated rations (84).

Walker (196) stated that a maximum profit model must incorporate production, milk prices, feed sources and prices, herd size, and all other factors comprising a dairy herd unit. A maximum profit dairy unit approach is not as simple as a least cost diet formulation technique. Least cost and maximum profit systems often prove too complex for many dairy farmers and extension agents (196). These procedures, as of 1976, were used less than other ration formulation systems. Between July 1, 1975 and January 20, 1976, only 221 uses of the maximum profit ration balancing program were recorded (196). The simplified system used in Virginia, not utilizing a least cost algorithm was accepted immediately. The program was run 2012 times during the same period (196). It should be noted that recent improvements in maximum-profit systems have markedly increased their use (171).

It is expected that the impact of a ration formulation system for heifers would be managerial as well as nutritional. Incorporation of a ration formulation system for heifers into existing main-frame and microcomputer systems would promote an increased awareness of heifer raising operations as a whole. Further, continued popularity of highly efficient replacement housing systems (47) that lend themselves to feeding total mixed rations would promote further use of a ration formulation system for heifers.

MATERIALS AND METHODS

A. Introduction

Concentration of total digestible nutrients (TDN) in ration DM (85%, 95%, 105%, 115% of 1978 NRC requirements) and body wt (136, 227, 318 kg) were arranged factorially (Table 3).

Selection of ration parameters was based on recommendations for heifers from 136 to 337 kg (89, 96). Levels of TDN are 85, 95, 105, and 115% of NRC requirement for 136, 227, and 317 kg heifers gaining .73 kg/day, and were selected to provide an estimate of nutrient content at practical feeding levels for all animals on the study.

Body weights of 136, 227, and 317 kg correspond generally to those body weights at which nutritional management is least intensive. Usually during this period (4 to 16 mo of age) heifers are switched from a commercial calf starter to less expensive concentrates and forages. Nutrient demand is high relative to the animal's ability to consume DM during this time also.

B. Experimental Model

From the previous discussion, the following factors would be expected to affect voluntary intake of dry matter: 1) nutrient concentration of the ration (pg. 13), 2) nutrient density of the ration (pg. 14), 3) energy requirements

TABLE 3. Composition of protein, calcium, phosphorous, and total digestible nutrients in ration dry matter (TDN), of rations for heifers weighing 136, 227, and 317 kg and gaining .73 kg/day as recommended by (139).

Body wt	136	227	317
	---------(% of dry matter)--------		
Crude protein	13.2	11.6	10.6
Calcium	.52	.39	.33
Phosphorous	.32	.28	.24
TDN	---------------(kg)---------------		
85% of reqt	2.17	3.12	4.05
95% of reqt	2.42	3.49	4.58
105% of reqt	2.68	3.86	5.00
115% of reqt	2.93	4.23	5.48

of the animal for maintenance and growth (pg. 36), 4) level of feeding and efficiency of feed utilization (pg. 41), 5) physical form of the ration (including processing effects) (pg. 20), 6) plant cell wall content of rations (pg. 18), 7) seasonal effects (pg. 31), and 8) palatability (pg. 43). This may be restated in the following model:

DMI (kg/day) = μ + (f)nutrient concentration + (f)nutrient density + (f)energy requirement + (f)feed efficiency + (f)physical form of ration + (f)season + (f)palatability + random effects.

At present, no quantitative measure of palatability is available; the assumption must be made that total mixed rations will be accepted by all animals in the study with no depression of intake due to palatability. Physical form of the ration, particle size and other factors affecting extent of digestion are not included, but are estimated by bulk density. It should be noted that grinding increases intake and decreases digestibility of alfalfa hay fed to Holstein heifers (147). Therefore, care must be exercised when results obtained in this study are extrapolated to include rations with long hay separate from other forages/concentrates.

Brown et al. (31) found season (expressed as a classification variable) to affect intake of lactating dairy cows. In this study ambient temperature is used as an estimate of seasonal effects.

Nutrient concentration of feeds is included in the model as total NE_m and NE_g (Mcal/kg DM). Total digestible nutrient concentration replaced NE_m and NE_g in some models. Net energy requirements and feed efficiency may be integrated in the model as NE systems account for decreased feed efficiency at levels above maintenance (139). National Research Council estimates of NE_m and NE_g requirements for growing heifers may be considered a function of body weight and gain. Thus, body weight and gain are included in the model as estimates of energy requirement. The model may be written: $DMI_i = \beta_0 + \beta_1(NE_m)_i + \beta_2(NE_g)_i + \beta_3(\text{bulk density})_i + \beta_4(NDF)_i + \beta_5(\text{body weight})_i + \beta_6(\text{body gain})_i + \beta_7(\text{ambient temp})_i + \varepsilon_i$, $i = 1..n$. Full expansion of independent variables (i.e., quadratic and interaction terms) are listed in Table 4.

C. Experimental Procedure

1. Preliminary

Heifers born at VPI & SU herd were raised according to accepted management practices until weaning, when animals entered the preliminary phase of the experiment. In this phase heifers were placed into 3 groups according to body weight (weaning to 200 kg, 200 to 300 kg, 300 to 400 kg) and fed a total mixed ration (TMR) of corn silage, ground

TABLE 4. Independent variables in experimental model.

Independent variable		Remarks
1.	BWT/METBWT	Body weight, kg / Metabolic body weight, kg.
2.	TDN	Ration total digestible nutrients; % of DM.
3.	NEM	Net energy maintenance (NEm); Mcal/kg DM. Predicted from ADF.
4.	NEG	Net energy gain (NEg); Mcal/kg DM. Predicted from ADF.
5.	BULK	Bulk density, g/ml as fed.
6.	GAIN	Daily gain, kg.
7.	NDF	Ration neutral detergent fiber, % of DM.
8.	ADF	Ration acid detergent fiber, % of DM.
9.	AMBT	Daily ambient temperature.
10.	BWTSQ	Body weight squared.
11.	NEMSQ	NEm squared.
12.	NEGSQ	NEg squared.
13.	BULKSQ	Bulk density squared.
14.	GAINSQ	Daily gain squared.
15.	NDFSQ	NDF squared.
16.	ADFSQ	ADF squared.
17.	AMBTSQ	Daily ambient temperature squared.
18.	AGEBWT	Age of animal, days * BWT.
19.	BWTNEM	BWT * NEM.
20.	BWTNEG	BWT * NEG.
21.	BWTBUL	BWT * BULK.
22.	BWTGAN	BWT * GAIN.
23.	BWTADF	BWT * ADF.
24.	BWTAMB	BWT * AMBT.
25.	NEMNEG	NEM * NEG.
26.	NEMBUL	NEM * BULK.
27.	NEMGAN	NEM * GAIN.
28.	NEMADF	NEM * ADF.
29.	NEGGAN	NEG * GAIN.
30.	NEGADF	NEG * ADF.
31.	NEGAMB	NEG * AMBT.
32.	BULGAN	BULK * GAIN.
33.	BULAMB	BULK * AMBT.
34.	GANADF	GAIN * ADF.
35.	GANAMB	GAIN * AMBT.
36.	ADFAMB	ADF * AMBT.

orchardgrass hay[1], soybean meal, ground shell corn and a mineral mix once daily to provide nutrients according to 1978 NRC requirements for that body weight. At the beginning of each experimental period, 6 to 8 heifers weighing approximately 136, 227, and 317 kg were assigned randomly to the appropriate treatment[2] in 1 of 3 blocks in each of 2 trials and moved to the pinpointer facility for a 14 day acclimation period (Figure 5). [Note: It was assumed that up to 15 heifers can use a pinpointer without affecting dry matter intake due to competition (153)]. Each TMR was prepared and fed daily at a rate to maintain approximately 5% feed refusal.

2. Experimental

Following acclimation, measurement of daily intakes[3] and ambient temperature were made during the 28 day feeding trial. Rations were sampled daily and stored at 4°C prior to analysis. A duplicate subsample was analyzed for DM, (convection oven, 100°C) and remaining portions were composited into weekly samples and measured for bulk density by the method of Bull et al. (33), DM,[4] crude protein[4] by

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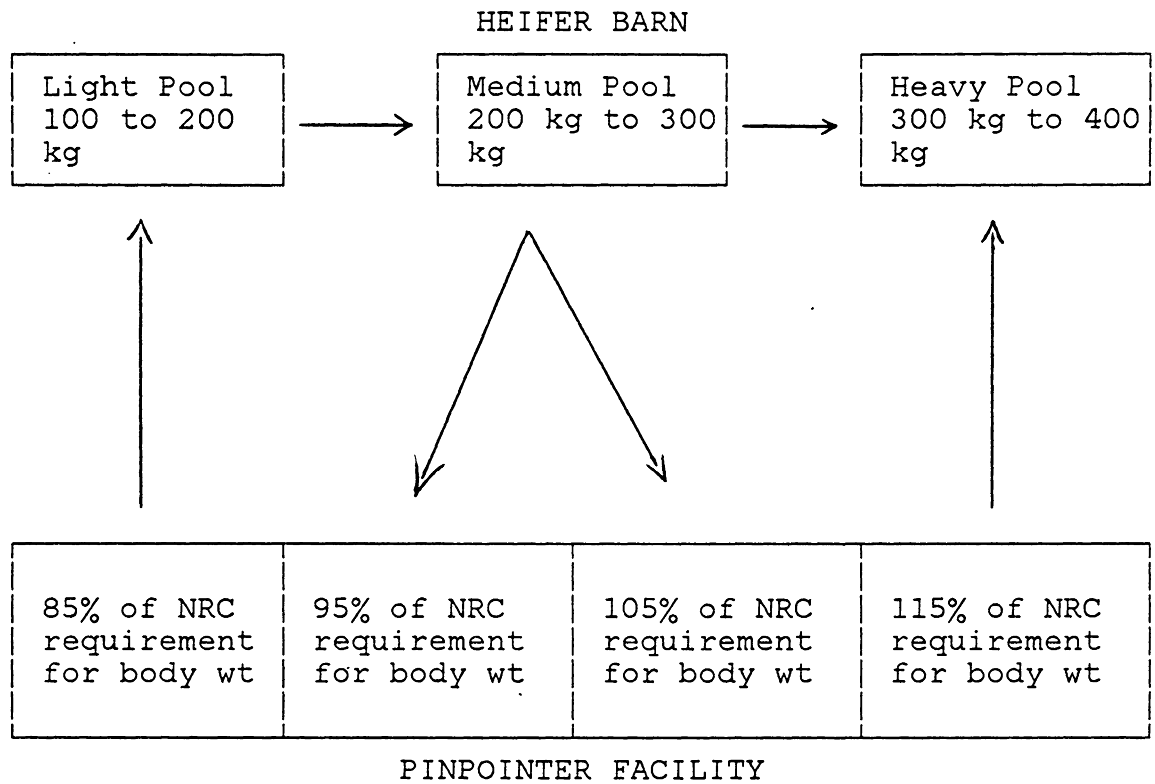
[1]Orchardgrass hay was ground in a tub-grinder to an average length of 7 cm.

[2]Treatments were ordered randomly prior to initiation of the trial.

[3]Pinpointer 4000B. UIS Inc., Cookeville, TN.



1. Heifers enter heifer barn at weaning.
2. Pools of heifers in the weight groups shown were housed at the heifer barn.
3. Groups were fed rations according to NRC requirements for their weight class.
4. Groups of 6 to 8 heifers were selected from each weight class and placed in the pinpointer barn for 14 day acclimation and 4 wk feeding trial.
5. Groups were moved into bays in the pinpointer facility at the beginning of each experimental period.
6. Animals not chosen for the intake trial reach maximum weight for the pool were moved into the succeeding pool in the heifer barn.
7. At the end of the 4 wk intake trial, heifers were moved back to the heifer barn to await possible selection for another intake trial.

Figure 5. Summary of animal housing for experiment.

macro-Kjehldahl, acid detergent fiber[4] (ADF) and neutral detergent fiber (NDF)[5], by the method of Goering and Van Soest (76). Daily samples of feed ingredients were stored at 4°C, composited into weekly samples, and analyzed for DM, crude protein, and ADF as above. Body weights were measured at standard times once weekly. Following the 28 day intake period heifers returned to the preliminary phase, and were held for at least 28 days prior to assignment to a subsequent group to minimize carryover effects.

D. Analysis

Statistical analysis of data was conducted by regression procedures as outlined in (111, 158). Variables used in model development were assumed to be continuous variables.

Each trial was divided into 3 blocks in which 4 treatments were assigned randomly. Blocks were required because the experimental facility contained 4 pens, and 12 treatments were used per trial. Neiter blocks nor treatment classifications were used in analyses.

Preliminary analysis. Data set was completed by including all variables from both trials on a daily basis. Variables of ration quality analyzed weekly were extrapo-

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[4]Virginia Tech forage testing lab. Blacksburg, VA.

[5]New York DHIC forage testing lab. Ithaca, NY.

lated to a daily basis. Daily body weights and daily gains were estimated by regression using the model:

$$\text{Body weight}_i = \beta_0 + \beta_1(\text{day})_i + \beta_2(\text{day}^2)_i + \varepsilon_i$$

where day = day of experiment (0 to 27).

Pearson product-moment correlation coeffecients were generated between DM intake and independent variables to determine degree of relationships, and between independent variables to determine degree of colinearity among independent variables.

Model development. Stepwise regression (142, 158) of the full model, of model pooled by week, were conducted as in (158). Each independent variable was added to the model if contribution of that variable as estimated by level of significance of a calculated F statistic was less than .05. Similarly, variables already in the model were removed after addition of a new variable if significance of calculated F statistic became greater than .05. Model building ended when no variable outside the model had an F statistic significant at .05 level and every variable in the model had an F statistic significant at .05 level.

RESULTS AND DISCUSSION

A. Trial 1

Classification of experimental rations for both trials is in Table 5. Nutrient and mineral compositions of ingredients used in both preliminary and experimental rations are in Tables 6 and 7, respectively. Forages were of average quality. Corn silage was similar to (139). Ground hay was higher in ADF (44% of DM) and lower in TDN (51% of DM) than (139). Concentrate components showed less variation than forages, and generally were of high quality.

Animals were healthy throughout the trial. Due to animal availability, 32 heifers were used in block 1, 29 in block 2, and 31 in block 3.

Ingredient composition of rations fed during preliminary period of Trial 1 is in Table 8. A basal ration containing corn silage, high moisture corn, ground hay, soybean meal and mineral mix was formulated for heifers weighing 317 kg and fed to all heifers; soybean meal, ground shell corn, and minerals were added to medium and light weight group rations at the bunk. Basal ration averaged 50.5% DM, 9.6% CP, 29.1% ADF, and 67% TDN on a DM basis during Trial 1. Nutrient concentrations are consistent with published requirements (139) except slightly lower CP, due to lower CP in all feed ingredients than original analyses predicted.

TABLE 5. Classification of experimental rations.

Body wt (kg):	136	227	316
% of NRC[a]	-----(treatment number)----		
85	1	2	3
95	4	5	6
105	7	8	9
115	10	11	12

[a]Percent of NRC requirement for energy.

TABLE 6. Mean[a] plus standard error (SE) of dry matter (DM), crude protein (CP), acid detergent fiber (ADF), and total digestible nutrients (TDN) in feed ingredients of all rations, Trial 1.

Item	Block 1	SE	Block 2	SE	Block 3	SE
	(%)					
Corn Silage						
DM	39.0	1.1	34.8	1.0	43.1	.9
CP	8.5	.3	8.7	.3	8.4	.2
ADF	25.9	1.9	28.2	1.4	24.0	1.6
TDN	68.0	.9	66.9	.7	68.9	.8
Orchardgrass hay						
DM	87.4	.5	89.3	.9	88.7	.5
CP	10.7	.2	9.9	.1	10.4	.4
ADF	43.9	2.1	46.9	1.5	41.5	1.8
TDN	51.2	2.3	47.9	1.7	54.0	2.0
High moisture corn						
DM	80.1	.2	77.1	1.3	76.4	.2
CP	9.9	.2	10.3	.2	11.1	.2
ADF	8.5	2.0	6.4	.4	6.9	.1
TDN	83.3	1.5	84.9	.3	84.5	.1
Soybean meal						
DM	88.0	.4	86.5	.5	88.9	.3
CP	47.0	.9	47.3	.4	46.2	.7
ADF	13.4	1.2	14.7	.7	14.2	.5
TDN	79.5	.9	78.5	.6	78.9	.4

[a]Mean and standard error for n = 4.

TABLE 7. Content of minerals in feed ingredients used in preliminary and experimental rations, Trial 1.

	Corn silage	Orchardgrass hay	High moisture corn	Soybean meal
	(% of dry matter)			
Calcium	.37	.57	.01	.55
Phosphorous	.31	.24	.27	.62
Magnesium	.24	.35	.27	.36
Potassium	1.45	1.43	.17	2.12
Sodium	.03	.01	.001	.01
Sulfur	.15	.25	.0	.45
	(ppm)			
Iron	215	93	51	222
Zinc	44	14	30	52
Copper	8	6	1	15
Manganese	20	56	9	38

TABLE 8. Ingredient composition of preliminary rations, Trial 1.

Ingredient	Body weight group		
	light	medium	heavy
	------(% of dry matter)------		
Corn silage	33.0	47.9	54.7
Orchardgrass hay	15.9	23.0	26.3
Corn[a]	43.6	26.0	17.6
Soybean meal	6.8	2.8	1.1
Mineral mixture	.8	.4	.3

[a]Both high moisture and dried corn.

Ingredient composition of experimental rations fed in Trial 1 varied as energy concentration of the ration increased (Table 9). This was required to assure that requirements for protein and minerals were met. Treatments 2 and 3 were formulated with 100% ground hay (Table 9). Requirements for all macrominerals were met except sodium (10% of requirement supplied for both treatments) and phosphorous (89 and 97% supplied for treatments 2 and 3, respectively). Block trace mineral salt was supplied to all heifers to allow ad libitum consumption. No apparent effects of feed refusal due to extremes in ration energy composition were observed.

Percent DM of experimental rations was analyzed to determine whether daily variation was attributable to random variation, and therefore, could be ignored by pooling daily samples into weekly composites. Daily DM was tested separately for each treatment using the model:

$$DM_i = \beta_0 + \beta_1(day)_i + \beta_2(day^2)_i + \varepsilon_i$$

where: DM = daily DM of ration, %

day = day of experiment,

Only daily DM of ration 8 was affected significantly ($\underline{P}<.05$) by effects of day or day^2. Dry matter of ration 8 was lower during wk 1 and 2 (54.6 and 56.3, respectively), higher during wk 3 (59.0), and decreased during wk 4 (57.1). It was concluded that rations could be composited by week

TABLE 9. Ingredient composition of experimental rations, Trial 1.

	136 kg				227 kg				317 kg			
	85	95	105	115	85	95	105	115	85	95	105	115
	(% of dry matter)											
CS[a]	48.3	47.7	23.6	27.8	.0	50.8	41.4	39.0	.0	36.7	61.1	64.1
Hay[b]	39.2	24.5	15.3	.0	100	34.7	27.9	20.7	100	58.1	22.2	7.9
SBM[c]	7.8	7.7	5.7	10.1	.0	2.4	4.8	3.2	.0	.6	1.1	1.1
HMC[d]	3.9	19.3	54.7	60.7	.0	11.3	25.5	36.6	.0	4.3	15.3	26.5
TM salt	.7	.1	.0	.1	.0	.0	.2	.2	.0	.2	.0	.0
Min[e,f]	.1	.6	.7	1.3	.0	.8	.2	.5	.0	.0	.3	.3

[a]Corn silage.

[b]Orchardgrass hay.

[c]Soybean meal.

[d]High moisture corn.

[e]Mineral mixture.

[f]Treatment 10 contained .8% of ration DM as dolomitic limestone.

and one DM determined with no loss of predictability. Diurnal variation of rations fed once daily would result in changes in DM of the ration throughout the day, possibly greater than variation in daily DM determinations.

Dry matter intake and ration energy parameters pooled for Trial 1 (Table 10) suggest data contained a sufficiently wide range of energy concentration (TDN, NE_m, NE_g) and fiber levels (NDF, ADF) to be predictive of most practical situations. Dry matter intake ranged from a minimum of 0 kg/day to a maximum of 12.6 kg/day; a range greater than listed by (139) for growing dairy heifers. Greater range than that of NRC would be expected, as tables of nutrient requirements are averages for a given body weight, and do not contain variation inherent in experimental data.

Energy in rations (NE_m, NE_g, TDN) varied with treatment and was consistent with ration formulations. Net energy for maintenance and gain averaged 1.46 and .84 Mcal/kg DM (Table 10), with ranges of .84 and 1.07 Mcal/kg.

Ration acid detergent fiber concentration pooled for Trial 1 were greater than that allowing for maximum DM intake (23%) (88), but a range of 32.4% ADF allowed for both physical and metabolic effectors of intake to be observed.

Intake of ration DM and other selected variables for heifers weighing approximately 136 kg are in Table 11. Body weights were greater than 136 kg for all energy level

TABLE 10. Mean, standard error (SE), minimum and maximum dry matter intake (DMI), ration acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), net energy maintenance (NEm), net energy gain (NEg), and bulk density (BD), and body weight (BWT), daily gain (GAIN), and ambient temperature (AMBT) for all treatments, Trial 1.

	N	Mean	SE	Min	Max
DMI[a]	2513	6.0	.04	.0	12.6
ADF[b]	48	29.4	1.2	12.2	44.6
NDF[b]	48	50.5	1.7	28.0	71.8
TDN[b]	48	66.5	1.1	50.5	80.4
NEm[c]	48	1.46	.03	1.03	1.87
NEg[c]	48	.84	.04	.18	1.25
BD[d]	42	.16	.01	.06	.33
BWT[e]	2576	240.	1.3	117.	393.
GAIN[e]	2484	1.0	.01	-1.2	4.0
AMBT[f]	2512	4.1	.10	-11.3	14.8

[a]Kilograms/day.

[b]Percent of DM.

[c]Megacalories/kg DM.

[d]Grams/ml as fed.

[e]Kilograms. Predicted by regression from weekly body weights.

[f]Degrees.

groups, and tended to increase with increasing ration energy. Intake of ration DM increased from 4.0 kg/day at 85% of NRC requirement for energy to 5.7 kg/day at 105% of NRC requirement; at 115% of NRC requirement for energy, intake decreased to 5.0 kg/day (Table 11). This trend must be interpreted carefully, as both energy in rations and body weight increased with increasing DM intake, and effects may be confounded. When expressed as a percent of body weight, heifers consumed daily 2.53, 2.72, 3.26, and 2.78 of body weight as DM. No explanation is proposed for unusually high intake of DM by heifers fed rations containing 105% of NRC requirements for energy during Trial 1. Generally, average intake at 85% of NRC requirement for energy was similar to that of (139) for heifers weighing 158 kg; all other DM intakes were higher than (139) for their respective body weights. Requirements as stated by (139) for heifers weighing 169, 175, and 180 kg are 4.4, 4.5, and 4.7 kg DM intake/day. Rates of daily gain were acceptable (.6 kg/day) for light heifers even at 85% of NRC requirement for energy. Gain was 1.3 kg/day at 105 and 115% of NRC requirement for energy, somewhat higher than current recommendations (43, 44, 61, 89, 139, 175).

