Effect of Varying levels of Neutral Detergent Fiber and Total Digestible Nutrients on Dry Matter Intake of Dairy Heifers.

by

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(ABSTRACT)

One hundred and eight Holstein dairy heifers were divided into two weight blocks based on beginning body weight ($\bar{x}$ = < 182 kg, light, > 270 kg, heavy). Heifers within weight blocks were randomly assigned to one of five treatments. Treatments consisted of three levels of NDF (35%, 45%, 55%) at 100% of NRC TDN recommendation, and three levels of TDN (85%, 100%, 115 of NRC) at 45% NDF for light heifers. For heavy heifers, treatments consisted of three levels of NDF (40%, 50%, 60%) at 100% NRC TDN, and three treatments with similar levels of TDN at 50% NDF. Heifers were fed total mixed rations of corn silage, alfalfa haylage, ground orchardgrass hay, soybean meal, high moisture corn and a mineral mix formulated for 0.68 kg ADG. Mean gains (kg/d) were 1.07 and .96 for the light and heavy blocks, respectively. DMI as a percent of BWT differed across NDF levels for light heifers ($\bar{x}$= 2.96, 2.56, 2.57, 2.57, and 2.87 % of BWT for the low, med., high NDF, and low, high TDN treatments, respectively). Heavy heifer DMI% did not differ ($\bar{x}$= 2.45, 2.40, 2.24, 2.15, and 2.42 % of BWT for low, med., and high NDF, and low, high TDN treatments, respectively). Equations to predict DMI were developed using intake information from this and a previous study. Backward stepwise regression was utilized to generate a simplified model. Model selected was: DMI (kg/d) = -5.9781 + (2.2120E-05 * BWTSQ) - (5.5527 * GAIN) +

(2.7837 * GAINSQ) + (0.4668 * NDF) + (5.3930 * NDFSQ) + (0.03285 * DM) + (7.7859E-03 * BWT * GAIN); n = 514, r^2 = .67.

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INTRODUCTION

Computerization in the animal industry has enhanced the use of on-farm ration formulation programs. Acceptance and use of these programs is highly dependent upon their ability to generate practical feeding recommendations. Such recommendations require accurate prediction of an animal's nutrient requirements and dry matter intake. Estimation of requirements is dependent upon known nutrient values for protein, and energy as needed for growth and maintenance, as well as representative analysis of forages and concentrates. Frequently, ration formulations are based upon published feed nutrient composition, rather than accurate chemical analysis. It would therefore be desirable for ration formulations to be based on accurate intake predictions using a measure of nutritive value which reflects the intake characteristics of the ration and ensures the diet permits optimal nutrient intake.

Researchers have found that neutral detergent fiber is related to factors associated with many of the intake-limiting characteristics of rations, such as digestibility, bulk density, energy density, rumination and rate of passage. Research conducted at V.P.I. & S.U. to elucidate factors most predictive of dry matter intake by dairy heifers indicated that body weight, ration fiber, energy density, bulk density, body weight gain, and ambient temperature were important variables for intake prediction. Through development of an intake prediction model this study determined acid detergent fiber (ADF) and neutral detergent fiber (NDF) as a % of dry matter were negatively correlated with dry matter intake. A negative correlation between ADF and/or NDF and intake would be expected as these measures of nutrient fiber content contain the fibrous plant materials associated with depression in digestibility and dry matter intake. Correlation between ADF and dry matter intake was greater than NDF and dry matter intake suggesting ADF or ration digestibility was more closely related to