Mean DM intake and other selected variables for heifers weighing approximately 227 kg are in Table 12. Energy increased and fiber decreased with increasing proportion of

TABLE 11. Mean and standard error (SE) of dry matter intake (DMI), ration acid detergent fiber (ADF), neutral detergent fiber (NDF), net energy maintenance (NEm), net energy gain (NEg), bulk density (BD), daily body weight (BW), body weight gain (GAIN), and ambient temperature (AMBT) for heifers weighing 136 kg, Trial 1.

Item	Percent of NRC Requirement 85		95		105		115	
	X	SE	X	SE	X	SE	X	SE
DMI[a]	4.0	.1	4.6	.1	5.7	.1	5.0	.1
ADF[b]	35.2	.2	27.8	1.6	17.8	1.9	15.0	.9
NDF[b]	51.9	2.0	41.7	3.7	40.9	4.0	30.9	1.4
TDN[b]	62.8	.1	68.5	1.2	76.1	1.4	78.6	.8
NEm[c]	1.4	.0	1.5	.0	1.7	.0	1.8	.0
NEg[c]	.75	.0	.93	.03	1.09	.06	1.2	.02
BD[d]	.14	.0	.17	.01	.22	.01	.30	.02
BW[e]	158.	1.6	169.	1.5	175.	1.5	180.	1.1
GAIN[e]	.6	.0	.9	.0	1.3	.0	1.4	.0
AMBT[f]	5.0	.3	5.0	.3	-.5	.3	7.6	.2

[a]Kilograms; n = 214, 217, 224, and 224.

[b]Percent of dry matter; n = 4.

[c]Megacalories/kg dry matter; n = 4.

[d]Grams/ml as fed basis; n = 4.

[e]Kilograms; n = 224 for body weight and n = 216 for body weight gain.

[f]Degrees; n = 224, 224, 208, and 224.

TABLE 12. Mean and standard error (SE) of dry matter intake (DMI), ration acid detergent fiber (ADF), neutral detergent fiber (NDF), net energy maintenance (NEm), net energy gain (NEg), bulk density (BD), daily body weight (BW), body weight gain (GAIN) and ambient temperature (AMBT) for heifers weighing 227 kg, Trial 1.

Item	Percent of NRC Requirement							
	85		95		105		115	
	X	SE	X	SE	X	SE	X	SE
DMI[a]	4.3	.1	6.2	.1	6.8	.1	6.5	.1
ADF[b]	41.5	1.8	31.0	1.5	28.2	1.1	27.6	1.1
NDF[b]	69.3	.9	55.7	1.4	50.5	2.0	45.3	1.9
TDN[b]	54.0	2.0	66.0	1.1	68.2	.8	68.7	.8
NEm[c]	1.1	.1	1.4	.0	1.5	.0	1.5	.0
NEg[c]	.39	.10	.86	.03	.92	.03	.93	.02
BD[d]	.08	.01	.17	.0	.15	.0	.18	.02
BW[e]	209.	1.9	244.	1.4	246.	2.7	246.	2.0
GAIN[e]	.6	.1	1.1	.0	1.1	.0	1.3	.0
AMBT[f]	7.6	.2	-.5	.3	7.6	.2	5.0	.3

[a]Kilograms; n = 189, 216, 224, and 196.

[b]Percent of dry matter; n = 4.

[c]Megacalories/kg dry matter; n = 4.

[d]Grams/ml as fed basis; n = 4.

[e]Kilograms; n = 196, 224, 224, and 196 for body weight and 189, 216, 216, and 189 for body weight gain.

[f]Degrees; n = 196, 208, 224, and 196.

NRC requirement for energy. Heifer body weights tended to be least at 85% of NRC requirement (209 kg). Both intake and gain were similar to or greater than NRC requirements at 95, 105, and 115% of NRC requirements of energy.

Trends for intake, ration energy and fiber concentrations, and animal gain for heifers weighing approximately 317 kg were similar to lighter heifers (Table 13). Both intake and gain were depressed somewhat at 85% of NRC requirement for energy compared to higher energy levels. Ration variables increased (TDN, NE_m, NE_g, bulk density) and decreased (ADF, NDF) with increasing percent of NRC requirement.

Data for all body weight groups (Tables 10 to 14) suggest that DM intake and independent variables measured include the range of energy and fiber levels typical of present TMR feeding systems, and therefore may be used to generate predictive equations.

B. Trial 2

Nutrient and mineral content of feed ingredients used in preliminary and experimental rations are in Tables 14 and 15, respectively. Corn silage used during the preliminary period and week 1 of block 4 averaged 14.3% protein in DM due to use of ammonia at ensiling. Large standard error of CP of corn silage during block 4 is attributed to variation resulting from changing to nonammoniated silage during week

TABLE 13. Mean and standard error (SE) of dry matter intake (DMI), ration acid detergent fiber (ADF), neutral detergent fiber (NDF), net energy maintenance (NEm), net energy gain (NEg), bulk density (BD), daily body weight (BW), body weight gain (GAIN), and ambient temperature (AMBT) for heifers weighing 317 kg, Trial 1.

Item	Percent of NRC Requirement							
	85		95		105		115	
	X	SE	X	SE	X	SE	X	SE
DMI[a]	5.5	.1	7.5	.1	8.1	.1	8.1	.1
ADF[b]	41.5	1.8	35.9	1.2	27.8	1.1	24.4	.6
NDF[b]	69.3	.9	53.7	2.8	49.8	3.2	46.5	2.4
TDN[b]	54.0	2.0	62.2	.9	68.5	.9	71.0	.5
NEm[c]	1.1	.1	1.3	.0	1.5	.0	1.6	.0
NEg[c]	.39	.98	.74	.03	.93	.03	1.01	.01
BD[d]	.08	.01	.12	.01	.17	.01	.24	.01
BW[e]	307.	1.4	296.	1.6	339.	1.8	319.	1.6
GAIN[e]	.6	.0	.6	.0	1.1	.0	1.2	.0
AMBT[f]	7.6	.2	5.0	.4	-.5	.3	-.5	.3

[a]Kilograms; n = 215, 162, 224, and 208.

[b]Percent of dry matter; n = 4.

[c]Megacalories/kg dry matter; n = 4.

[d]Grams/ml as fed basis; n = 4.

[e]Kilograms; n = 224, 168, 224, and 224 for body weight and 216, 162, 216, and 216 for body weight gain.

[f]Degrees; n = 224, 168, 208, and 208.

TABLE 14. Mean[a] plus standard error (SE) of dry matter (DM), crude protein (CP), acid detergent fiber (ADF), and total digestible nutrients (TDN) in feed ingredients of all rations, Trial 2.

Item	Block 4	SE	Block 5	SE	Block 6	SE
	(%)					
Corn Silage						
DM	41.5	.9	47.0	1.0	44.4	.6
CP	10.2	1.4	8.1	.2	10.0	1.9
ADF	27.4	1.1	31.0	1.8	28.4	1.2
TDN	67.2	.5	65.5	.9	66.8	.6
Orchardgrass hay						
DM	86.8	1.2	86.4	.9	84.2	1.1
CP	10.2	.5	11.3	.6	9.6	.3
ADF	40.6	2.2	38.3	1.5	39.4	.8
TDN	54.9	2.5	57.6	1.7	56.3	.8
High moisture corn						
DM	74.3	.4	72.0	.5	72.6	.5
CP	10.6	.8	11.1	.6	10.6	.0
ADF	6.2	.6	5.9	.6	4.9	.2
TDN	85.1	.5	85.3	.5	86.1	.1
Soybean meal						
DM	89.4	.5	85.6	.8	87.3	.7
CP	45.3	1.4	51.1	2.2	50.5	.7
ADF	12.8	.7	10.7	.8	9.8	.2
TDN	80.0	.5	81.6	.6	82.3	.2

[a]Mean and standard error for n = 4.

2 of block 4. Content of nutrients used in feed ingredients during Trial 2 were consistent with those of Trial 1, and similar to (139). Corn silage tended to be higher in DM during Trial 2, and contained slightly more CP than in Trial 1. Orchardgrass contained less ADF during Trial 2, which resulted in a higher predicted TDN. Soybean meal tended to contain somewhat more CP during blocks 5 and 6 (51.1 and 50.5% of DM) than in previous blocks (Table 14).

Minerals in feed ingredients used in Trial 2 were similar to Trial 1, except for more calcium and less sodium in soybean meal used in Trial 2. Sulfur was not determined in Trial 2 (Table 15).

Animals were generally healthy during Trial 2. One animal was removed from the study during block 5 after treatment for infectious conjunctivitis (pinkeye). One suspected case of infectious conjunctivitis was not removed from the data set. Due to animal availability, 32, 30, and 28 animals were used during blocks 4, 5, and 6, respectively.

Ingredient composition of preliminary rations fed during Trial 2 are in Table 16. Feeding management was similar to that of Trial 1. Rations were, when possible, formulated to contain more corn silage due to somewhat higher protein in silage during Trial 2. Trace mineral salt was fed in all rations in accordance with published requirements (139), and

TABLE 15. Content of minerals in feed ingredients used in preliminary and experimental rations, Trial 2.

	Corn silage	Orchardgrass hay	High moisture corn	Soybean meal
	(% of dry matter)			
Calcium	.34	.31	.03	.93
Phosphorous	.31	.20	.32	.60
Magnesium	.22	.20	.15	.27
Potassium	1.13	1.59	.37	2.11
Sodium	.01	.08	.01	.00
Sulfur				
	(ppm)			
Iron	248	79	56	133
Zinc	26	24	28	41
Copper	5	4	2	9
Manganese	29	54	9	45

limestone was added to light group rations to provide proper amounts of calcium. Basal ration fed to all heifers prior to addition of concentrate to light and medium groups averaged 50.7% DM, 9.2% CP, 28.1% ADF, and 68.2% TDN.

Ingredient compositions of experimental rations formulated in Trial 2 are in Table 17. Formulations were similar to Trial 1 except for treatments 1, 4, and 11. Treatments 1 and 4 were formulated to provide lower and higher amounts of energy, respectively, during Trial 2. Treatment 11 was formulated to similar energy as in Trial 1, but with less high moisture corn added to the ration.

Table 18 contains DM intake, body weight and gain, and ration and temperature parameters pooled for Trial 2. Generally, all parameters were similar to those of Trial 1, except for a higher mean ambient temperature during Trial 2 (4.1 vs 20.8°C). Minimum and maximum temperatures were also higher during Trial 2. Intake of DM during Trial 2 averaged 6.1 kg/day vs. 6.0 kg/day during Trial 1 with a standard error of .04 and range of 16.8 kg/day (Table 18). Such a range should provide data descriptive of most TMR feeding systems.

Fiber and energy parameters provide independent variables in the data with ranges larger than those reported in (89), (90), and (139) and are probably descriptive of most practical situations. Bulk density of rations was similar

TABLE 16. Ingredient composition of preliminary rations, Trial 2.

Ingredient	Body weight group light	medium	heavy
	------(% of dry matter)-----		
Corn silage	42.5	67.3	68.3
Orchardgrass hay	12.9	21.1	21.6
High moisture corn	5.1	8.9	9.2
Soybean meal	7.7	2.4	.6
Mineral mixture	.3	.0	.0
Trace mineral salt	.1	.2	.2
Ground shell corn	30.9	.0	.0
Limestone	.5	.0	.0

for both trials. Body weights averaged 15 kg more during Trial 2 than Trial 1, although minimum and maximum values for the data set were obtained during Trial 1. Average daily gains were similar (Table 10 and 14), but tended to have greater variation during Trial 2.

Mean DM intake and ration, animal, and temperature parameters for heifers weighing 136 kg are in Table 19. Unlike Trial 1, intake of DM did not increase with increasing ration energy. When expressed as a percent of body weight, heifers consumed daily 2.72, 2.74, 2.78, and 2.74% of body weight as DM. Explanations for this apparent discrepancy are not evident. Energy in rations expressed as TDN or NE_m and NE_g were similar (Tables 11 and 19). It is possible that at 85% of energy requirement, physical limitation of intake affected lighter, smaller heifers in Trial 1 (average body weight 158 kg) more acutely than larger heifers in Trial 2 (average body weight 202 kg). Also possibly affecting these animals was different ingredient composition of rations used in both trials. Treatment 1 (85% of NRC requirement, 136 kg) during Trial 1 contained 48% corn silage, 40% hay and 4% high moisture corn, whereas treatment 1 in Trial 2 contained 27% corn silage, 45% hay and 19% high moisture corn. Ration containing less corn silage and more high moisture corn during Trial 2 was more palatable or digestible than Trial 1, thereby resulting in DM intake

TABLE 17. Ingredient composition of experimental rations, Trial 2.

	136 kg				227 kg				317 kg			
	85	95	105	115	85	95	105	115	85	95	105	115
	(% of dry matter)											
CS[a]	27.4	45.6	32.7	26.7	.0	52.9	42.7	42.5	.0	39.7	62.4	64.9
Hay[b]	44.6	25.1	11.1	.0	100	35.33	27.7	50.9	100	53.3	21.0	5.3
SBM[c]	8.4	8.5	8.3	7.7	.0	5.3	4.9	2.1	.0	5.3	2.6	2.7
HMC[d]	18.8	20.1	46.7	64.1	.0	6.2	24.4	4.3	.0	6.2	13.8	26.7
TM salt	.0	.0	.1	.1	.0	.2	.0	.1	.0	.2	.2	.2
Min[e,f]	.4	.4	.5	.6	.0	.2	.3	.2	.0	.2	.1	.2

[a]Corn silage.

[b]Orchardgrass hay.

[c]Soybean meal.

[d]High moisture corn.

[e]Mineral mixture.

[f]Treatments 1, 4, 7, and 10 contained .4, .3, .6, and .8% of ration DM, respectively, as dolomitic limestone.

above satiety. Finally, higher temperature during Trial 2 (21.9°C) may have affected heifers receiving low energy rations more than lower temperatures during Trial 1 (5.0°C).

Intake of DM and ration, performance, and temperature parameters for heifers weighing 227 kg in Trial 2 are in Table 20. Although heifers receiving 85% of NRC requirements averaged 36 kg more body weight than heifers in Trial 1 (Table 12), they consumed an average of 1.1 kg DM/day less than those in Trial 1, and only 1.3% of body weight in daily DM. Energy was somewhat higher and fiber lower during Trial 2, therefore it would be expected that intake would be higher during Trial 2. Ration fiber and energy as formulated did not vary as anticipated; ration ADF averaged 34, 33, and 32% of DM for 95, 105, and 115% of NRC requirement for energy. Bulk density of rations did not vary from .14 to .15 g/ml as fed (Table 20). From 95 to 115% of NRC requirement for energy in rations, heifers consumed 2.6, 2.7, and 2.7% of body weight in daily DM.

Daily gains for heifers weighing 227 kg during Trial 2 averaged .4, .8, 1.0, and 1.0 kg/day for 85, 95, 105, and 115% of NRC requirement for energy (Table 20). Daily gain did not differ markedly above 95% of NRC requirement for energy; this is due probably to similarity of energy content of rations.

Intake of DM and ration, performance, and environmental

TABLE 18. Mean, standard error (SE), minimum and maximum dry matter intake (DMI), ration acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients (TDN), net energy maintenance (NEm), net energy gain (NEg), and bulk density (BD), and body weight (BWT), daily gain (GAIN), and ambient temperature for all treatments, Trial 2.

	N	Mean	SE	Min	Max
DMI[a]	2459	6.1	.04	.0	16.8
ADF[b]	48	30.5	1.2	9.4	45.4
NDF[b]	48	52.8	1.7	24.1	72.4
TDN[b]	48	65.8	1.0	49.6	82.6
NEm[c]	48	1.44	.0	1.06	1.95
NEg[c]	48	.84	.03	.26	1.30
BD[d]	48	.16	.01	.06	.32
BWT[e]	2520	255.	1.2	122.	386.
GAIN[e]	2430	.8	.01	-2.4	4.3
AMBT[f]	2520	20.8	.07	8.6	25.6

[a]Kilograms/day.

[b]Percent of DM.

[c]Megacalories/kg DM.

[d]Grams/ml as fed.

[e]Kilograms. Predicted by regression from weekly body weights.

[f]Degrees.

TABLE 19. Mean and standard error (SE) of dry matter intake (DMI), ration acid detergent fiber (ADF), neutral detergent fiber (NDF), net energy maintenance (NEm), net energy gain (NEg), bulk density (BD), daily body weight (BW), body weight gain (GAIN), and ambient temperature (AMBT) for heifers weighing 136 kg, Trial 2.

Item	Percent of NRC Requirement							
	85		95		105		115	
	X	SE	X	SE	X	SE	X	SE
DMI[a]	5.5	.1	4.9	.1	4.9	.1	5.1	.1
ADF[b]	34.5	1.7	29.2	1.0	19.1	1.0	13.1	1.6
NDF[b]	60.1	2.4	48.9	2.2	40.7	.7	30.2	3.0
TDN[b]	63.3	1.3	67.4	.8	75.2	.7	79.7	1.3
NEm[c]	1.4	.0	1.5	.0	1.7	.0	1.9	.0
NEg[c]	.77	.04	.90	.02	1.12	.02	1.23	.03
BD[d]	.10	.0	.19	.01	.23	.01	.30	.01
BW[e]	202.	1.6	179.	1.4	176.	2.1	186.	1.8
GAIN[e]	.7	.0	.7	.0	1.1	.0	1.4	.0
AMBT[f]	21.9	.2	21.5	.3	18.8	.3	18.8	.2

[a]Kilograms; n = 116, 223, 162, and 189.

[b]Percent of dry matter; n = 4.

[c]Megacalories/kg dry matter; n = 4.

[d]Grams/ml as fed basis; n = 4.

[e]Kilograms; n = 168, 224, 168, and 196 for body weight and n = 162, 216, 162, and 189 for body weight gain.

[f]Degrees; n = 168, 224, 168, and 196.

TABLE 20. Mean and standard error (SE) of dry matter intake (DMI), ration acid detergent fiber (ADF), neutral detergent fiber (NDF), net energy maintenance (NEm), net energy gain (NEg), bulk density (BD), daily body weight (BW), body weight gain (GAIN), and ambient temperature (AMBT) for heifers weighing 227 kg, Trial 2.

Item	Percent of NRC Requirement 85		95		105		115	
	X	SE	X	SE	X	SE	X	SE
DMI[a]	3.2	.1	6.2	.1	7.1	.1	7.0	.1
ADF[b]	39.4	.8	34.4	2.0	32.9	.9	31.6	1.0
NDF[b]	65.6	.4	58.3	.9	45.9	5.9	55.7	1.6
TDN[b]	55.8	1.1	63.4	1.5	64.6	.7	65.6	.8
NEm[c]	1.2	.0	1.4	.0	1.4	.0	1.4	.0
NEg[c]	.54	.02	.77	.05	.81	.02	.8	.02
BD[d]	.08	.0	.15	.0	.14	.0	.14	.0
BW[e]	245.	.5	237.	1.4	264.	1.2	258.	1.0
GAIN[e]	.4	.0	.8	.1	1.0	.0	1.0	.0
AMBT[f]	18.8	.2	21.5	.3	21.9	.1	21.9	.1

[a]Kilograms; n = 216, 217, 224, and 224.

[b]Percent of dry matter; n = 4.

[c]Megacalories/kg dry matter; n = 4.

[d]Grams/ml as fed basis; n = 4.

[e]Kilograms; n = 224 for body weight and n = 216 for body weight gain.

[f]Degrees; n = 224.

parameters for heifers weighing 317 kg in Trial 2 are in Table 21. Intake of heifers fed 85 and 115% of NRC requirement for energy tended to be lower (1.9 and 2.4% of body weight, respectively) than of heifers fed 95 or 105% of NRC requirement for energy (2.5% of body weight). Both ADF and NDF decreased and bulk density, energy parameters (TDN, NE_m, NE_g) and daily gain increased with increasing ration energy. Similar trends were observed in Trial 1 (Table 13).

C. Development of prediction equations

1. Introduction

Effects of ADF, NDF, and bulk density on DM intake (g/kg body weight$^{.75}$) estimated by second order polynomial regression are shown in Figure 6, 7, and 8, respectively. Equations generated were: ADF, Y = 76.35 + 2.93 * ADF - .07 * ADF^2, r^2 = .44, $s_{y.x}$ = 11.10, n = 96, (Figure 6); NDF, Y = 45.42 + 3.03 * NDF - .04 * NDF^2, r^2 = .46, $s_{y.x}$ = 10.89 n = 96, (Figure 7); bulk density, Y = 43.65 + 569.07 * BD - 1257.42 * BD^2, r^2 = .46, $s_{y.x}$ = 10.95, n = 88, (Figure 8). Each equation was generated using means of each treatment for each week for each trial.

Maximum intake of DM is reached when ADF in ration DM is between 20 and 23%, (Figure 6), in close agreement with findings of Jahn et al. (88) and Kang and Liebholz (99), who reported maximum intake of DM at 20 and 23% ADF in ration DM, respectively. Below 20% ADF, metabolic factors appa-

TABLE 21. Mean and standard error (SE) of dry matter intake (DMI), ration acid detergent fiber (ADF), neutral detergent fiber (NDF), net energy maintenance (NEm), net energy gain (NEg), bulk density (BD), daily body weight (BW), body weight gain (GAIN), and ambient temperature (AMBT) for heifers weighing 317 kg, Trial 2.

	Percent of NRC Requirement							
Item	85		95		105		115	
	X	SE	X	SE	X	SE	X	SE
DMI[a]	5.7	.1	7.5	.1	8.3	.1	8.0	.1
ADF[b]	40.6	2.2	37.2	1.2	29.0	1.0	25.4	1.0
NDF[b]	67.4	1.8	63.8	1.5	50.6	1.5	50.0	1.2
TDN[b]	55.0	2.5	61.3	.9	67.6	.8	70.3	.8
NEm[c]	1.2	.1	1.3	.0	1.5	.0	1.6	.02
NEg[c]	.47	.09	.70	.03	.91	.02	.98	.02
BD[d]	.07	.0	.11	.01	.20	.01	.25	.02
BW[e]	307.	1.7	303.	1.1	336.	2.2	334.	1.0
GAIN[e]	.4	.1	.7	.0	.8	.0	1.2	.0
AMBT[f]	21.5	.3	21.9	.1	21.5	.3	18.8	.2

[a]Kilograms; n = 215, 215, 224, and 182.

[b]Percent of dry matter; n = 4.

[c]Megacalories/kg dry matter; n = 4.

[d]Grams/ml as fed basis; n = 4.

[e]Kilograms; n = 224, 224, 224, and 196 for body weight and n = 216, 216, 216, and 189 for body weight gain.

[f]Degrees; n = 224, 224, 224, and 196.

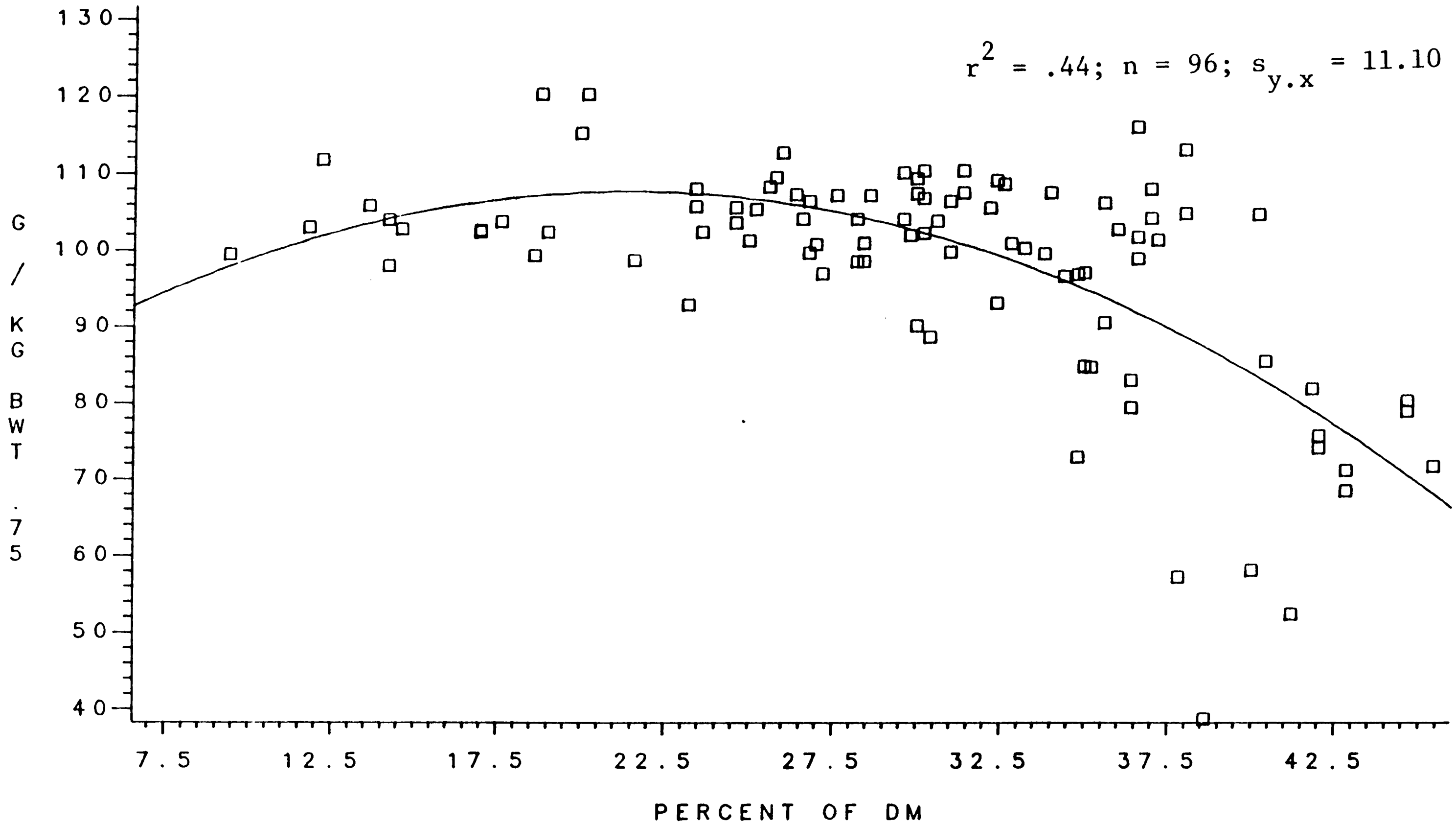

Figure 6. Second order polynomial regression of acid detergent fiber (PERCENT OF DM) on dry matter intake (G/KG BWT$^{.75}$) of heifers weighing 100 to 400 kg.

rently control intake, and above 23% ADF in ration DM, intake of DM by heifers may have been limited by physical factors (rumen distention, rate of passage, rate of fermentation).

Relationship between intake of DM as a percent of metabolic body weight and NDF in ration DM is curvilinear (Figure 7). Maximum intake of DM occurs between 38 and 43% NDF, in agreement with findings of Mertens (119) that intake of DM was maximized in lactating dairy cows at 39% NDF in total mixed ration DM. Rations fed by Mertens were based on coastal bermudagrass, corn, and soybean meal. Van Soest (191) reported that maximum intake of forages occurs between 50 and 60% cell wall content in the ration. Inclusion of concentrate ingredients, thus changing ratio of NDF to energy in the current study and by Mertens (119) may affect the point of maximum intake.

Bulk density expressed g/ml on an as fed basis was related to intake of DM by a quadratic function as shown in Figure 8. Bulk density, a physical measure of feed quality, resulted in prediction of DM intake equivalent (as estimated by r^2) to other chemical methods such as ADF. Below approximately .22 g/ml intake appears to be limited by physical control factors. Above .22 g/ml, metabolic factors become effective, and intake is decreased (Figure 8).

Coefficients of correlation between intake of DM and

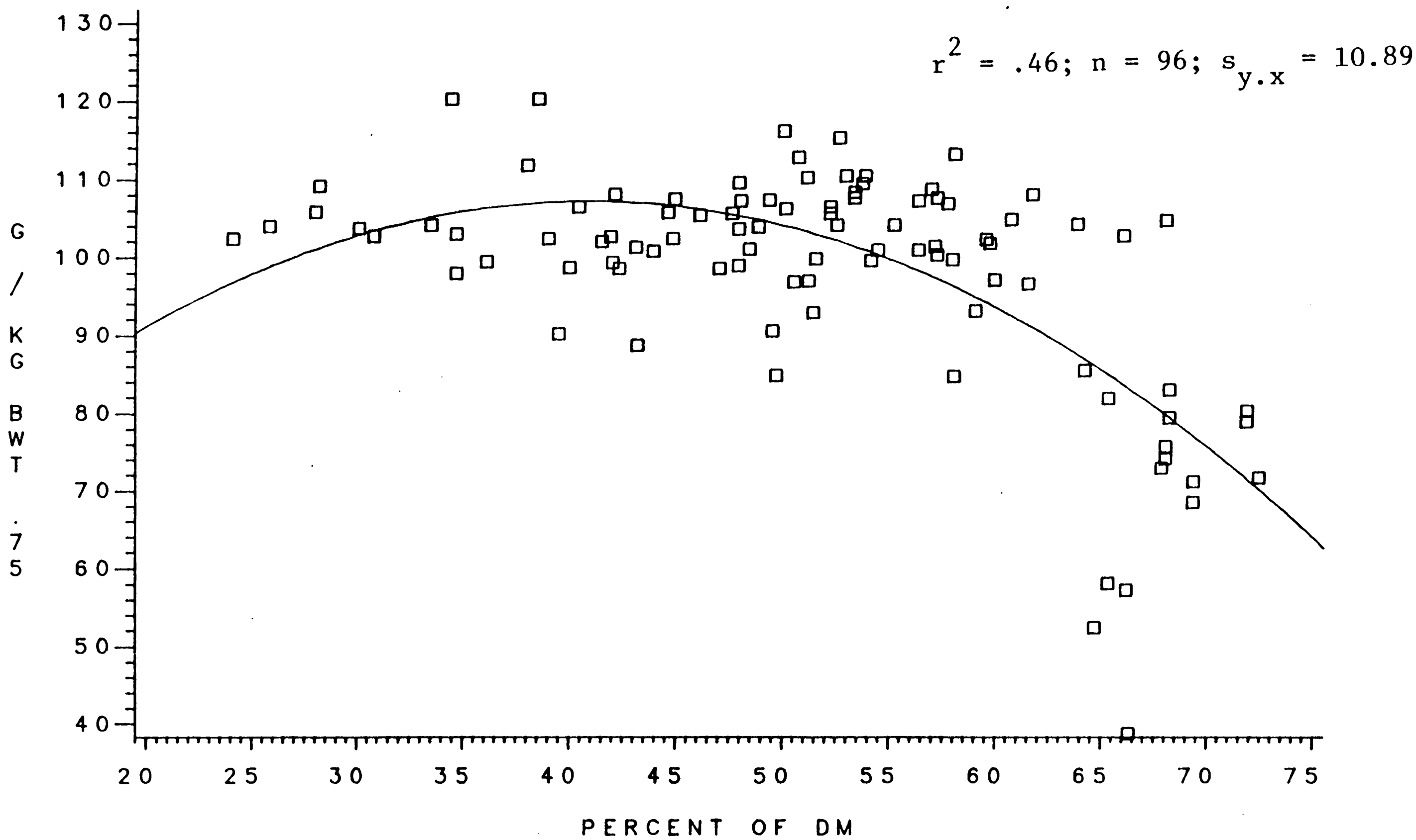

Figure 7. Second order polynomial regression of neutral detergent fiber (PERCENT OF DM) on dry matter intake (G/KG $BWT^{.75}$) of heifers weighing 100 to 400 kg.

independent variables were significant at $P<.0001$ (Table 22). Relationship between intake of DM and body weight was highest (.66), and NDF was lowest (-.05). Because of the large number of observations, biological significance of many coefficients may be questionable. It is probable that the relationship between fiber and energy parameters and intake of DM were actually curvilinear, (Figures 6, 7, and 8), therefore, linear coefficients would not be expected to be large.

Van Soest and coworkers (120, 191) reported high correlations between NDF content of forages and voluntary intake. It is of interest, then, that correlations between NDF in ration DM and intake of DM are low (-.05), and curvilinear regression of NDF and intake of DM as a percent of metabolic body weight (Figure 7) should be similar in predictive ability to those of ADF (Figure 6) and bulk density (Figure 8). Because forages appear to involve physical control of intake, it was of interest to determine whether NDF was more highly correlated with DM intake at higher NDF than when NDF was lower. Correlations between intake of DM, ADF and NDF in ration DM, and bulk density when NDF in ration DM was greater than 40% (physical regulation) or less than 40% (metabolic regulation) are in Table 23. Approximately 4000 observations were greater than 40%, and 800 less than 40% NDF in ration DM. Correlation between NDF and DM intake at

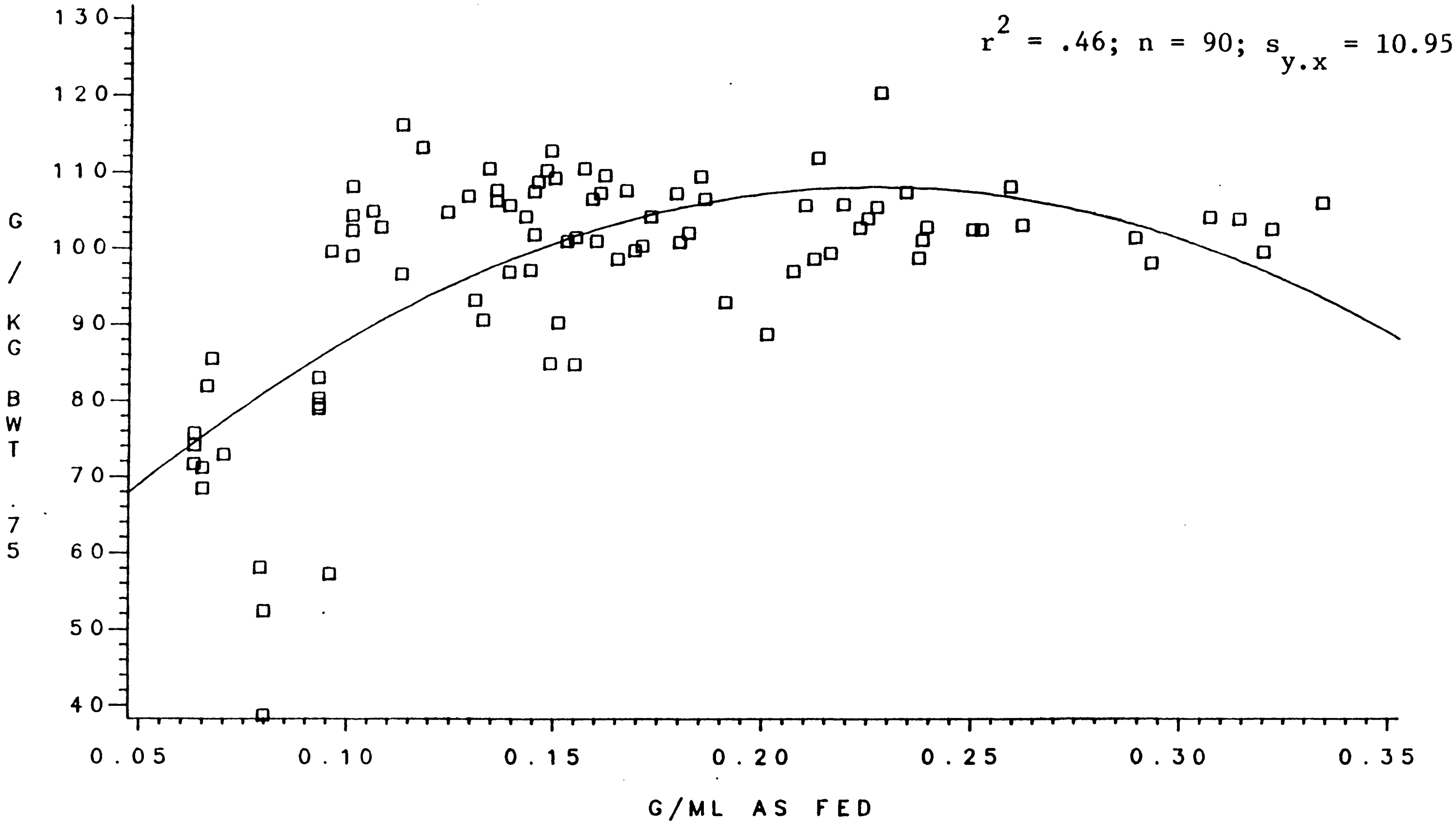

Figure 8. Second order polynomial regression of bulk density (G/ML AS FED) on dry matter intake (G/KG BWT$^{.75}$) of heifers weighing 100 to 400 kg.

TABLE 22. Correlation coefficients[a] and probabilities of dry matter intake (DMI), predicted daily body weight (BWT) and daily gain (GAIN), and ration acid detergent fiber (ADF), neutral detergent fiber (NDF), total digestible nutrients, and net energy maintenance (NEm), and gain (NEg), Trial 1.

	BWT	GAIN	ADF	NDF	TDN	NEm	NEg	BULK
DMI[b]	.66	.14	-.07	-.05	.12	.11	.16	.11
BWT[c]		-.08	.30	.33	-.28	-.29	-.25	-.21
GAIN[d]			-.38	-.37	.38	.37	.35	.38
ADF[f]				.84	-.99	-.99	-.94	-.89[g]
NDF[f]					-.85	-.85	-.84	-.85
TDN[f]						.99	.98	.89[g]
NEm[f]							.98	.89[g]
NEg[f]								.86[g]

[a]All coefficients significant at $\underline{P}$<.0001.

[b]Coefficients for n = 4972.

[c]Coefficients for n = 5109.

[d]Coefficients for n = 4927.

[e]Coefficients for n = 2484.

[f]Coefficients for n = 96.

[g]Coefficients for n = 90.

NDF greater and less than 40% were -.29 and -.14, respectively, suggesting that NDF may be more involved in regulation of voluntary intake in higher NDF rations. Similarly removing variation of metabolic body weight increased the correlation between NDF and DM intake to -.41 (Table 23). Removing variation of metabolic body weight caused the coefficient between DM intake and NDF to become nonsignificant (P=.73). Coefficients between ADF and DM intake (g/kg body weight$^{.75}$) followed trends similar to those of NDF. However, in contrast to the findings of Van Soest (191), ADF was more highly correlated to intake of DM than NDF in almost all cases (Table 23). Bulk density was more highly correlated with intake of DM than NDF or ADF when NDF was less than or greater than 40% of ration DM. When NDF was less than 40% of ration DM, correlation of bulk density and DM intake was -.15 (Table 23). Removing metabolic body weight from DM intake caused bulk density to become nonsignificant. A significant correlation between DM intake and ration parameters is expected, due to experimental design.

Correlation between NDF and ADF was .82 when NDF was greater than 40% of ration DM, whereas it was only .09 when NDF was less than 40% of ration DM. Such a decline indicates that the ratio of NDF to ADF in the total ration changed with varying types of feed ingredients used in this trial. Correlation between NDF and bulk density behaved in

TABLE 23. Correlation coefficients[a] of intake of dry matter and ADF, NDF, and bulk density when NDF in ration dry matter is greater (physical) or less than (metabolic) 40%.

Correlation[b]	Physical	Metabolic
DMI : NDF	-.29	-.14
DMIBWTM : NDF	-.41	-.01[c]
DMI : ADF	-.30	.11
DMIBWTM : ADF	-.42	-.03[c]
DMI : Bulk	.34	-.15
DMIBWTM : Bulk	.39	-.02[c]
NDF : ADF	.82	.09
NDF : Bulk	-.82	-.41

[a]Number of observations: physical = 4148, metabolic = 824.

[b]DMI = intake of dry matter, kg/day,

DMIBWTM = intake of dry matter, g/kg metabolic body weight,

NDF = neutral detergent fiber, % of ration DM,

ADF = acid detergent fiber, % of ration DM,

Bulk = Bulk density, g/ml as fed basis.

[c]$\underline{P}>.05$.

a similar fashion.

Coefficient of correlation between intake of DM and ambient temperature was .006, $\underline{P}<.68$, n = 4908. Quadratic regression of ambient temperature for each day of the experiment on intake of DM as a percentage of metabolic body weight (Figure 9) was significant ($\underline{P}<.0001$), but only accounted for about 22% of total variation in the data set, suggesting other variables are important also.

Intake did not decrease above approximately 20 to 25^{o}C as predicted (140). It is possible that when ambient temperature was greater than 30^{o}C, heifers simply consumed feed during cooler night hours when heat stress was not a factor. Dulphy (59) reported that during hot weather 14 to 35% of grazing occurs at night in cattle.

Coefficients of correlation between independent variables are indicative of degree of colinearity, and suggests which independent variables, if any, may be substituted for one another in the data set (142). Variables estimated from ADF (NE_m, NE_g, and TDN) are related closely (Table 22) and may substitute for one another in predictive equations. Bulk density is also correlated with ADF, TDN, and NE_m (r = .89), and NE_g (r = .86), suggesting volume and fiber account for similar amounts of variation in intake of DM. High correlation between ADF and NDF (r = .84) was expected as ADF accounts for a major portion of total cell walls of plant

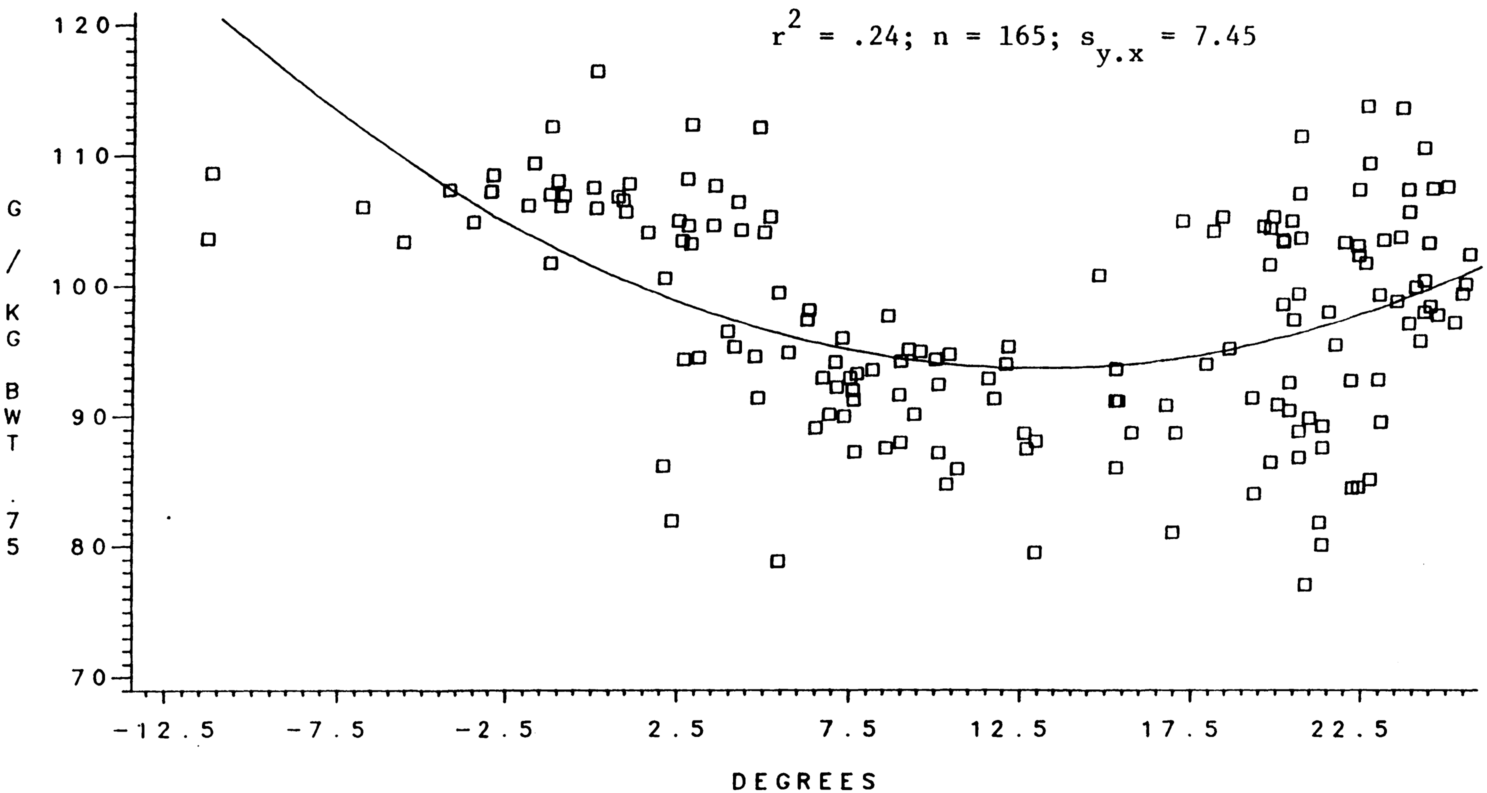

Figure 9. Second order polynomial regression of ambient temperature (DEGREES) on dry matter intake (G/KG $BWT^{.75}$) of heifers weighing 100 to 400 kg.

material. Below and above 40% NDF, correlations between NDF and ADF are .82 and .09, respectively, indicating that ADF and NDF can vary between rations. Correlations between body weight and ration energy and fiber parameters were significant due to design of the experiment. Formulating rations according to NRC requirements, which are a function of body weight and rate of gain (139) should result in significant relationships between body weight and ration energy. Correlations between daily gain and ration energy and fiber parameters were significant for similar reasons. Correlation between gain and NE_g was lower (r = .35) than any energy or fiber parameter tested (Table 22), possibly due to crude methods of estimating NE_g in this experiment.

2. Simplified model

A simplified equation was designed to be predictive of DM intake using variables commonly available to producers; body weight, rate of daily gain, ration TDN, and possibly ambient temperature. Included in initial screening were those variables listed above, their squared terms, metabolic body weight, and interaction terms gain * ambient temperature and body weight * ambient temperature.

Stepwise regression of independent variables on intake of DM indicated all variables contributed significantly to the model; however, r^2 increased only slightly (.59 to .60) after body weight, gain, ration TDN, and their squared terms were in the model. Although other variables were statistically significant, they did not appear to add to predictive power for the model.

All possible regression analyses conducted on independent variables (Appendix 3) produced r^2 and C_p statistics for each model. The r^2 statistics ranged from zero with ambient temperature as the only independent variable to .60 with all variables present. Only slight increases in r^2 were obtained with models containing more than 3 variables. The C_p statistic is an estimate of amount of deviation in predictability from that of the full model. It may be considered an estimate of bias in the model, assuming that the full model contains a low bias component (142). The C_p statistic decreased from 6954.9 with ambient temperature as the only variable in the model to 10.1 with 10 variables in the model. When more than 5 variables were in the model, C_p decreased only slightly. Minimum C_p statistics were obtained consistently when body weight, TDN, gain, ambient temperature and their squared terms were included, suggesting all were important in reducing bias. Selected models containing 6 or more independent variables were compared to determine amount of improvement by including ambient temperature (Table 24). Included in the analysis was the PRESS statistic, an estimate of influence of individual observations on prediction. The PRESS statistic decreased as models became larger, from 6725 with 6 variables to 6585 with the full model (Table 24). Inclusion of ambient temperature (models 4, 5, and 6, Table 24) did not improve predictive ability, and was excluded from further testing. Models 1, 2, and 3 (Table 24) were then evaluated by cross-validation procedures. Full data set was sampled randomly to obtain 100 observations which were used to fit each model to the data. Subsampling was repeated 6 times, and r^2, mean square error, and PRESS statistics were determined. Only small differences were observed in any statistic measured with any of the 6 subsets. Subsequently, one fitted equation was selected randomly from the above 6 models, and a second subset of 100 observations obtained to determine the degree of accuracy of the model selected. Comparison of each model was based on a calculated sum of squared residuals [$\sigma(Y \text{ predicted} - Y \text{ actual})^2$] for 5 subsets of data. Only minor differences were observed in any subset. Any of the three models can adequately predict intake of DM in this data set. Based on slightly better r^2, C_p, and PRESS statistics of model 3 (Table 24) using the full data set, the simplified model selected was body weight squared (BWTSQ), body weight$^{.75}$ (METBWT), body weight gain (GAIN), body weight gain squared (GAINSQ), ration total digestible nutrients (TDN) and ration TDN squared (TDNSQ).

Interaction terms body weight * TDN (BWTTDN), body

TABLE 24. Diagnostic statistics of selected simplified models to predict dry matter intake.

Model[b]	r^2	MSE[a]	C_p	PRESS
1	.590	1.40	56.55	6725.13
2	.590	1.40	56.43	6725.03
3	.590	1.40	56.32	6724.84
4	.594	1.39	27.36	6606.50
5	.596	1.39	11.72	6584.56
6	.596	1.39	12.00	6584.96

[a]MSE = mean square error.

[b]Models are: (see text for abbreviations)

1. BWT, BWTSQ, GAIN, GAINSQ, TDN, TDNSQ
2. BWT, METBWT, GAIN, GAINSQ, TDN, TDNSQ
3. BWTSQ, METBWT, GAIN, GAINSQ, TDN, TDNSQ
4. BWT, BWTSQ, GAIN, GAINSQ, TDN, TDNSQ, AMBT, AMBTSQ
5. BWT, BWTSQ, GAIN, GAINSQ, TDN, TDNSQ, AMBT, AMBTSQ, BWTAMB
6. BWT, METBWT, BWTSQ, GAIN, GAINSQ, TDN, TDNSQ, AMBT, AMBTSQ, BWTAMB, GANAMB.

weight * body weight gain (BWTGAN), and TDN * body weight gain (TDNGAN) were added to the above model to test possible improvement as recommended in (142). All possible regressions were calculated, and r^2 and C_p statistics obtained. Results of models containing BWTGAN and TDNGAN, the full model, and the 6 variable model were (r^2 and C_p): .592, 8.03; .592, 10.0; and .588, 44.7, respectively. Inclusion of BWTGAN and TDNGAN reduced PRESS (6702.2 vs. 6724.8 for full model) and suggests that the 8 variable model is most descriptive for the data, and is therefore selected as the simplified model (Table 25).

Effects of body weight and ration TDN are shown in Figure 10. At low body weight and ration TDN, intake is depressed. At the same body weight and higher ration TDN, intake increases in a curvilinear fashion. Similarly, increasing body weight at a given ration TDN results in a curvilinear increase in DM intake, indicating effects of decreasing energy requirement as animals reach breeding age.

Comparison of simplified model with data from NRC (139) is in Table 26. Concentrations of TDN in ration DM are recommendations of NRC for listed body weights and rates of gain. Below .6 kg gain/day, intake of DM estimated by simplified model is lower than estimated by NRC. These comparisons indicate importance of ration energy on intake of DM, a factor NRC does not include in their equation. At typical

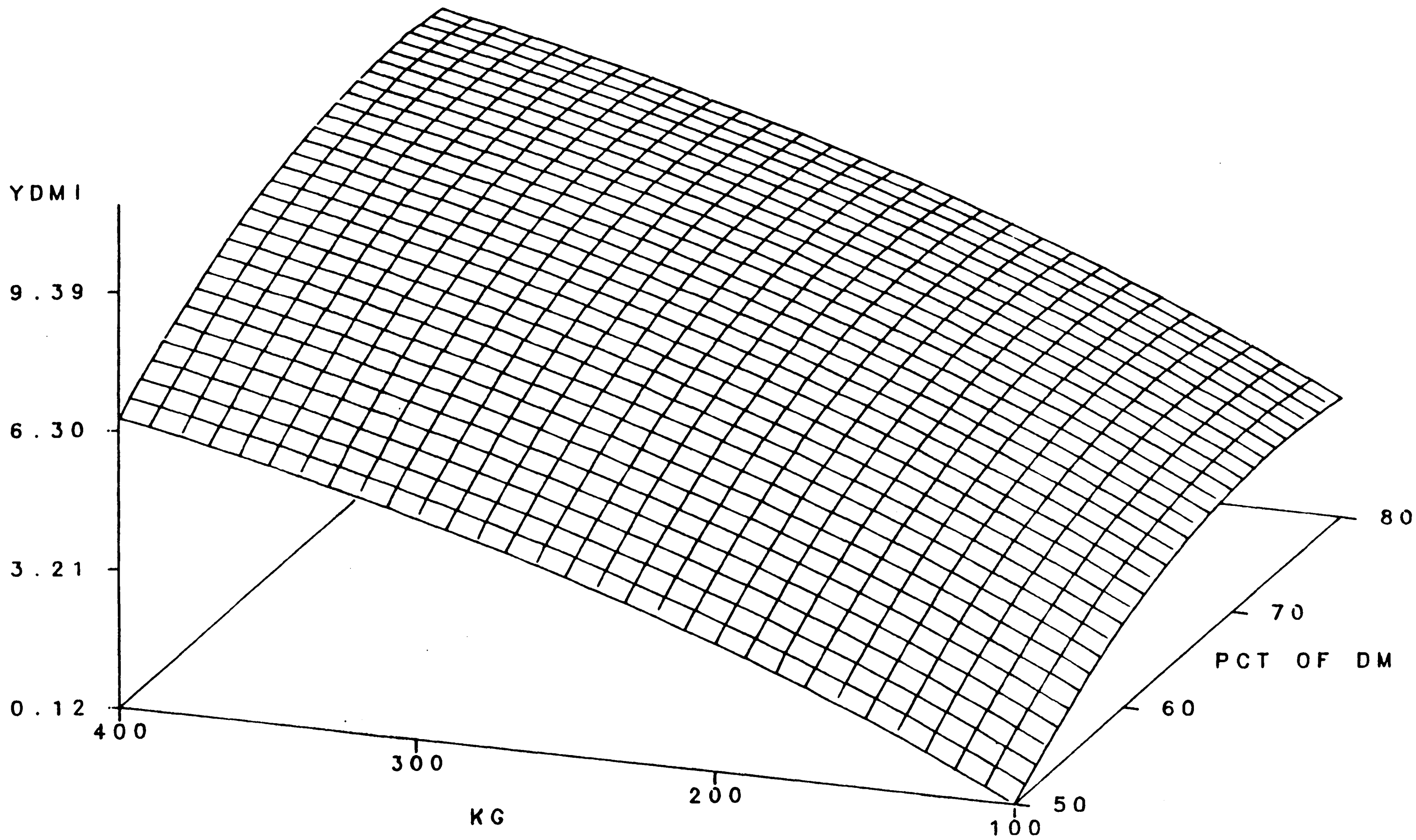

Figure 10. Effects of body weight (KG) and ration total digestible nutrients (PCT OF DM) on dry matter intake (YDMI, kg/day) as predicted by simplified model. Gain = .8 kg/day.

TABLE 25. Parameter estimates[a] and standard error (SE) of estimates for simplified model to predict dry matter intake.

Independent variable	Coefficient	SE
Intercept	-29.86365959	1.143
BWTSQ[b]	-1.5425468E-05	3.51E-06
METBWT[c]	.15748749	.010
GAIN[d]	2.08951563	.350
GAINSQ[e]	-.11770722	.024
TDN[f]	.72957095	.033
TDNSQ[g]	-.00481779	2.55E-04
BWTGAN[h]	-.00136331	5.12E-04
TDNGAN[i]	-.01908410	.005

[a]All estimates significant at $\underline{P}<.0001$, except BWTGAN, $\underline{P}<.001$ - n = 4797 $r^2 = .592$; $s_{y.x} = 1.18$, CV = 19.4.

[b]Body weight, kg.

[c]Body weight$^{.75}$.

[d]Body weight gain, kg/day.

[e]Body weight gain squared.

[f]Total digestible nutrients (TDN), percent of dry matter.

[g]TDN squared.

[h]Body weight * gain interaction.

[i]TDN * gain interaction.

TABLE 26. Comparison of simplified model vs NRC[a] predictions of dry matter (DM) intake of heifers from 100 to 400 kg.

Body weight	Daily gain	TDN in ration DM	NRC	Simplified model
(kg)	(kg)	(%)	(kg)	(kg)
100	.5	67.5	2.80	2.56
	.6	71.4	2.80	2.80
	.7	75.0	2.80	2.89
	.8	77.9	2.80	2.86
150	.5	63.0	4.00	3.69
	.6	66.0	4.00	4.04
	.7	69.0	4.00	4.28
	.8	72.0	4.00	4.43
200	.5	61.3	5.20	4.81
	.6	63.7	5.20	5.14
	.7	66.3	5.20	5.42
	.8	68.5	5.20	5.60
250	.5	59.4	6.30	5.69
	.6	62.1	6.30	6.10
	.7	64.3	6.30	6.37
	.8	66.5	6.30	6.59
300	.5	60.7	7.20	6.87
	.6	63.3	7.20	7.22
	.7	65.1	7.20	7.43
	.8	67.6	7.20	7.64
350	.5	59.0	8.00	7.46
	.6	61.3	8.00	7.83
	.7	63.3	8.00	8.09
	.8	65.0	8.00	8.28
400	.4	57.1	8.50	7.87
	.6	61.3	8.68	8.56
	.7	63.4	8.68	8.82
	.8	65.2	8.68	9.01

[a]1978 National Research Council (139).

rates of gain (.6 to .7 kg/day), ration energy is similar to that fed in this study, and intake of DM is similar between the two models (Table 26).

3. Expanded model

Stepwise regression utilized dependent variables DMI (kg/day), natural log of DMI (DMI_l), DMI as a percent of body weight (DMI_b), and DMI as a percent of metabolic body weight (DMI_m), and independent variables listed in Table 3. Significance levels for entry and removal of variables were .05 (158). Maximum r^2 obtained with the 4 dependent variables listed above were .65, .60, .42, and .39, respectively. Because DMI resulted in best r^2, it was used in subsequent model development. That DMI_l resulted in lower r^2 than DMI does not agree with Brown et al. (31). Differences may be artifacts of each data set.

Maximum r^2 (Table 27) was lower than those reported by others (31, 32), and is a result of recording daily DMI on individual animals. Others have recorded DMI on individual animals pooled on a weekly or monthly basis, or daily intake of DM on groups of animals. Pooling data removes variation, and improves r^2. To compare model development with those in the literature, data for each heifer were pooled into 4 weekly observations to remove daily variation. Stepwise regression generated a model with r^2 of .80, similar to those reported by others. Methods used to obtain data and

TABLE 27. Variables[a] entering or leaving equation to predict dry matter intake and descriptive statistics.

Step	Variable[b]	r^2	MSE[c]	C_p
1	BWT	.42	1.97	2871.7
2	NEG	.54	1.56	1359.1
3	NEMADF	.57	1.46	1000.2
4	NEM	.60	1.38	687.9
5	NEGSQ	.61	1.32	481.8
6	METBWT	.62	1.30	394.2
7	GANADF	.62	1.28	332.6
8	NEGADF	.63	1.27	298.1
9	BULKSQ	.63	1.27	288.7
10	AMBTSQ	.63	1.27	285.4
11	AMBT	.63	1.26	261.1
12	BWTAMB	.63	1.25	219.8
13	NEGAMB	.63	1.25	207.5
14	ADFAMB	.64	1.24	179.4
15	NEMNEG	.64	1.24	169.2
16	NEGADF*	.64	1.24	167.7
17	ADF	.64	1.23	141.3
18	NEGADF	.64	1.21	89.8
19	NEMSQ	.65	1.21	76.2
20	NEMNEG*	.65	1.21	75.3
21	ADFSQ	.65	1.21	65.0
22	ADFAMB*	.65	1.21	66.6
23	NEMNEG	.65	1.21	58.6
24	GANAMB	.65	1.20	48.5
25	BWTADF	.65	1.20	40.7
26	NDFSQ	.65	1.20	36.7

[a]See Table 4 for explanation of abbreviations.

[b]Variable entering equation, except *, variable removed from equation.

[c]Mean square error; n = 4429.

develop models in this study were adequate.

Stepwise regression selects variables resulting in maximum improvement in r^2. Therefore, r^2 is increased most by the first variable entering the equation, and least by the last variable (Table 27). Due to size of data set and large number of error degrees of freedom, variables can enter equation with only minimal improvement in r^2 and limited biological or practical significance. After step 4 (Table 27), r^2 improved .01 or less with addition of each variable. The C_p statistic decreased with each addition, but after step 6 reduction was minimal (Table 27). Models selected for cross validation analyses were those at steps 4, 5, 6, and 26. Full model predicted DM intake with consistently higher r^2, lower mean square error, and C_p than models 4, 5, or 6. Removal of NDFSQ (step 26, Table 27) did not reduce predictive ability of the model, and simplified data procurement. Expanded model is step 25, Table 27. Coefficients and standard errors of the expanded model are in Table 28. Validation of this model is contingent upon data containing variables not readily available in the literature (ambient temperature and bulk density), and therefore awaits further research designed specifically for that purpose.

TABLE 28. Parameter estimates[a,b] and standard error (SE) of estimates for expanded model to predict dry matter intake.

Independent variable	Coefficient	SE
Intercept	-1906.91	
BWT	-0.04	0.009
METBWT	0.37	0.046
ADF	32.36	5.115
NEM	2305.51	322.390
NEG	-664.06	99.081
AMBT	-0.08	0.016
ADFSQ	-0.13	0.024
NEMSQ	-637.68	95.380
NEGSQ	42.31	11.821
BULKSQ	-5.35	1.515
AMBTSQ	0.001	0.001
BWTADF	-1.56E-04	0.000
BWTAMB	8.87E-05	0.000
NEMNEG	246.30	59.468
NEMADF	-21.30	3.054
NEGADF	7.83	0.958
NEGAMB	0.04	0.011
GANADF	0.01	0.002
GANAMB	-0.01	0.005

[a]All coefficients significant at $\underline{P}<.0001$: n = 4429; r^2 = .65; $s_{y.x}$ = 1.09; C_p = 40.7.

[b]See Table 4 for explanation of abbreviations.

SUMMARY

Dry matter intake of dairy heifers in this experiment is affected most by body weight, and to a lesser degree by ration fiber, energy and density, body weight gain, and ambient temperature. Development of simplified equation utilizing body weight, daily gain, and ration TDN suggests that previous equations utilizing body weight only are inadequate to predict intake of DM. Curvilinear terms of ration energy and/or fiber are necessary to account for changing DM intake due to different factors controlling intake.

Fill capacity of rations limits intake up to a point of maximum intake, then as energy content of rations increase, metabolic factors begin to reduce DM intake as animals consume relatively constant energy.

Equations developed in this experiment require critical examination prior to practical application, but serve as a starting point for improved management of dairy heifers fed total mixed rations under intensive management conditions.

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APPENDIX 1

Evaluation of Techniques of Energy Expression

1. Description of Energy Terms

Controversy regarding methods of energy expression for growing and lactating ruminants has arisen from the use of five separate methods to express energy requirements of ruminants and energy content of feedstuffs. These are: gross energy (GE), digestible energy (DE), metabolizable energy (ME), net energy (NE), and total digestible nutrients (TDN) (Figure 11). Gross energy is the amount of energy (expressed in kcal or Mcal in the U.S.) contained in a given feed. Intake of GE minus energy lost in feces is DE. Subtraction of energy contained in urine and eructated methane from DE gives ME. Subtraction of heat production results in NE for production NE_p (130). Total digestible nutrients is the sum of digestible carbohydrates, digestible protein, and digestible fat expressed as a percent of dry matter intake. Proximate analysis conducted on feed, orts and feces will provide TDN. Because TDN is not precisely DE or ME, it has been considered to be a "hybrid" measurement (141). It does not measure digestible nutrients as the name implies; it is not a measure that has direct relevance to NE or energy metabolism in general (141).

2. Evaluation of techniques

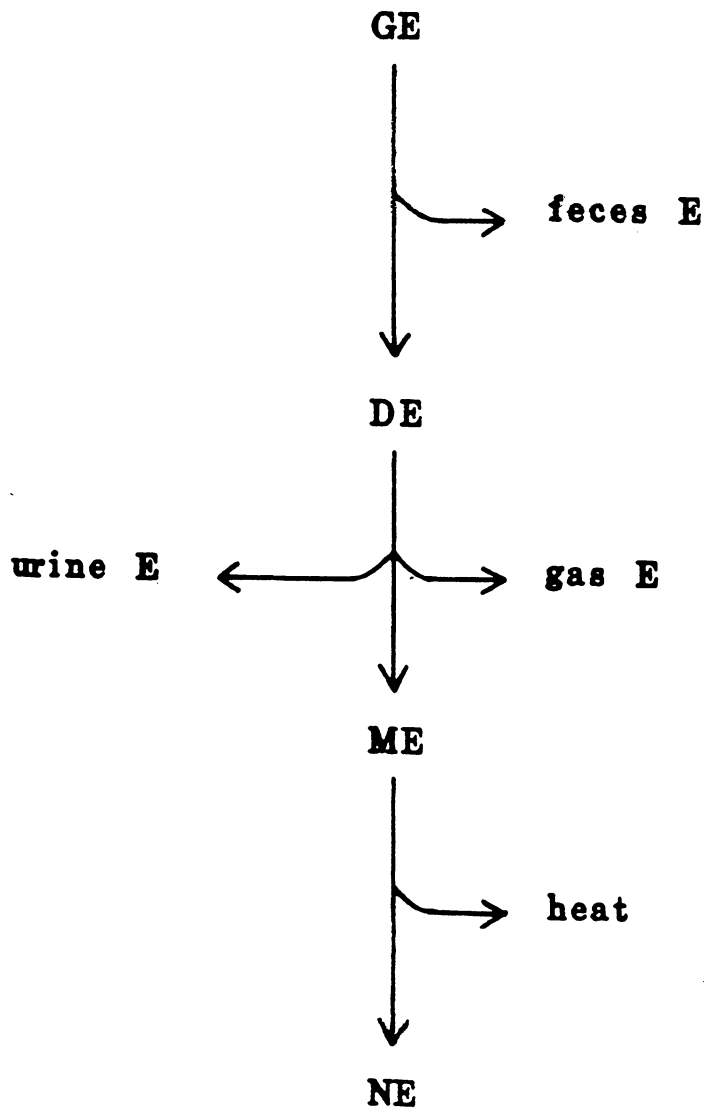

Figure 11. Flow of energy through animals.

Gross energy. Gross energy of feeds is not used generally to evaluate energy requirements. Amount of energy lost in the feces [20 to 60% of GE (107)] makes this method relatively inaccurate.

Digestible energy and TDN. When DE is used as a measure of energy availability, energy losses from urine, methane, and heat increment are considered to be available to the cow for productive functions (183). In contrast, endogenous secretions into the gut tend to bias DE and TDN toward underestimation of true digestive efficiency (183).

Digestibility of an individual feed is usually determined by its incorporation into a basal ration (usually forage) at several ratios of ingredients. Extrapolation to 0 and 100% gives an estimate of digestibility of the two components (183). Content of digestible components (protein, fat, carbohydrates) is summed, giving TDN. Both DE and TDN have the advantage of relatively rapid and inexpensive determination. It is for these reasons that TDN has been the basis for energy formulation in the U.S. for many years.

Research during the 1970's (127) gave evidence of discrepency in TDN or DE values of a particular feed when fed. Variation in these values rises from two sources: 1) variation in quality of the feedstuff according to the source, and 2) level of intake (188). Level of intake was shown to affect significantly digestive efficiency as early as 1911 (cf. 183). More recent studies (128, 129, 181, 182) have defined a clear relationship between digestive efficiency and level of intake. Most TDN values are based on digestion trials conducted at or near maintenance level (188); when fed at increments above maintenance, TDN of the total ration decreases by approximately 4% of TDN at maintenance for each increment above maintenance. It was also determined that rate of depression of digestive efficiency increases as proportion of grain in ration increases when hay or hay crop silage is the only forage (183). Effects of grain in the ration on digestive efficiency are not as pronounced with corn silage as the major forage (141, 183).

Decreased ration digestibility appears to be due to a change in the cell wall digestibility (188). Increasing concentrate in a ration and/or increasing rate of passage indicative of increased intake appear to affect the rumen environment to depress digestibility (188).

Metabolizable energy and net energy. Metabolizable energy is superior to DE for use as a measure of energy expression because it considers losses of energy in urine and methane (141). Metabolizable energy does, however, suffer deficiencies similar to DE, as DE and ME are highly correlated (141). Energy in urine of domestic ruminants typically accounts for 3 to 5% of GE (107), and gaseous energy usually accounts for approximately 5 to 12% of GE (107),

(Figure 5).

Estimates of requirements for growth and fattenning developed by the Agricultural Research Council (ARC) (1) are based on the ME concept. In contrast to NE systems that account for feeding values, the ME system uses an iterative approach to estimate animal's ME requirements on a given ration (206). Zulbertt and Reid (206) developed equations to predict the ME requirement of growing cattle that do not require iteration, and estimated accurately ARC ME requirements. Included in this equation were: ME content of ration (Mcal/kg DM), age of animal, kg body wt$^{.73}$, daily gain (kg/day). Metabolizable energy in this equation is calculated as ME for maintenance (ME_m) and growth (ME_g), and both are adjusted for efficiency of utilization of ME for the respective functions (141, 206).

Efficiency of ME use varies for different productive purposes (26, 71, 127). Efficiency terms for each productive function are being developed with increasing accuracy (26), and British workers are devising feeding systems utilizing the ME concept (26, 135). Metabolizability of a feed is commonly referred to as q, and is expressed as a percent of GE. It has been determined that the metabolizability of GE at a given feeding level (q_l) is related to the q at maintenance (q_m) with a correction factor for feeding level:

$$q_l = q_m + (L-1)(.20[q_m - .623]) \quad (2, 71).$$

This formula implies that above approximately 2.75 kcal ME/g feed, little or no depression in digestibility occurs. This finding by the ARC (87) is in contrast with those of Tyrrell and Moe (183) who predicted little depression in digestibility of forage diets with increasing intake unless the forage is ground or pelleted (71).

Net energy may be considered as the change in energy retained / the change in quantity of a given feed consumed (141). NE values are obtained by "difference trial", and assume that the relationship between feed intake and energy retained is estimatable by a rectilinear function (Figure 12). Energy intake that results in negative energy balance (EB) represents one segment, and energy intake resulting in positive EB represents the second segment (141). The point at which EB = 0 is the level of feed intake that supports body maintenance (141).

Because various productive purposes (deposition of fat or protein, or production of milk) use energy with different efficiencies, separate NE values each productive function and individual feeds are required. Indeed, NE value of a feed is influenced by such factors as composition of the remainder of the diet, level of feed intake, physiological state of the animal, and other factors (126). In growing ruminants, NRC has adopted the system of Lofgreen and Garrett (113, 139). This system utilizes two values, net

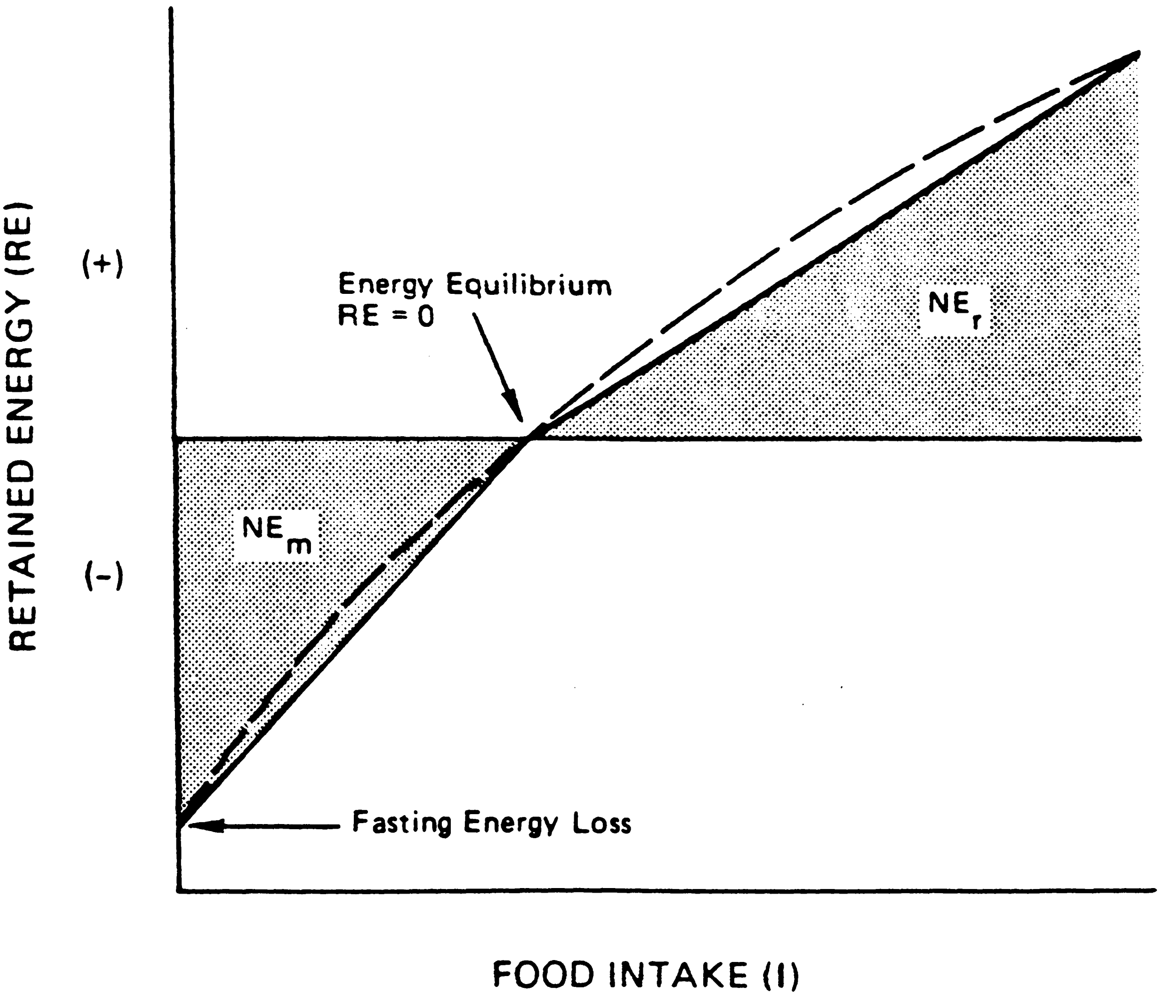

Figure 12. Relationship between food intake and retained energy, net energy for maintenance (NE_m), and net energy for production (NE_r) (140).

energy for maintenance (NE_m) and net energy for gain (NE_g).

Net energy for maintenance is energy in feed that is used by the animal to maintain its present body weight, and has been determined experimentally to be .077 * body weight$^{.75}$ (113). Net energy for gain is dependent upon amount of energy deposited in body weight gain and depends upon type of gain deposited (fat or protein). Net energy system is theoretically more correct and desirable in identifying energy use in the body as compared to TDN or DE systems. It is an exact description of the amount of energy recovered as animal product (126). Unfortunately, NE_m and NE_g are influenced by many factors including composition of diet, level of intake, physiological state of the animal and several others (126), and therefore is not a constant value. Changing any of the above factors results in different NE value or requirement. Thus, tables of feed composition and requirements can be considered at best estimates to be used in the context of more knowledgable ration formulation. Several authors (126, 180) have suggested that tables of nutrient composition are outmoded and should be replaced. This approach merits critical investigation.

Under practical situations where exact nutrient requirements and/or nutrient compositions may not be available, selection of an energy system is arbitrary. Systems (TDN, NE, ME, DE) are all useful in balancing rations under practical situations. Factors influencing selecting a system of energy terminology should include knowledge of the person balancing rations, the individual interpreting and using ration formulation, information regarding animals and feedstuffs available to the producer and individual balancing rations, and objectives of the ration.

APPENDIX 2

Formulas Used to Estimate Energy Content of Feed Ingredients and Total Mixed Rations

The following equations have been used to predict and/or convert energy terms.

1. Prediction of TDN (Source: VA Tech Forage lab).
   a. corn silage: TDN = 80.4 - .481 * ADF r = -.80.
   b. grass hay: TDN = 100.32 - 1.118 * ADF r = .654.
   c. soybean meal: TDN = 89.8 - .7680 * ADF.
   d. corn grain: same as c.
   e. total mixed rations: same as c.
   f. high moisture corn: same as c.

2. Conversion of TDN to NE_m and NE_g in feeds (131).
   a. ME(kcal/kg DM) = .036155 * TDN(% of DM)
   b. Log F = 2.2577 - .2213 * ME
   c. $F = 10^{\log F}$
   d. NE_m(Mcal/kg DM) = 77/F
   e. NE_g(Mcal/kg DM) = 2.54 - .0314 * F

3. Calculation of NE_m and NE_g requirements of dairy heifers.
   a. NE_m(Mcal) = .077 * (body wt, kg)$^{.75}$
   b. NE_g = -.322286 + 2.986287E-3 * bwt + 1.491215 * gain - 6.3116E-6 * bwt^2 + 6.286167E-3 * (bwt * gain); where bwt = body weight, kg,

gain = daily gain, kg. r^2 = .9998

(139).

APPENDIX 3

All possible regressions output - simplified model

NUMBER IN MODEL	R-SQUARE	C_p	VARIABLES IN MODEL
1	0.0000	6954.92592	AMBT
1	0.0034	6915.22749	GANAMB
1	0.0048	6899.37038	AMBTSQ
1	0.0060	6884.97535	GAINSQ
1	0.0102	6836.07779	TDNSQ
1	0.0157	6771.70746	TDN
1	0.0206	6714.18821	GAIN
1	0.0281	6626.58637	BWTAMB
1	0.4252	1986.29104	BWTSQ
1	0.4291	1941.73808	METBWT
1	0.4298	1933.13575	BWT
2	0.4426	1785.41936	METBWT GAINSQ
2	0.4433	1777.53690	BWT GAINSQ
2	0.4625	1553.13007	BWTSQ GAIN
2	0.4679	1489.62466	METBWT GAIN
2	0.4684	1483.46628	BWT GAIN
2	0.5099	998.56861	BWTSQ TDNSQ
2	0.5193	888.84810	BWTSQ TDN
2	0.5303	760.13976	BWT TDNSQ
2	0.5329	729.79107	METBWT TDNSQ
2	0.5405	641.82149	BWT TDN
2	0.5433	609.30166	METBWT TDN
3	0.5437	605.71337	METBWT GAINSQ TDN
3	0.5438	604.89936	METBWT TDN AMBTSQ
3	0.5447	594.02166	METBWT TDN GANAMB
3	0.5453	587.99195	BWT METBWT TDN
3	0.5454	585.99934	BWTSQ METBWT TDN
3	0.5455	584.52812	BWT BWTSQ TDN
3	0.5462	576.67882	BWT GAIN TDN
3	0.5488	546.95135	METBWT GAIN TDN
3	0.5566	455.44082	BWTSQ TDN TDNSQ
3	0.5759	229.36069	BWT TDN TDNSQ
3	0.5786	197.98413	METBWT TDN TDNSQ
4	0.5781	206.02797	BWT TDN TDNSQ GANAMB
4	0.5786	199.79140	METBWT TDN TDNSQ AMBTSQ
4	0.5787	198.99308	METBWT TDN TDNSQ BWTAMB

4	0.5789	196.68854	METBWT TDN TDNSQ AMBT
4	0.5803	181.04439	METBWT GAINSQ TDN TDNSQ
4	0.5806	177.10998	METBWT TDN TDNSQ GANAMB
4	0.5807	175.37603	BWT BWTSQ TDN TDNSQ
4	0.5808	175.16856	BWT METBWT TDN TDNSQ
4	0.5808	175.07192	BWTSQ METBWT TDN TDNSQ
4	0.5843	134.20257	BWT GAIN TDN TDNSQ
4	0.5867	106.08366	METBWT GAIN TDN TDNSQ
5	0.5844	134.02511	BWT GAIN TDN TDNSQ AMBTSQ
5	0.5847	131.20916	METBWT TDN TDNSQ AMBT GANAMB
5	0.5867	108.08334	METBWT GAIN TDN TDNSQ GANAMB
5	0.5867	108.07741	METBWT GAIN TDN TDNSQ BWTAMB
5	0.5867	107.45191	METBWT GAIN TDN TDNSQ AMBT
5	0.5868	106.61851	METBWT GAIN TDN TDNSQ AMBTSQ
5	0.5872	101.93810	BWT GAIN GAINSQ TDN TDNSQ
5	0.5883	89.50719	BWT BWTSQ GAIN TDN TDNSQ
5	0.5883	88.96170	BWTSQ METBWT GAIN TDN TDNSQ
5	0.5883	88.75607	BWT METBWT GAIN TDN TDNSQ
5	0.5896	73.78715	METBWT GAIN GAINSQ TDN TDNSQ
6	0.5884	89.36430	BWTSQ METBWT GAIN TDN TDNSQ AMBT
6	0.5885	89.12187	BWT METBWT GAIN TDN TDNSQ AMBT
6	0.5885	88.09332	METBWT TDN TDNSQ AMBT AMBTSQ GANAMB
6	0.5892	80.15650	METBWT GAIN TDN TDNSQ AMBT AMBTSQ
6	0.5896	75.78521	METBWT GAIN GAINSQ TDN TDNSQ BWTAMB
6	0.5896	75.40399	METBWT GAIN GAINSQ TDN TDNSQ GANAMB
6	0.5897	75.04514	METBWT GAIN GAINSQ TDN TDNSQ AMBT

6	0.5897	74.32811	METBWT GAIN GAINSQ TDN TDNSQ AMBTSQ
6	0.5912	56.54769	BWT BWTSQ GAIN GAINSQ TDN TDNSQ
6	0.5913	56.43272	BWT METBWT GAIN GAINSQ TDN TDNSQ
6	0.5913	56.31647	BWTSQ METBWT GAIN GAINSQ TDN TDNSQ
7	0.5913	58.25733	BWTSQ METBWT GAIN GAINSQ TDN TDNSQ BWTAMB
7	0.5913	57.90869	BWT BWTSQ GAIN GAINSQ TDN TDNSQ AMBTSQ
7	0.5913	57.83490	BWT METBWT GAIN GAINSQ TDN TDNSQ AMBTSQ
7	0.5913	57.70174	BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBTSQ
7	0.5913	57.65358	BWT BWTSQ GAIN GAINSQ TDN TDNSQ GANAMB
7	0.5913	57.49347	BWT METBWT GAIN GAINSQ TDN TDNSQ GANAMB
7	0.5913	57.39695	BWTSQ METBWT GAIN GAINSQ TDN TDNSQ GANAMB
7	0.5914	56.80331	BWT BWTSQ GAIN GAINSQ TDN TDNSQ AMBT
7	0.5914	56.62177	BWT METBWT GAIN GAINSQ TDN TDNSQ AMBT
7	0.5914	56.53306	BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBT
7	0.5923	45.90816	METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ
8	0.5923	47.82446	BWT BWTSQ GAIN TDN TDNSQ AMBT AMBTSQ BWTAMB
8	0.5924	47.09988	BWTSQ METBWT GAIN TDN TDNSQ AMBT AMBTSQ BWTAMB
8	0.5924	46.67359	BWT METBWT GAIN TDN TDNSQ AMBT AMBTSQ BWTAMB
8	0.5925	45.85813	METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ GANAMB
8	0.5929	41.00664	BWT BWTSQ GAIN GAINSQ TDN TDNSQ AMBT BWTAMB
8	0.5930	40.54375	BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBT BWTAMB
8	0.5930	40.43983	BWT METBWT GAIN GAINSQ TDN TDNSQ AMBT BWTAMB

8	0.5934	35.73000	METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ BWTAMB
8	0.5941	27.36433	BWT BWTSQ GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ
8	0.5941	27.29869	BWT METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ
8	0.5941	27.15093	BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ
9	0.5931	41.43731	BWT BWTSQ GAIN TDN TDNSQ AMBT AMBTSQ BWTAMB GANAMB
9	0.5931	40.74620	BWTSQ METBWT GAIN TDN TDNSQ AMBT AMBTSQ BWTAMB GANAMB
9	0.5931	40.36415	BWT METBWT GAIN TDN TDNSQ AMBT AMBTSQ BWTAMB GANAMB
9	0.5936	35.11879	METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ BWTAMB GANAMB
9	0.5941	29.14839	BWT BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ
9	0.5943	26.93039	BWT BWTSQ GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ GANAMB
9	0.5943	26.88797	BWT METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ GANAMB
9	0.5943	26.72607	BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ GANAMB
9	0.5956	11.72375	BWT BWTSQ GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ BWTAMB
9	0.5956	11.31909	BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ BWTAMB
9	0.5956	11.28251	BWT METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ BWTAMB
10	0.5556	480.77063	BWT BWTSQ METBWT GAIN GAINSQ TDNSQ AMBT AMBTSQ BWTAMB GANAMB

10	0.5644	378.33050	BWT BWTSQ METBWT GAIN GAINSQ TDN AMBT AMBTSQ BWTAMB GANAMB
10	0.5919	56.67228	BWT BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBTSQ BWTAMB GANAMB
10	0.5924	50.56478	BWT BWTSQ METBWT GAINSQ TDN TDNSQ AMBT AMBTSQ BWTAMB GANAMB
10	0.5930	44.09292	BWT BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBT BWTAMB GANAMB
10	0.5931	42.34889	BWT BWTSQ METBWT GAIN TDN TDNSQ AMBT AMBTSQ BWTAMB GANAMB
10	0.5943	28.72462	BWT BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ GANAMB
10	0.5956	13.23683	BWT BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ BWTAMB
10	0.5959	10.47697	BWT BWTSQ GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ BWTAMB GANAMB
10	0.5959	10.07733	BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ BWTAMB GANAMB
10	0.5959	10.05226	BWT METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ BWTAMB GANAMB
11	0.5959	12.00000	BWT BWTSQ METBWT GAIN GAINSQ TDN TDNSQ AMBT AMBTSQ BWTAMB GANAMB

APPENDIX 4

DAIR4H Pascal Source code

The following source code applies to DAIR4H version 1.1. This code will not be totally applicable as updates are made.

```
(*

         PROGRAM   DAIR4H

         Author:   Jim Quigley,   VPI & SU
         Date:     15 Feb 85

   Introduction:  DAIR4H is designed to calculate and evaluate rations
                  specifically for dairy replacement heifers.  It is
                  especially useful for total mixed ration (TMR) feeding.
                  Past experience with similar ration balancing programs
                  has shown this type of balancer to be effective in
                  educational programs such as college problems and in
                  continuing education of farmers and extension agents.

                  This program is designed to incorporate J. Quigley's
                  equation to predict DM intake of dairy heifers, and
                  as such, should be used with caution until the
                  equation can be more adequately tested.

                  DAIR4H uses 2 files as output - HEFRFEED.DAT, an ASCII
                  file containing feed ingredients used in TMR feeding;
                  it is similar to the BASIC version, but is in a different
                  format to be read by Pascal.  The second file is also
                  an ASCII file that is used as storage of formulated rations.
                  This file is named by the user.

                  DAIR4H is designed to be as user-friendly as possible, and
                  as such will accept many non-useful inputs.  It will bomb
                  out only under certain circumstances.

                  This programmer makes no guarantee as to the accuracy of
                  information provided by this program.  You will get out
                  what you put in.  Changes to the code are urged - if such
                  changes will improve speed, accuracy, or ease of use of the
                  program.  It is requested that minor changes be reflected in
                  updating the version number (1.1, 1.2, etc.), and major
                  changes results in a new version (2.0, 3.0, etc.)

                                                                         *)
PROGRAM DAIR4H(INPUT, OUTPUT);

CONST                            (* IBM PC Codes for ASCII chars *)
  BELL      = #7;                (* ring bell *)
  BS        = #8;                (* backspace *)
  TAB       = #9;                (* tab *)
  CR        = #13;               (* carriage return *)
  ESC       = #27;               (* Escpae *)
```

```
  DOT       = #46;            (* decimal point *)
  NUMCOLS   = 80;
  NUMFEEDS  = 8;              (* Number of ROWS on screen *)
  VERSION   = 1.1;            (* Version of this program  *)
  TABSPACE  = 65;             (* Column jumped by tab *)
  COLON     = #58;            (* Colon *)
  SPACE     = ' ';
  LB_TO_KG  = 0.4535924;      (* Converts LBS to KG *)
  KG_TO_LB  = 2.2046226;      (* Converts KG to LBS *)
  DEF_FILE  = 'TEMP.DYH';     (* Default file name  *)
TYPE
  FILESTR   = STRING(11);
  FILEOUT   = TEXT;
  REALARR   = ARRAY(1..NUMFEEDS) OF REAL;
  DESCRIPT  = STRING(20);
  SHORT_STRING = STRING(5);
  LONG_STRING = STRING(NUMCOLS);
  BIGARR    = ARRAY(1..NUMFEEDS) OF LONG_STRING;
  DESCARR   = ARRAY(1..NUMFEEDS) OF DESCRIPT;
  NUMERAL   = 0..80;

($I B:VARIABLE.PAS  )          (* Gets variable declarations & info *)


(*
       File VARIABLE.PAS contains the variable  declarations
       associated with DAIR4H.PAS in a format acceptable  to
       Pascal, with further information concerning important
       variables.
                                                           *)
VAR
  QUITEST,                         (* Flag set if PF-7 is hit *)
  OPEN_FILE,                       (* Flag set if             *)
  FOUND,                           (* Flag set if             *)
  FOUND_FILE,                      (* Flag set if             *)
  FLAG_1               : BOOLEAN;  (* Flag set if             *)

          (*  REALARR are arrays (1..NUMFEEDS) of reals corresponding to
              the variables on nutrient screen or mineral screen          *)
  FEEDNO,                          (* feed number associated with NRC file   *)
  FEEDLBS,                         (* lbs of each feed (as is basis)         *)
  DM_PCT,                          (* % dry matter of each feed              *)
  DM_LBS,                          (* lbs of dm in each feed FEEDLBS *
                                      DM_PCT / 100                           *)
  CP_PCT,                          (* % crude protein in each feed, DM basis *)
  CP_LBS,                          (* lbs protein in each feed on a DM basis *)
  TDN_PCT,                         (* % TDN in each feed, DM basis           *)
```

```
TDN_LBS,                          (* lbs TDN in each feed on a DM basis      *)
ADF_PCT,                          (* % ADF in each feed, DM basis            *)
ADF_LBS,                          (* lbs ADF in each feed, DM basis          *)
COST_TON,                         (* cost of each feed per ton, as fed       *)
COST_COW             : REALARR;   (* cost of each feed fed to 1 cow, as fed *)

CA_PCT,                           (* The following variables are similar to *)
P_PCT,                            (* those listed above, but for the miner-  *)
NA_PCT,                           (* screen.  All are real arrays.           *)
MG_PCT,                           (* PCT's are % on DM basis, and LBS are    *)
S_PCT,                            (* lbs on DM basis.                        *)
K_PCT,
CA_LBS,
P_LBS,
NA_LBS,
MG_LBS,
S_LBS,
K_LBS                : REALARR;

          (*  SCR1_LIN and SCR2_LIN are BIGARR - 2 arrays each of 8 rows
              by 80 cols to allow screen input in a fashion so as to change
              variables in any column on the screen.  Input from the screen
              goes to these arrays, and upon a recalculate command, is then
              converted to the respective variables by the procedures
              available in TURBO.                                       *)
SCR1_LIN,                           (* nutrient screen array *)
SCR2_LIN             : BIGARR;      (* mineral screen array  *)

           (* The following vars are real, and are the sums calculated
              from REALARR's, requirements based on NRC and Quigley's
              requirements for nutrients and dry matter, and the perc-
              entage of the requirement being met by the ration fed.
              Also included are BWT (body weight) and GAIN (daily gain).
              Both are entered in POUNDS and are converted to KG before
              use in formulas.                                        *)
TOTAL_DM,      (* Total DM being fed in the ration *)
TOTAL_CP,      (* Total crude protein being fed    *)
TOTAL_TDN,     (* Total TDN                        *)
TOTAL_ADF,
TOTAL_COST,
TOTAL_CA,
TOTAL_P,
TOTAL_NA,
TOTAL_S,
TOTAL_K,
TOTAL_MG,
CA_REQT,       (* Requirement for Ca based on NRC *)
P_REQT,        (* Requirement for P based on NRC  *)
```

```
MG_REQT,      (* Requirement for Mg based on NRC *)
K_REQT,
NA_REQT,
S_REQT,
REQ_CA_PCT,   (* Percentage of Ca reqt. met by the ration fed *)
REQ_P_PCT,    (* Percentage of P reqt. met by the ration fed  *)
REQ_MG_PCT,   (* Percentage of Mg reqt. met by the ration fed *)
REQ_K_PCT,
REQ_NA_PCT,
REQ_S_PCT,
REQ_DM_PCT,
DM_REQT,      (* Requirement for DM based on Quigley's equation *)
REQ_CP_PCT,   (* Percentage of CP requirement met by the ration *)
CP_REQT,
REQ_TDN_PCT,
TDN_REQT,
PCT_RATION_TDN,              (* Percent TDN in the total ration  *)
PCT_RATION_FIBER,            (* Percent ADF in the total ration  *)
PCT_RATION_PROTEIN,          (* Percent protein in total ration  *)
PCT_BWT,                     (* Intake as a % of body weight     *)
BWT,
GAIN                  : REAL;

INPT2, INPT3,
INPT,
BREED                 : CHAR;  (* Breed - set to 'H' ONLY  *)

I, J, SCREEN, CODE,
ROW, COL,                      (* Row and col represent cursor location *)
                               (* on the active screen                  *)
STCOL                 : INTEGER;

TEMPVAR               : STRING(2);

FEED_DESC             : DESCARR;  (* Descriptions of each feed ingredient  *)
                                  (* in use                                *)
FILENAME              : FILESTR;  (* String used (TURBO) to refer to files *)

SAVE_FILE,                        (* File used to save nutrient and min.   *)
                                  (* screens                               *)
NRC_FILE              : FILEOUT;  (* File used to get ingredient info      *)

S1_DOT_SET : SET OF NUMERAL;      (* Set of screen 1 decimal points used   *)
                                  (* evaluate if decimals are entered      *)
                                  (* properly                              *)
S2_DOT_SET : SET OF NUMERAL;
```

```
(* END VARIABLE DECLARATIONS *)

($I B:CONVRT.PAS    )          (* Screen array conversion routines  *)


(* Imbed CONVRT.PAS contains procedure CONVERT_TO_NUMS that
   takes screen array values and converts them to real variables
   for recalculation.  It is necessary for screen input and cursor
   movement to specified columns on an active screen.          *)

PROCEDURE CONVERT_TO_NUMS(SCR1_LIN, SCR2_LIN : BIGARR;
     VAR FEEDLBS, DM_PCT, CP_PCT, TDN_PCT, ADF_PCT, COST_TON,
     CA_PCT, P_PCT, NA_PCT, S_PCT, K_PCT, MG_PCT : REALARR; SCREEN : INTEGER);
VAR
    CODE, I : INTEGER;

  BEGIN
    FOR I := 1 TO NUMFEEDS DO
      BEGIN
        CASE SCREEN OF
          1 : BEGIN
                VAL(COPY(SCR1_LIN(I),1,3), FEEDNO(I), CODE);
                VAL(COPY(SCR1_LIN(I),8,4), FEEDLBS(I), CODE)
              END;
          2 : BEGIN
                VAL(COPY(SCR2_LIN(I),1,3), FEEDNO(I), CODE);
                VAL(COPY(SCR2_LIN(I),6,5), FEEDLBS(I), CODE)
              END
        END; (* CASE SCREEN *)

        VAL(COPY(SCR1_LIN(I),15,4), DM_PCT(I), CODE);
        VAL(COPY(SCR1_LIN(I),27,4), CP_PCT(I), CODE);
        VAL(COPY(SCR1_LIN(I),39,4), TDN_PCT(I), CODE);
        VAL(COPY(SCR1_LIN(I),52,4), ADF_PCT(I), CODE);
        VAL(COPY(SCR1_LIN(I),64,4), COST_TON(I), CODE);

        VAL(COPY(SCR2_LIN(I),12,5), CA_PCT(I), CODE);
        VAL(COPY(SCR2_LIN(I),23,5), P_PCT(I), CODE);
        VAL(COPY(SCR2_LIN(I),34,5), NA_PCT(I), CODE);
        VAL(COPY(SCR2_LIN(I),44,5), MG_PCT(I), CODE);
        VAL(COPY(SCR2_LIN(I),55,5), S_PCT(I), CODE);
        VAL(COPY(SCR2_LIN(I),66,5), K_PCT(I), CODE)
      END
   END;

(*    END CONVERT_TO_NUMS   *)

($I B:CONVERT.PAS   )          (* Screen array conversion routines  *)
```

```
(* Imbed file CONVERT.PAS contains procedure CONVERT_TO_STR to
   convert numeric variables obtained from NRC file to string
   vars in active screen arrays.  It is necessary to assure
   cursor movement and input to an individual column on a screen
   are correct.                                                   *)


PROCEDURE CONVERT_TO_STR(VAR SCR1_LIN, SCR2_LIN : BIGARR; FEEDNO, FEEDLBS,
  DM_PCT, CP_PCT, TDN_PCT, ADF_PCT, COST_TON, CA_PCT, P_PCT, NA_PCT, MG_PCT,
  S_PCT, K_PCT : REALARR);

  VAR
    REW_STRING : SHORT_STRING;
    I : INTEGER;

  PROCEDURE INVERT(VAR A : LONG_STRING; B : SHORT_STRING; POSITION, LENG :
    INTEGER);
      BEGIN
        DELETE(A, POSITION, LENG);
        INSERT(B, A, POSITION)
      END; (* INSERT *)

  PROCEDURE ZEROES(VAR SCREEN : BIGARR);
      VAR
      I, J : INTEGER;

      BEGIN
        J := 0;
        FOR I := 1 TO NUMFEEDS DO
            WHILE POS(SPACE, SCREEN(I)) <> 0 DO
              BEGIN
                J := POS(SPACE, SCREEN(I));
                DELETE(SCREEN(I), J, 1);
                INSERT('0', SCREEN(I), J)
              END
      END;

  BEGIN
    FOR I := 1 TO NUMFEEDS DO
      BEGIN
        STR(FEEDNO(I):3:0, REW_STRING);
        INVERT(SCR1_LIN(I), REW_STRING, 1, 3);
        INVERT(SCR2_LIN(I), REW_STRING, 1, 3);

        STR(FEEDLBS(I):4:1, REW_STRING);
        INVERT(SCR1_LIN(I), REW_STRING, 8, 4);
```

```
        INVERT(SCR2_LIN(I), REW_STRING, 6, 5);

        STR(DM_PCT(I):4:1, REW_STRING);
        INVERT(SCR1_LIN(I), REW_STRING, 15, 4);

        STR(CP_PCT(I):4:1, REW_STRING);
        INVERT(SCR1_LIN(I), REW_STRING, 27, 4);

        STR(TDN_PCT(I):4:1, REW_STRING);
        INVERT(SCR1_LIN(I), REW_STRING, 39, 4);

        STR(ADF_PCT(I):4:1, REW_STRING);
        INVERT(SCR1_LIN(I), REW_STRING, 52, 4);

        STR(COST_TON(I):4:0, REW_STRING);
        INVERT(SCR1_LIN(I), REW_STRING, 64, 4);

        STR(CA_PCT(I):5:2, REW_STRING);
        INVERT(SCR2_LIN(I), REW_STRING, 12, 5);

        STR(P_PCT(I):5:2, REW_STRING);
        INVERT(SCR2_LIN(I), REW_STRING, 23, 5);

        STR(NA_PCT(I):5:2, REW_STRING);
        INVERT(SCR2_LIN(I), REW_STRING, 34, 5);

        STR(MG_PCT(I):5:2, REW_STRING);
        INVERT(SCR2_LIN(I), REW_STRING, 44, 5);

        STR(S_PCT(I):5:2, REW_STRING);
        INVERT(SCR2_LIN(I), REW_STRING, 55, 5);

        STR(K_PCT(I):5:2, REW_STRING);
        INVERT(SCR2_LIN(I), REW_STRING, 66, 5)

      END;

      ZEROES(SCR1_LIN);
      ZEROES(SCR2_LIN)
  END;

(*  End CONVERT_TO_STRING *)

($I B:CURMOVE.PAS   )          (* Cursor movement routine         *)
($I B:INPUTCHR.PAS  )          (* Gets proc to input to nutr screen *)
```

```
(* Procedure INPUT_CHAR allows for screen input based on the location
   of the cursor on the active screen.  You should note that any change
   in the fields of the active screen WILL MESS UP this procedure.
   Therefore, EXTREME CAUTION is recommended before making any changes
   to either procedures NUTR_SCR or MIN_SCR.

                                                                       *)

PROCEDURE INPUT_CHAR(VAR INPT : CHAR; VAR ROW, COL, SCREEN :
    INTEGER; VAR SCR1_LIN, SCR2_LIN : BIGARR;  VAR BWT,GAIN : REAL);
VAR
  TROW : INTEGER;
  LOCAT : INTEGER;
  SHSTRING : STRING(4);             (* String for bwt input from screen  *)
  VSSTRING : STRING(3);             (* String for gain input from screen *)

BEGIN
  TROW := 0;
  STR(BWT:4:0, SHSTRING);
  STR(GAIN:3:1, VSSTRING);
  WHILE POS(SPACE, SHSTRING) <> 0 DO   (* If there is a space in the string *)
    BEGIN                              (* convert it to a zero before chan- *)
      LOCAT := POS(SPACE, SHSTRING);   (* ging it to a numeric variable.    *)
      DELETE(SHSTRING, LOCAT, 1);
      INSERT('0', SHSTRING, LOCAT)
    END;
  WHILE POS(SPACE, VSSTRING) <> 0 DO   (* If there is a space in the string *)
    BEGIN                              (* convert it to a zero before chan- *)
      LOCAT := POS(SPACE, VSSTRING);   (* ging it to a numeric variable.    *)
      DELETE(VSSTRING, LOCAT, 1);
      INSERT('0', VSSTRING, LOCAT)
    END;
CASE SCREEN OF
  1 : CASE ROW OF
        4..11 : BEGIN
                  TROW := ROW - 3;
                  CASE COL OF
                    1..3,
                    8..9,11,
                    15,16,18,
                    27,28,30,
                    39,40,42,
                    52,53,55,
                    64..67 : BEGIN
                               DELETE(SCR1_LIN(TROW), COL,1);
                               INSERT(INPT, SCR1_LIN(TROW), COL);
                               PRINT_CHAR(COL, INPT)
                             END
```

```
              ELSE
                RING_BELL
              END (* CASE  *)
            END;  (* 4..11 *)

    21 : IF (COL >= 22) AND (COL <= 25) THEN
           BEGIN                              (* Delete the numeral to  *)
             PRINT_CHAR(COL, INPT);           (* be changed in SHSTRING *)
             DELETE(SHSTRING, COL-22, 1);     (* then insert new numeral*)
             INSERT(INPT, SHSTRING, COL-22); (* into that position;    *)
             VAL(SHSTRING, BWT, CODE)         (* finally, recalculate   *)
                                              (* new body weight.       *)
           END
         ELSE
           RING_BELL;
    22 : IF (COL = 23) OR (COL = 25) THEN
           BEGIN                              (* Delete the numeral to  *)
             PRINT_CHAR(COL, INPT);           (* be changed in VSSTRING *)
             DELETE(VSSTRING, COL-23, 1);     (* then insert new numeral*)
             INSERT(INPT, VSSTRING, COL-23); (* into that position;    *)
             VAL(VSSTRING, GAIN, CODE)        (* finally, recalculate   *)
                                              (* new GAIN.              *)
           END
         ELSE
           RING_BELL
  ELSE
    RING_BELL
  END;   (* SCREEN_1 *)

2 : BEGIN
      IF (ROW >= 4) AND (ROW <= 11) THEN
        BEGIN
          TROW := ROW -3;
          CASE COL OF
            1..3,
            6,7,9,10,
            12,13,15,16,
            23,24,26,27,
            34,35,37,38,
            45,46,48,49,
            56,57,59,60,
            67,68,70,71 : BEGIN
                            DELETE(SCR2_LIN(TROW), COL, 1);
                            INSERT(INPT, SCR2_LIN(TROW), COL);
                            PRINT_CHAR(COL, INPT)
                          END
          ELSE
            RING_BELL
```

```
          END  (* CASE *)
        END    (* THEN IF *)
    END;  (* SCREEN 2 *)

  3 : BEGIN
        CLRSCR;
        WRITELN('MINCOMINERAL SCREEN NOT AVA.')
    END
  END   (* CASE SCREEN *)
END;     (* INPUT_CHAR *)

($I B:FEEDLIST.PAS  )          (* Gets feedlist procedure          *)

(*  Procedure FEED_LIST reads feed numbers and descriptions from
    the file HEFRFEEDS.DAT and prints selected items to the screen.
    The procedure will then return to the active screen.
                                                                  *)

PROCEDURE FEED_LIST(VAR NRC_FEEDS : FILEOUT);

  VAR
    INCHR : CHAR;                       (* Input variable      *)
    FOUND_ALL, OK : BOOLEAN;            (* Assorted flags      *)
    FEEDNO : REAL;                      (* feed number - file  *)
    FEE_TYPE : DESCRIPT;                (* A string of 20 chars *)

  PROCEDURE FEED(FEEDNO, MIN, MAX : REAL; VAR FOUND_ALL : BOOLEAN;
    FEE_TYPE : DESCRIPT);
    BEGIN                                           (* Proc feed writes the  *)
      IF (FEEDNO >= MIN) AND (FEEDNO <= MAX) THEN   (* no. & desc. to screen *)
        WRITELN(FEEDNO:3:0, ' ', FEE_TYPE);         (* if no. is >= min no.  *)
      IF FEEDNO > MAX THEN                          (* and <= to max no.     *)
        FOUND_ALL := TRUE
    END;  (* FEED *)

  BEGIN
    OK := TRUE;
    WHILE OK = TRUE DO
      BEGIN
        FOUND_ALL := FALSE;
        CLRSCR;
        WRITELN('Which type of feed would you like a listing of?');
        WRITELN;
        WRITELN('1) Hays          4) Silages               7) Mineral supplements');
        WRITELN('2) By-products   5) Basal feeds           8) Additives          ');
        WRITELN('3) Fresh plants  6) Protein supplements   9) Concentrate mixes');
        WRITELN('0) Return to worksheet         ');
        WRITELN;
```

```
      WRITE('Enter a value ');
      READ(KBD, INCHR);
        IF INCHR IN ('0'..'9') THEN
          BEGIN
            WRITELN(INCHR);
            WRITELN;
            RESET(NRC_FEEDS);
            WHILE (NOT EOF(NRC_FEEDS)) AND (FOUND_ALL = FALSE) DO
              BEGIN
                READ(NRC_FEEDS, FEEDNO, FEE_TYPE);
                CASE  INCHR OF
                  '0' : BEGIN
                          FOUND_ALL := TRUE;
                          OK := FALSE
                        END;
                  '1' : FEED(FEEDNO, 100, 150, FOUND_ALL, FEE_TYPE);
                  '2' : FEED(FEEDNO, 151, 200, FOUND_ALL, FEE_TYPE);
                  '3' : FEED(FEEDNO, 201, 300, FOUND_ALL, FEE_TYPE);
                  '4' : FEED(FEEDNO, 301, 400, FOUND_ALL, FEE_TYPE);
                  '5' : FEED(FEEDNO, 401, 500, FOUND_ALL, FEE_TYPE);
                  '6' : FEED(FEEDNO, 501, 600, FOUND_ALL, FEE_TYPE);
                  '7' : FEED(FEEDNO, 601, 700, FOUND_ALL, FEE_TYPE);
                  '8' : FEED(FEEDNO, 701, 800, FOUND_ALL, FEE_TYPE);
                  '9' : FEED(FEEDNO, 801, 999, FOUND_ALL, FEE_TYPE)
                 END (* CASE *)
               END;
             IF INCHR <> '0' THEN
               BEGIN
                 WRITELN; WRITELN('More feeds (Y/N) ');
                 READ(KBD, INCHR);
                 WRITE(INCHR);
                 IF UPCASE(INCHR) = 'N' THEN
                   OK := FALSE
               END (* IF *)
           END (* If Inchr *)
        ELSE
          RING_BELL
    END  (* While *)
 END;     (* Feed_list *)

($I B:CHNGFEED.PAS  )          (* Gets change feed description proc *)


(*  Procedure CHANGE_FEED_NAME will take as input the feed description
    array, and change a selected description for a more appropriate one.
    This change is good for the session ONLY.  There is no update to
    B:HEFRFEED.DAT.                                                  *)
```

```
PROCEDURE CHANGE_FEED_NAME(VAR FEED_DESC : DESCARR);

  VAR
    I, X : INTEGER;
    NEW_DESC : DESCRIPT;

  BEGIN
    CLRSCR;
    WRITELN('Which feed name would you like to change?' );
    FOR I := 1 TO NUMFEEDS DO
      IF FEED_DESC(I) <> SPACE THEN
        WRITELN(I, '. ', FEED_DESC(I));
    WRITE('Enter 1 - ', NUMFEEDS, ' then <CR>');
    READ(X);
    WRITELN;
    WRITE('Enter new name (max 20 chars) ');
    READ(NEW_DESC);
    FEED_DESC(X) := NEW_DESC
  END;  (* Change_feed_name *)

($I B:STARTSCR.PAS  )          (* Gets intro screen                    *)


(* Procedure START_SCREEN prints to the screen the intro screen and
   version number prior to starting the program.  BE SURE that any
   major or minor changes are reflected in updating the version
   number.                                                        *)

PROCEDURE START_SCREEN;

  VAR
    I : INTEGER;
    INKEY : CHAR;
    STAR : STRING(80);
  BEGIN
    CLRSCR;
    TEXTBACKGROUND(BLUE);      (* IBM-PC Turbo "Goodies" to set colors *)
    TEXTCOLOR(WHITE);
    STAR := '';
    FOR I := 1 TO 79 DO
      STAR := STAR + '*';
    WRITELN(STAR);
    FOR I := 2 TO 20 DO
      WRITELN('*',' ':77, '*');
    WRITE(STAR);
    GOTOXY(37,4);
    WRITE('DAIR4H');
```

```
    GOTOXY(35,6);
    WRITE('Version ', VERSION:3:1);
    GOTOXY(9,8);
    WRITE('AUTHORS: J. Quigley, C. Stallings, G. Kroll');
    GOTOXY(30,10);
    WRITE('@ Copyright 1985');
    GOTOXY(22,12);
    WRITE('Dairy Science Dept - Virginia Tech');
    GOTOXY(30,13);
    WRITE('Blacksburg, VA  24061');
    GOTOXY(25,20);
    WRITE('Press any key to continue');
    READ(KBD, INKEY)
  END;  (* START_SCREEN *)

(*  END START_SCREEN  *)

($I B:COLOR.PAS     )          (* Function COLR - IBM-PC unique!    *)


(* Procedure COLR uses the IBM-PC procedure to set color to either
   red or yellow if amt of a nutrient in ration DM is greater (red)
   or less than (yellow) 100%. This is an IBM-PC UNIQUE set of
   TURBO procedures, and if a non-PC is used, should be removed
   from both MINSCR and NUTRSCR prior to use.                     *)


PROCEDURE COLR(PERCT : REAL; MIN_M, MAX_M : INTEGER);

  BEGIN
    IF PERCT > MAX_M THEN
      TEXTCOLOR(4)              (* Red    *)
    ELSE
      IF (PERCT >= MIN_M) AND (PERCT <= MAX_M) THEN
        TEXTCOLOR(2)
      ELSE
        TEXTCOLOR(14);            (* Yellow *)
    WRITE(PERCT:3:0);
    TEXTCOLOR(YELLOW)
  END;

(* END COLR *)

($I B:NUTRSCR.PAS   )          (* Gets nutrient screen procedure    *)

(*   Procedure NUTR_SCR prints to the screen the nutrient screen,
     which acts as a grid for input of data.  It is imperative that
```

```
     any changes in the grid be followed with changes in the main
     program and ALL procedures.  It is NOT RECOMMENDED that any
     changes be made without careful consideration of the consequenses.
                                                                    *)

PROCEDURE NUTR_SCR(FEEDNO, FEEDLBS, DM_PCT, DM_LBS, CP_PCT, CP_LBS,
      TDN_PCT, TDN_LBS, ADF_PCT, ADF_LBS, COST_TON, COST_COW : REALARR;
      TOTAL_DM, TOTAL_CP, TOTAL_TDN, TOTAL_ADF, TOTAL_COST, REQ_DM_PCT,
      DM_REQT, REQ_CP_PCT, CP_REQT, REQ_TDN_PCT, TDN_REQT, PCT_RATION_TDN,
      PCT_RATION_FIBER, PCT_RATION_PROTEIN, PCT_BWT, GAIN : REAL; BREED : CHAR;
      FILENAME : FILESTR; FEED_DESC :DESCARR);
  VAR
    I : INTEGER;
  BEGIN
    CLRSCR;
    WRITELN('                    DM           CP           TDN           ADF          COST');
    writeln('FEED   LBS     pct   lb     pct   lb     pct   lb     pct   lb  $/ton $/cow');
    WRITE('    +-------+');
    WRITE('----------+-----------+-----------+----------+-----------+');
    WRITELN;
    FOR I := 1 TO 8 DO
      WRITELN(FEEDNO(I):3:0, ' |', FEEDLBS(I):6:1, ' | ', DM_PCT(I):4:1, ' ',
        DM_LBS(I):4:1, ' | ', CP_PCT(I):4:1, '  ', CP_LBS(I):3:1,
        ' | ', TDN_PCT(I):4:1, '  ', TDN_LBS(I):4:1, ' | ',
        ADF_PCT(I):4:1, '  ', ADF_LBS(I):3:1, ' | ', COST_TON(I):4:0, ' ',
        COST_COW(I):5:2, ' |');
    WRITELN('    +-------+    =====       =====       =====       =====       =====');
    WRITELN(' ':18, TOTAL_DM:5:1, '       ', TOTAL_CP:5:1, '        ', TOTAL_TDN:5:1,
      '       ',TOTAL_ADF:5:1, '       ', TOTAL_COST:5:2);
    WRITELN('Heifer              -----       -----       -----');
    WRITE('Requirements  ');
    COLR(REQ_DM_PCT,95,105);
    WRITE('% ', DM_REQT:4:1, '  ');
    COLR(REQ_CP_PCT,95,105);
    WRITE('% ', CP_REQT:5:1, '   ');
    COLR(REQ_TDN_PCT,95,105);
    WRITE('% ', TDN_REQT:5:1);
    WRITELN; WRITELN;
    WRITELN('Percent TDN        ', PCT_RATION_TDN:2:0);
    WRITELN('Percent fiber      ', PCT_RATION_FIBER:4:1);
    WRITELN('Percent protein    ', PCT_RATION_PROTEIN:4:1);
    WRITELN('DM intake (% BWT)', '  ', PCT_BWT:3:1);
    WRITE('  Body weight         ');
    IF BWT >= 1200 THEN
      TEXTCOLOR(RED)
    ELSE
      TEXTCOLOR(GREEN);
    WRITELN(BWT:4:0);
```

```
    TEXTCOLOR(YELLOW);
    WRITE('  Daily lbs gain       ');
    IF GAIN >= 2.5 THEN
      TEXTCOLOR(RED)
    ELSE
      TEXTCOLOR(GREEN);
    WRITELN(GAIN:3:1);
    TEXTCOLOR(YELLOW);
    WRITELN('  Breed (A, B, G, J, H)  ', BREED);
    FOR I := 1 TO NUMFEEDS DO
      BEGIN
        GOTOXY(31, 16+I);
        WRITE(FEEDNO(I):3:0, ' ', FEED_DESC(I))
      END;
    GOTOXY(60,17);
    WRITE('PF2 - Minerals');
    GOTOXY(60,18);
    WRITE('PF3 - Micro-min');
    GOTOXY(60,19);
    WRITE('PF4 - SAVE SCREEN');
    GOTOXY(60,20);
    WRITE('PF5 - Recalculate');
    GOTOXY(60,21);
    WRITE('PF6 - Feed list');
    GOTOXY(60,22);
    WRITE('PF7 - Quit / Report');
    GOTOXY(60,23);
    WRITE('PF8 - Feed name');
    GOTOXY(60,24);
    WRITE('File *              *');
    GOTOXY(67,24);
    WRITE(FILENAME)
  END; (* NUTRSCREEN *)

($I B:MINSCR.PAS    )          (* Gets mineral screen procedure     *)


(*  Procedure MIN_SCR is the screen "overlay" for inputting data from
    the screen.  It is VERY important that if changes are made to this
    procedure, the ENTIRE program be changed to accomodate the change.
    MIN_SCR works by first doing a few simple calculations, then
    printing out the results.  It then serves as the format for
    SCR2_LIN - the array for input from this screen.                *)


PROCEDURE MIN_SCR(VAR FEEDNO, FEEDLBS, CA_PCT, CA_LBS, P_PCT, P_LBS,
  NA_PCT, NA_LBS,
```

```
  MG_PCT, MG_LBS, S_PCT, S_LBS, K_PCT, K_LBS : REALARR; VAR TOTAL_CA,
  TOTAL_P, TOTAL_NA, TOTAL_MG, TOTAL_S, TOTAL_K, CA_REQT, REQ_CA_PCT,
  P_REQT, REQ_P_PCT, NA_REQT, REQ_NA_PCT, MG_REQT, REQ_MG_PCT, S_REQT,
  REQ_S_PCT, K_REQT, REQ_K_PCT, TOTAL_DM : REAL; FEED_DESC : DESCARR);

VAR
  I, COLUMN, ROW : INTEGER;
  CA_DM, P_DM, NA_DM, MG_DM, S_DM, K_DM :REAL;

PROCEDURE CALC(VAR A, B, C : REAL);
  BEGIN
    IF (B >0) AND (C > 0) THEN
      A := B / C * 100
    ELSE A := 0.0
  END;  (* CALC *)

BEGIN
  CLRSCR;
  WRITELN('                Calcium   Phosphorous  Sodium   Magnesium   Sulfur   Potassium');
  WRITELN('FEED  LBS      pct    lb    pct    lb    pct    lb    pct    lb    pct    lb    pct    lb');
  WRITELN('     +-----+----------+----------+----------+----------+----------+----------+');
  FOR I := 1 TO NUMFEEDS DO
    WRITELN(FEEDNO(I):3:0, ' ', FEEDLBS(I):6:2, ' ', CA_PCT(I):5:2, ' ',
      CA_LBS(I):4:2, ' ', P_PCT(I):5:2, ' ', P_LBS(I):4:2, ' ', NA_PCT(I):5:2,
      ' ', NA_LBS(I):4:2, ' ', MG_PCT(I):5:2, ' ', MG_LBS(I):4:2, ' ',
      S_PCT(I):5:2, ' ', S_LBS(I):4:2, ' ', K_PCT(I):5:2, ' ', K_LBS(I):4:2,
      '|');
  WRITELN(' ':16, '=====', ' ':6, '=====', ' ':6, '=====', ' ':6, '=====',
    ' ':6, '=====', ' ':6, '=====');
  WRITELN(' ':17, TOTAL_CA:4:2, ' ':7, TOTAL_P:4:2, ' ':7, TOTAL_NA:4:2,
    ' ':7, TOTAL_MG:4:2, ' ':7, TOTAL_S:4:2, ' ':7, TOTAL_K:4:2);
  WRITELN(' ':16, '-----', ' ':6, '-----', ' ':6, '-----', ' ':6, '-----',
    ' ':6, '-----', ' ':6, '-----');
  WRITE('Reqts.  ', ' ':4);
    COLR(REQ_CA_PCT,95,105);
    WRITE('% ', CA_REQT:4:2, '  ');
    COLR(REQ_P_PCT,95,105);
    WRITE('% ', P_REQT:4:2, '  ');
    COLR(REQ_NA_PCT,95,105);
    WRITE('% ', NA_REQT:4:2, '  ');
    COLR(REQ_MG_PCT,95,105);
    WRITE('% ', MG_REQT:4:2, '  ');
    COLR(REQ_S_PCT,95,105);
    WRITE('% ', S_REQT:4:2, '  ');
    COLR(REQ_K_PCT,95,105);
    WRITE('% ', K_REQT:4:2);
  WRITELN; WRITELN;
```

```
  CALC(CA_DM, TOTAL_CA, TOTAL_DM);
  CALC(P_DM, TOTAL_P, TOTAL_DM);
  CALC(NA_DM,TOTAL_NA, TOTAL_DM);
  CALC(MG_DM,TOTAL_MG, TOTAL_DM);
  CALC(S_DM, TOTAL_S, TOTAL_DM);
  CALC(K_DM, TOTAL_K, TOTAL_DM);

  WRITELN('Percent DM     ( ', CA_DM:4:2, ' )   ( ', P_DM:4:2, ' )   ( ',
    NA_DM:4:2, ' )   ( ', MG_DM:4:2, ' )   ( ', S_DM:4:2, ' )   ( ',
    K_DM:4:2, ' )');

  COLUMN := 22; ROW := 20;
  GOTOXY(1, ROW);
  I := 1;
  WHILE I <= NUMFEEDS DO
    BEGIN
      WRITE(FEEDNO(I):3:0, ' ', FEED_DESC(I));
      GOTOXY(COLUMN, ROW);
      WRITELN(FEEDNO(I+1):3:0, ' ', FEED_DESC(I+1));
      ROW := ROW + 1;
      I := I + 2
    END;

 GOTOXY(45,20);
 WRITELN('PF1 - Nutrient  PF6 - Feed list');
 GOTOXY(45,21);
 WRITELN('PF3 - Micr-min  PF7 - Quit/Report');
 GOTOXY(45,22);
 WRITELN('PF4 - SAVE SCR  PF8 - Change feed');
 GOTOXY(45,23);
 WRITELN('PF5 - RECALC')

END;

($I B:RECALC.PAS    )          (* Gets recalculate procedure        *)


(* Procedure RECALCULATE does all recalculations based on all data
   entered since last recalculate.                                *)

PROCEDURE RECALCULATE(VAR FEEDLBS, DM_PCT,
  DM_LBS, CP_PCT, CP_LBS, TDN_PCT, TDN_LBS,
  ADF_PCT, ADF_LBS, COST_TON, COST_COW        : REALARR;  (* Procedure recalculate     *)
  VAR TOTAL_DM, TOTAL_CP, TOTAL_TDN,                      (* does all calc. on data    *)
  TOTAL_ADF, TOTAL_COST,                                  (* entered since the previous*)
  REQ_DM_PCT, DM_REQT, REQ_CP_PCT,                        (* recalculation.            *)
  CP_REQT, REQ_TDN_PCT, TDN_REQT,                         (*                           *)
  PCT_RATION_TDN, PCT_RATION_FIBER,                       (*  Calculations include:    *)
```

```
PCT_RATION_PROTEIN, PCT_BWT,                                (*   A. for each feed:          *)
BWT, GAIN                              : REAL;              (*      1. mult lbs fed by      *)
VAR CA_PCT, P_PCT, NA_PCT, MG_PCT,                          (*         DM %                 *)
S_PCT, K_PCT,  CA_LBS, P_LBS,                               (*      2. mult lbs DM by %     *)
NA_LBS, S_LBS, K_LBS, MG_LBS           : REALARR;           (*         each nutrient in     *)
VAR TOTAL_CA, TOTAL_P, TOTAL_NA,                            (*         DM                   *)
TOTAL_S, TOTAL_K, TOTAL_MG             : REAL;              (*   B. Sum total nutrients     *)
VAR CA_REQT, P_REQT, MG_REQT, K_REQT,                       (*   C. % each nutrient in      *)
NA_REQT, S_REQT                        : REAL;              (*      DM                      *)
VAR REQ_CA_PCT, REQ_P_PCT, REQ_NA_PCT,                      (*   D. nutrient reqts based    *)
REQ_K_PCT, REQ_MG_PCT, REQ_S_PCT       : REAL;              (*      on NRC and JDQ          *)
SCREEN                                 : INTEGER);          (*   E. amt of nutrient as a    *)
VAR                                                         (*      % of requirements       *)
  CODE, I : INTEGER;
  METBWT, BWT_KG, GAIN_KG, E  : REAL;

PROCEDURE CALC(VAR A, B, C : REAL);
  BEGIN
    IF (B <> 0) AND (C <> 0) THEN
      A := B * (C /100)
    ELSE A := 0
  END;   (* CALC *)

PROCEDURE CALC_PCT(VAR A, B, C : REAL);
  BEGIN
    IF (B <> 0) AND (C <> 0) THEN
      A := B / C * 100
    ELSE A := 0
  END;  (* CALC_PCT *)

PROCEDURE POSITIVE(VAR R_VAR : REAL);
  BEGIN
    IF R_VAR > 0 THEN
      R_VAR := R_VAR * KG_TO_LB
    ELSE
      R_VAR := 0
  END;

PROCEDURE PWR(VAR A, B, C : REAL);
(* COMPUTES B**C, RETURNS IN A *)
  BEGIN
    IF B > 0 THEN
      A := EXP(C * LN(B))
    ELSE
      A := 0
  END;  (* PWR *)

BEGIN
```

```
TOTAL_DM := 0; TOTAL_CP := 0; TOTAL_TDN := 0; TOTAL_ADF := 0;
TOTAL_COST := 0; TOTAL_CA := 0; TOTAL_P := 0; TOTAL_K := 0;
TOTAL_MG := 0; TOTAL_S := 0; TOTAL_NA := 0;
CODE := 0;
FOR I := 1 TO NUMFEEDS DO
  BEGIN
    CALC(DM_LBS(I), FEEDLBS(I),DM_PCT(I));
    CALC(CP_LBS(I),  DM_LBS(I), CP_PCT(I));
    CALC(TDN_LBS(I), DM_LBS(I), TDN_PCT(I));
    CALC(ADF_LBS(I), DM_LBS(I), ADF_PCT(I));
    CALC(CA_LBS(I),  DM_LBS(I), CA_PCT(I));
    CALC(P_LBS(I),   DM_LBS(I), P_PCT(I));
    CALC(NA_LBS(I),  DM_LBS(I), NA_PCT(I));
    CALC(MG_LBS(I),  DM_LBS(I), MG_PCT(I));
    CALC(S_LBS(I),   DM_LBS(I), S_PCT(I));
    CALC(K_LBS(I),   DM_LBS(I), K_PCT(I));

    IF (COST_TON(I) <> 0) AND (FEEDLBS(I) <> 0) THEN
      COST_COW(I) := COST_TON(I) / 2000 * FEEDLBS(I);

    TOTAL_DM := TOTAL_DM + DM_LBS(I);
    TOTAL_CP := TOTAL_CP + CP_LBS(I);
    TOTAL_TDN := TOTAL_TDN + TDN_LBS(I);
    TOTAL_ADF := TOTAL_ADF + ADF_LBS(I);
    TOTAL_COST := TOTAL_COST + COST_COW(I);
    TOTAL_CA := TOTAL_CA + CA_LBS(I);
    TOTAL_P := TOTAL_P + P_LBS(I);
    TOTAL_NA := TOTAL_NA + NA_LBS(I);
    TOTAL_MG := TOTAL_MG + MG_LBS(I);
    TOTAL_S := TOTAL_S + S_LBS(I);
    TOTAL_K := TOTAL_K + K_LBS(I)
  END;

  CALC_PCT(PCT_RATION_TDN, TOTAL_TDN, TOTAL_DM);
  CALC_PCT(PCT_RATION_FIBER, TOTAL_ADF, TOTAL_DM);
  CALC_PCT(PCT_RATION_PROTEIN, TOTAL_CP, TOTAL_DM);
  CALC_PCT(PCT_BWT, TOTAL_DM, BWT);

  E := 0.75;
  BWT_KG := BWT * LB_TO_KG;
  PWR(METBWT, BWT_KG, E);
  GAIN_KG := GAIN * LB_TO_KG;

  DM_REQT := -29.86365959 + (-1.5425468E-05 * BWT_KG * BWT_KG) +
             (0.15748749 * METBWT) + (2.08951563 * GAIN_KG) +
             (-0.11770722 * GAIN_KG * GAIN_KG) + ( 0.72957095 * PCT_RATION_TDN)
             + (-0.00481779 * PCT_RATION_TDN * PCT_RATION_TDN) +
             (-0.00136331 * BWT_KG * GAIN_KG) + (-0.01908410 * PCT_RATION_TDN
```

```
                  * GAIN_KG);
                                               (* Equation: Jim Quigley, Ph.D.
                                                  Dissertation.   1985.
                                                  r(2) = .592              *)
      POSITIVE(DM_REQT);

      CP_REQT := (-139.724 + 762.881 * GAIN_KG + 2.845548 * BWT_KG +
          (-0.0023063 * BWT_KG * BWT_KG) + (-438.952 * GAIN_KG * GAIN_KG)
          + (-0.281704 * BWT_KG * GAIN_KG)) / 1000;
      POSITIVE(CP_REQT);
                   (* r(2) = .9904 - data from 1978 NRC Tables *)
      TDN_REQT :=  1.194965 + 0.320326 * GAIN_KG + 6.029265E-03 * BWT_KG
                   + 5.34712E-03 * BWT_KG * GAIN_KG;
      POSITIVE(TDN_REQT);
                   (* r(2) = .9769 - data from 1978 NRC Tables *)
      P_REQT := (-2.639036 + 11.732249 * GAIN_KG + 0.073361 * BWT_KG +
                (-7.00517E-05 * BWT_KG * BWT_KG) + (-5.377443 * GAIN_KG *
                 GAIN_KG) + (-0.00320389 * GAIN_KG * BWT_KG))/ 1000;
      POSITIVE(P_REQT);
                   (* r(2) = .9838 - data from 1978 NRC Tables *)
      CA_REQT := (4.260041 + 17.929739 * GAIN_KG + 0.054551 * BWT_KG +
                 (-4.04742E-05 * BWT_KG * BWT_KG) + (-7.486495 *
                 GAIN_KG * GAIN_KG) + (-0.00816293 * BWT_KG * GAIN_KG))
                 / 1000;
      POSITIVE(CA_REQT);
                   (* r(2) = .9792 - data from 1978 NRC Tables *)
      MG_REQT := TOTAL_DM * 0.0016;
      K_REQT := TOTAL_DM * 0.008;
      NA_REQT := TOTAL_DM * 0.001;
      S_REQT := TOTAL_DM * 0.0016;

      CALC_PCT(REQ_DM_PCT, TOTAL_DM, DM_REQT);
      CALC_PCT(REQ_TDN_PCT, TOTAL_TDN, TDN_REQT);
      CALC_PCT(REQ_CP_PCT, TOTAL_CP, CP_REQT);
      CALC_PCT(REQ_CA_PCT, TOTAL_CA, CA_REQT);
      CALC_PCT(REQ_P_PCT, TOTAL_P, P_REQT);
      CALC_PCT(REQ_NA_PCT, TOTAL_NA, NA_REQT);
      CALC_PCT(REQ_K_PCT, TOTAL_K, K_REQT);
      CALC_PCT(REQ_MG_PCT, TOTAL_MG, MG_REQT);
      CALC_PCT(REQ_S_PCT, TOTAL_S, S_REQT)
END;

(*  END  RECALCULATE *)

($I  B:SCREEN.PAS    )          (* Gets screen save & get procedures *)
```

```
(* INBED File SCREEN contains the procedures:
            GET_FEED_INFO : reads NRC_FILE to obtain feed no's & descs.;
            SAVE_SCREEN   : writes screens to a disk file (ASCII);
            GET_SCREEN    : reads screens from a disk file (ASCII);
                                                                      *)

PROCEDURE GET_FEED_INFO(VAR FEEDNO : REAL; VAR DESC : DESCRIPT;
  VAR DM, CP, TDN, ADF, CA, P, NA, MG,
  S, K : REAL; VAR NRC_FILE : FILEOUT; VAR FOUND : BOOLEAN);
VAR
  IN_VAR : REAL;                              (* This proc. reads in feed *)
  BEGIN                                       (* info from NRC file for a *)
   RESET(NRC_FILE);                           (* given feed # entered on  *)
   FOUND := FALSE;                            (* the screen               *)
   WHILE (FOUND = FALSE) AND (NOT EOF(NRC_FILE)) DO
     BEGIN
       READ(NRC_FILE, IN_VAR);
       IF IN_VAR = FEEDNO THEN
         BEGIN
           FOUND := TRUE;
           READLN(NRC_FILE, DESC, DM, CP, TDN, ADF, CA, P, NA, MG, S, K);
           CLOSE(NRC_FILE)
         END
       ELSE
         READLN(NRC_FILE)
     END;
    IF FOUND = FALSE THEN
     BEGIN
       CLRSCR;
       FEEDNO := 0;
       WRITELN('THE FEED NUMBER YOU REQUESTED IS NOT AVAILABLE... ');
       DELAY(2000);
       FEED_LIST(NRC_FILE);
     END
  END; (* GET_FEED_INFO *)

PROCEDURE FILENAME_IN(VAR FILENAME : FILESTR; VAR SAVE_FILE : FILEOUT;
  VAR FOUND_FILE : BOOLEAN);
VAR
  OPEN_FILE, MAKE_FILE : BOOLEAN;

  BEGIN
    IF LENGTH(FILENAME) = 0 THEN
      FILENAME := DEF_FILE;

    IF POS(DOT, FILENAME) = 0 THEN
      FILENAME := FILENAME + '.DYH';
```

```
    IF (POS(COLON, FILENAME) <> 2) AND (POS(COLON, FILENAME) > 0) THEN
      FILENAME := DEF_FILE;
($I-)                               (* Sets I/O checking off so as not *)
                                    (* to abort program *)
    ASSIGN(SAVE_FILE, FILENAME);
    RESET(SAVE_FILE);
    OPEN_FILE := (IORESULT = 0);
    IF NOT OPEN_FILE THEN
      BEGIN
        REWRITE(SAVE_FILE);            (* If file not found, create a file for *)
        MAKE_FILE := (IORESULT = 0); (* output...                           *)
        IF NOT MAKE_FILE THEN
          WRITELN('Cannot find ',FILENAME)
      END (* IF not open_file *)
    ELSE
      FOUND_FILE := TRUE;           (* If file is found, set flag to true   *)
($I+)
    RESET_CURSOR(ROW,COL)
  END; (* FILENAME_IN *)


PROCEDURE SAVE_SCREEN(VAR FILENAME : FILESTR; VAR SAVE_FILE : FILEOUT;
  FEED_DESC : DESCARR; FEEDNO, FEEDLBS, DM_LBS, CP_PCT, CP_LBS, TDN_PCT, TDN_LBS,
  ADF_PCT, ADF_LBS, COST_TON, COST_COW, CA_PCT, P_PCT, NA_PCT, MG_PCT,
  S_PCT, K_PCT: REALARR; BWT, GAIN : REAL; BREED : CHAR);
  VAR
    I : INTEGER;                        (* Procedure SAVE_SCREEN takes vars    *)
    INTAS : CHAR;                       (* on screens 1 & 2 and puts them in   *)
    NO_NAME : BOOLEAN;                  (* the file FILENAME. Already existing *)
                                        (* file is erased and rewritten to     *)

   PROCEDURE GET_NAME(VAR FILENAME : FILESTR; VAR NO_NAME : BOOLEAN);
     BEGIN
       WRITELN;
       WRITE('Enter filename (B: if on B drive)...<CR> to return to screen  ');
       READ(FILENAME);
       IF LENGTH(FILENAME) = 0 THEN
         NO_NAME := TRUE
     END;    (* GET NAME *)

  BEGIN
    NO_NAME := FALSE;
    CLRSCR;
    IF FILENAME <> SPACE THEN
      BEGIN
        WRITE('Do you wish to use the name ', FILENAME, ' ? (Y/N) ');
        READ(KBD, INTAS);
```

```
        IF UPCASE(INTAS) <> 'Y' THEN
          GET_NAME(FILENAME, NO_NAME)
      END
    ELSE
      GET_NAME(FILENAME, NO_NAME);

    IF NO_NAME = FALSE THEN
      BEGIN
        CLOSE(SAVE_FILE);
        FILENAME_IN(FILENAME, SAVE_FILE, FOUND_FILE);
        CLOSE(SAVE_FILE);
        REWRITE(SAVE_FILE);
        FOR I := 1 TO NUMFEEDS DO
          BEGIN
            WRITELN(SAVE_FILE, FEEDNO(I):3:0, FEEDLBS(I):6:1,
              DM_PCT(I):5:1, CP_PCT(I):5:1, TDN_PCT(I):5:1, ADF_PCT(I):5:1,
              COST_TON(I):5:0);
            WRITELN(SAVE_FILE, CA_PCT(I):4:1, P_PCT(I):4:1, NA_PCT(I):4:1,
              MG_PCT(I):4:1, S_PCT(I):4:1, K_PCT(I):4:1);
            WRITELN(SAVE_FILE, FEED_DESC(I))
          END;
        WRITELN(SAVE_FILE, BWT:5:0, GAIN:4:1, ' ', BREED);
        CLOSE(SAVE_FILE)
      END (* THEN NO_NAME *)
  END;  (* SAVE_SCREEN *)

PROCEDURE GET_SCREEN(VAR  SAVE_FILE : FILEOUT;
  VAR FEED_DESC : DESCARR; VAR FEEDNO, FEEDLBS, DM_LBS, CP_PCT, CP_LBS,
  TDN_PCT, TDN_LBS, ADF_PCT, ADF_LBS, COST_TON, COST_COW, CA_PCT, P_PCT,
  NA_PCT, MG_PCT, S_PCT, K_PCT: REALARR; VAR BWT, GAIN : REAL; VAR BREED : CHAR);
  VAR
    I : INTEGER;
  BEGIN
     FOR I := 1 TO NUMFEEDS DO
       BEGIN
         READLN(SAVE_FILE, FEEDNO(I), FEEDLBS(I), DM_PCT(I), CP_PCT(I),
           TDN_PCT(I), ADF_PCT(I), COST_TON(I));
         READLN(SAVE_FILE, CA_PCT(I), P_PCT(I), NA_PCT(I), MG_PCT(I),
           S_PCT(I), K_PCT(I));
         READLN(SAVE_FILE, FEED_DESC(I))
       END;
       READLN(SAVE_FILE, BWT, GAIN, BREED);
       CLOSE(SAVE_FILE);
    END;  (* GET_SCREEN *)

($I B:DUMMY.PAS      )          (* Gets dummy proc. to set bigarrs   *)
                                (* to zero and inbed decimal points  *)
```

```
PROCEDURE DUMMY(VAR MAKE_DOT, MAKE_DOT2 : BIGARR);
  VAR
    I, J : INTEGER;

  PROCEDURE DOTTER(VAR MAKE_DOT3 : LONG_STRING; LOCAT : INTEGER);
    BEGIN
      DELETE(MAKE_DOT3, LOCAT, 1);
      INSERT(DOT, MAKE_DOT3, LOCAT)
    END;

  BEGIN
      FOR I := 1 TO NUMFEEDS DO
      BEGIN
          FOR J := 1 TO NUMCOLS DO
            BEGIN
              MAKE_DOT(I) := MAKE_DOT(I) + '0';
              MAKE_DOT2(I) := MAKE_DOT2(I) + '0'
            END;

                DOTTER(MAKE_DOT(I), 10);            (* Place decimal pts.     *)
                DOTTER(MAKE_DOT(I), 17);            (* in each screen array   *)
                DOTTER(MAKE_DOT(I), 29);            (* at the position on each*)
                DOTTER(MAKE_DOT(I), 41);            (* screen.  This allows   *)
                DOTTER(MAKE_DOT(I), 54);            (* error checking on input*)
                DOTTER(MAKE_DOT2(I), 8);
                DOTTER(MAKE_DOT2(I), 14);
                DOTTER(MAKE_DOT2(I), 25);
                DOTTER(MAKE_DOT2(I), 36);
                DOTTER(MAKE_DOT2(I), 47);
                DOTTER(MAKE_DOT2(I), 58);
                DOTTER(MAKE_DOT2(I), 69)
      END
  END;  (* DUMMY *)

PROCEDURE MICROMIN_SCR;
  BEGIN
    CLRSCR;
    WRITELN('Micromineral screen not available')
  END;

(*---------------------------------------------------------------------------*)
               (*  <<<<<<<<<< BEGIN MAIN PROGRAM >>>>>>>>>>  *)

BEGIN
  ASSIGN(NRC_FILE, 'HEFRFEED.DAT');             (* Assign file name to NRC file   *)
  S1_DOT_SET := (10, 17, 29, 41, 54);           (* Assign decimal point sets for  *)
  S2_DOT_SET := (8, 14, 25, 36, 47, 58, 69);    (* testing input of decimal pts.  *)
```

```
START_SCREEN;                                   (* Begin by printing intro screen *)
CLRSCR;
TEXTCOLOR(YELLOW);                          (* IBM-PC set color on screen     *)
FOR I := 1 TO NUMFEEDS DO                   (* Assign all vars to zero        *)
  BEGIN
    FEED_DESC(I) := SPACE;
    FEEDNO(I) := 0;
    FEEDLBS(I) := 0;
    DM_PCT(I) := 0;       CA_PCT(I) := 0;      S_PCT(I) := 0;
    DM_LBS(I) := 0;       CA_LBS(I) := 0;      S_LBS(I) := 0;
    CP_PCT(I) := 0;       MG_PCT(I) := 0;
    CP_LBS(I) := 0;       MG_LBS(I) := 0;
    TDN_PCT(I) := 0;      NA_PCT(I) := 0;
    TDN_LBS(I) := 0;      NA_LBS(I) := 0;
    ADF_PCT(I) := 0;      P_PCT(I) := 0;
    ADF_LBS(I) := 0;      P_LBS(I) := 0;
    COST_TON(I) := 0;     K_PCT(I) := 0;
    COST_COW(I) := 0;     K_LBS(I) := 0;
    SCR1_LIN(I) := '';    SCR2_LIN(I) := '';
 END;
  TOTAL_DM := 0; TOTAL_CP := 0; TOTAL_TDN := 0;
  TOTAL_ADF := 0; TOTAL_COST := 0; TOTAL_CA := 0; TOTAL_MG := 0;
  TOTAL_NA := 0; TOTAL_S := 0; TOTAL_P := 0; TOTAL_K := 0;
  REQ_CA_PCT := 0; CA_REQT := 0; REQ_MG_PCT := 0; MG_REQT := 0;
  REQ_NA_PCT := 0; NA_REQT := 0; REQ_S_PCT := 0;  S_REQT := 0;
  REQ_K_PCT := 0; K_REQT := 0; REQ_P_PCT := 0; P_REQT := 0;
  REQ_DM_PCT := 0; DM_REQT := 0; REQ_CP_PCT := 0; CP_REQT := 0;
  REQ_TDN_PCT := 0; TDN_REQT := 0; PCT_RATION_TDN := 0;
  PCT_RATION_FIBER := 0; PCT_RATION_PROTEIN := 0;

  PCT_BWT := 0; BWT :=600; GAIN := 1.5; BREED := 'H';
  FILENAME   := SPACE; SCREEN := 1;
  DUMMY(SCR1_LIN, SCR2_LIN);                (* Dummy sets both screen char *)
                                            (* arrays to zero              *)

                                            (* Print nutrient screen       *)

  NUTR_SCR(FEEDNO, FEEDLBS, DM_PCT, DM_LBS, CP_PCT, CP_LBS,
      TDN_PCT, TDN_LBS, ADF_PCT, ADF_LBS, COST_TON, COST_COW,
      TOTAL_DM, TOTAL_CP, TOTAL_TDN, TOTAL_ADF, TOTAL_COST, REQ_DM_PCT,
      DM_REQT, REQ_CP_PCT, CP_REQT, REQ_TDN_PCT, TDN_REQT, PCT_RATION_TDN,
      PCT_RATION_FIBER, PCT_RATION_PROTEIN, PCT_BWT, GAIN, BREED,
      FILENAME, FEED_DESC);
  RESET_CURSOR(ROW, COL);            (* Move cursor to begin of screen *)
  QUITEST := FALSE;
  WHILE QUITEST = FALSE DO
    BEGIN
      FLAG_1 := FALSE;
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        INPT3 := COLON;
        READ(KBD, INPT);             (* Accept input from keyboard - if input *)
        IF KEYPRESSED THEN           (* is cursor control, obtain second part *)
          BEGIN                      (* of input and respond to it            *)
            READ(KBD, INPT3);
            CASE INPT3 OF
              'P' : MOVE_DOWN(ROW, COL);
              'M' : MOVE_RIGHT(ROW, COL);
              'K' : MOVE_LEFT(ROW, COL);
              'H' : MOVE_UP(ROW, COL);
              'G' : IF SCREEN = 1 THEN
                      HOME_CURSOR(ROW, COL)
            END (* CASE *)
          END
        ELSE
          CASE UPCASE(INPT) OF              (* Begin interrogation of input *)
            ESC : BEGIN                     (* If input is a PF-key, then   *)
                    FLAG_1 := TRUE;         (* accept second input and go   *)
                    READ(KBD, INPT2);       (* the appropriate procedure    *)
                    VAL(INPT2,I,CODE);
                    CASE I OF
(* If PF is *)        1,2,3 : SCREEN := I;
(* then set screen *)
(* PF-4 save screen*)     4 : SAVE_SCREEN(FILENAME, SAVE_FILE, FEED_DESC, FEEDNO,
                                FEEDLBS, DM_LBS, CP_PCT, CP_LBS, TDN_PCT, TDN_LBS,
                                ADF_PCT, ADF_LBS, COST_TON, COST_COW, CA_PCT, P_PCT,
                                NA_PCT, MG_PCT, S_PCT, K_PCT, BWT, GAIN, BREED);
(* PF-5 Recalculate *)    5 :  BEGIN
(* Begin by convert *)           CONVERT_TO_NUMS(SCR1_LIN, SCR2_LIN, FEEDLBS,
(* screen arrays to *)             DM_PCT, CP_PCT, TDN_PCT, ADF_PCT, COST_TON, CA_PCT,
(* real vars        *)             P_PCT, NA_PCT, S_PCT, K_PCT, MG_PCT, SCREEN);
                                 RECALCULATE(FEEDLBS, DM_PCT,
(* Do the actual    *)             DM_LBS, CP_PCT, CP_LBS, TDN_PCT, TDN_LBS,
(* recalculations   *)             ADF_PCT, ADF_LBS, COST_TON, COST_COW,
                                   TOTAL_DM, TOTAL_CP, TOTAL_TDN,
                                   TOTAL_ADF, TOTAL_COST,
                                   REQ_DM_PCT, DM_REQT, REQ_CP_PCT,
                                   CP_REQT, REQ_TDN_PCT, TDN_REQT,
                                   PCT_RATION_TDN, PCT_RATION_FIBER,
                                   PCT_RATION_PROTEIN, PCT_BWT,
                                   BWT, GAIN,
                                   CA_PCT, P_PCT, NA_PCT, MG_PCT,
                                   S_PCT, K_PCT,  CA_LBS, P_LBS,
                                   NA_LBS, S_LBS, K_LBS, MG_LBS,
                                   TOTAL_CA, TOTAL_P, TOTAL_NA,
                                   TOTAL_S, TOTAL_K, TOTAL_MG,
                                   CA_REQT, P_REQT, MG_REQT,
                                   K_REQT, NA_REQT, S_REQT,
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                                                  REQ_CA_PCT, REQ_P_PCT, REQ_NA_PCT,
                                                  REQ_K_PCT, REQ_MG_PCT, REQ_S_PCT,
                                                  SCREEN);
                                                CONVERT_TO_STR(SCR1_LIN, SCR2_LIN, FEEDNO,
                                                  FEEDLBS, DM_PCT, CP_PCT, TDN_PCT, ADF_PCT,
                                                  COST_TON, CA_PCT, P_PCT, NA_PCT,
                                                  MG_PCT, S_PCT, K_PCT);
                                                RESET_CURSOR(ROW, COL)
                                              END;
(* PF-6 do feed list *)                   6 : FEED_LIST(NRC_FILE);
                                          7 : BEGIN
(* PF-7 quit - but   *)                         SCREEN := 0;
(* tidy up first     *)                         QUITEST := TRUE;
                                                CLOSE(SAVE_FILE);
                                                CLOSE(NRC_FILE)
                                              END;
(* PF-8 change name  *)                   8 : CHANGE_FEED_NAME(FEED_DESC)
(* of feed on screen *)

                              ELSE
                                RING_BELL
                              END; (* CASE TEMPVAR *)
                              RESET_CURSOR(ROW, COL)
                            END;     (* CASE - ESC *)
           'A'..'Z' : BEGIN
                              IF (SCREEN = 1) AND (ROW = 23) AND (COL = 26) THEN
(* If input is *)               BEGIN
(* alphabetic, *)                 BREED := 'J';
(* test if it  *)                 WRITE(BREED);
(* is legal, if*)                 RESET_CURSOR(ROW, COL)
(* so then do  *)               END
(* these       *)
                              ELSE
                                IF (COL IN (67..77)) AND (ROW = 24)  THEN
                                  BEGIN
(* keep tabs on *)                  PRINT_CHAR(COL, INPT);
(* changes in   *)                  DELETE(FILENAME, COL-67, 1);
(* filename so a*)                  INSERT(INPT, FILENAME, COL-67)
(* CR will do a *)
(* get or save  *)                END
                                ELSE
                                  RING_BELL
                            END;  (* CASE - A..Z *)
                 CR : BEGIN
                              IF COL =  4 THEN
(* On a CR        *)            BEGIN
(* test if legal *)               CASE SCREEN OF
(* input if so    *)                1 : VAL(COPY(SCR1_LIN(ROW-3), 1, 3), FEEDNO(ROW-3),
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(* do these      *)              CODE);
(* if col = 4,   *)          2 : VAL(COPY(SCR2_LIN(ROW-3), 1, 3), FEEDNO(ROW-3),
(* get feed no.  *)              CODE)
                           END; (* CASE - SCREEN *)
                           GET_FEED_INFO(FEEDNO(ROW-3), FEED_DESC(ROW-3),
                             DM_PCT(ROW-3), CP_PCT(ROW-3), TDN_PCT(ROW-3), ADF_PCT(ROW-3),
                             CA_PCT(ROW-3), P_PCT(ROW-3), NA_PCT(ROW-3), MG_PCT(ROW-3),
                             S_PCT(ROW-3), K_PCT(ROW-3), NRC_FILE, FOUND);
(* convert strings *)      CONVERT_TO_STR(SCR1_LIN, SCR2_LIN, FEEDNO, FEEDLBS, DM_PCT,
(* obtained from   *)        CP_PCT, TDN_PCT, ADF_PCT, COST_TON, CA_PCT, P_PCT, NA_PCT,
(* file to reals   *)        MG_PCT, S_PCT, K_PCT);
                           FLAG_1 := TRUE;
                           COL := 1; ROW := ROW + 1;
                           GOTOXY(COL, ROW)
                         END
                       ELSE                            (* If col is not = 4 *)
                         IF (ROW = 24) AND ( COL > 67) THEN
                                                    (* If we're entering a filename *)
                           BEGIN
                             FOUND_FILE := FALSE;
                             FLAG_1 := TRUE;
                             FILENAME_IN(FILENAME, SAVE_FILE, FOUND_FILE);
(* If file exists   *)       IF FOUND_FILE = TRUE THEN
(* then get it else *)         BEGIN
(* make a new one   *)           GET_SCREEN(SAVE_FILE, FEED_DESC,
                                   FEEDNO, FEEDLBS, DM_LBS, CP_PCT, CP_LBS, TDN_PCT,
                                   TDN_LBS, ADF_PCT, ADF_LBS, COST_TON, COST_COW,
                                   CA_PCT, P_PCT, NA_PCT, MG_PCT, S_PCT, K_PCT,
                                   BWT, GAIN, BREED);
                                 CONVERT_TO_STR(SCR1_LIN, SCR2_LIN, FEEDNO, FEEDLBS, DM_PCT,
                                   CP_PCT, TDN_PCT, ADF_PCT, COST_TON, CA_PCT, P_PCT, NA_PCT,
                                   MG_PCT, S_PCT, K_PCT)
                               END
                             ELSE
                               SAVE_SCREEN(FILENAME, SAVE_FILE, FEED_DESC, FEEDNO,
                                 FEEDLBS, DM_LBS, CP_PCT, CP_LBS, TDN_PCT, TDN_LBS,
                                 ADF_PCT, ADF_LBS, COST_TON, COST_COW, CA_PCT, P_PCT,
                                 NA_PCT, MG_PCT, S_PCT, K_PCT, BWT, GAIN, BREED);
(* Do recalculate with *)      RECALCULATE(FEEDLBS, DM_PCT,
(* the new data        *)        DM_LBS, CP_PCT, CP_LBS, TDN_PCT, TDN_LBS,
                                 ADF_PCT, ADF_LBS, COST_TON, COST_COW,
                                 TOTAL_DM, TOTAL_CP, TOTAL_TDN,
                                 TOTAL_ADF, TOTAL_COST,
                                 REQ_DM_PCT, DM_REQT, REQ_CP_PCT,
                                 CP_REQT, REQ_TDN_PCT, TDN_REQT,
                                 PCT_RATION_TDN, PCT_RATION_FIBER,
                                 PCT_RATION_PROTEIN, PCT_BWT,
                                 BWT, GAIN,
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                        CA_PCT, P_PCT, NA_PCT, MG_PCT,
                        S_PCT, K_PCT,  CA_LBS, P_LBS,
                        NA_LBS, S_LBS, K_LBS, MG_LBS,
                        TOTAL_CA, TOTAL_P, TOTAL_NA,
                        TOTAL_S, TOTAL_K, TOTAL_MG,
                        CA_REQT, P_REQT, MG_REQT,
                        K_REQT, NA_REQT, S_REQT,
                        REQ_CA_PCT, REQ_P_PCT, REQ_NA_PCT,
                        REQ_K_PCT, REQ_MG_PCT, REQ_S_PCT,
                        SCREEN)
                  END                   (* If row = 24  *)
                ELSE                    (* If row <> 24 *)
                  JUMP_AROUND(ROW, COL)
            END;     (* CASE - CR *)
      DOT : BEGIN
              CASE SCREEN OF
                1 : IF ((COL IN S1_DOT_SET) AND (ROW IN (4..11)))
                      OR ((COL = 24) AND (ROW = 22)) THEN
                      PRINT_CHAR(COL, DOT)
                    ELSE
                      RING_BELL;
                2 : IF COL IN S2_DOT_SET THEN
                      PRINT_CHAR(COL, DOT)
                    ELSE
                      RING_BELL
              END (* CASE - SCREEN *)
            END;  (* CASE - DOT *)
  '0'..'9': BEGIN
              INPUT_CHAR(INPT, ROW, COL, SCREEN, SCR1_LIN, SCR2_LIN,
                BWT, GAIN)
            END;  (* CASE - 0..9 *)
      BS  : MOVE_LEFT(ROW, COL);
     TAB  : BEGIN
              COL := TABSPACE;  GOTOXY(COL, ROW)
            END
  ELSE
    RING_BELL
  END;(* CASE - INPT *)
IF FLAG_1 = TRUE THEN
  BEGIN
    CASE SCREEN OF
      1 : NUTR_SCR(FEEDNO, FEEDLBS, DM_PCT, DM_LBS, CP_PCT, CP_LBS,
            TDN_PCT, TDN_LBS, ADF_PCT, ADF_LBS, COST_TON, COST_COW,
            TOTAL_DM, TOTAL_CP, TOTAL_TDN, TOTAL_ADF, TOTAL_COST, REQ_DM_PCT,
            DM_REQT, REQ_CP_PCT, CP_REQT, REQ_TDN_PCT, TDN_REQT, PCT_RATION_TDN,
            PCT_RATION_FIBER, PCT_RATION_PROTEIN, PCT_BWT, GAIN, BREED,
            FILENAME, FEED_DESC);
      2 : MIN_SCR(FEEDNO, FEEDLBS, CA_PCT, CA_LBS, P_PCT, P_LBS,
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                  NA_PCT, NA_LBS, MG_PCT, MG_LBS, S_PCT, S_LBS,
                  K_PCT, K_LBS, TOTAL_CA, TOTAL_P, TOTAL_NA, TOTAL_MG,
                  TOTAL_S, TOTAL_K, CA_REQT, REQ_CA_PCT, P_REQT,
                  REQ_P_PCT, NA_REQT, REQ_NA_PCT, MG_REQT, REQ_MG_PCT,
                  S_REQT, REQ_S_PCT, K_REQT, REQ_K_PCT, TOTAL_DM,
                  FEED_DESC);
            3 : MICROMIN_SCR
          END;  (* CASE SCREEN *)
        GOTOXY(COL, ROW)
      END
  END (* WHILE *)
END.


(*                     END MAIN PROGRAM                          *)
(* ¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢¢ *)
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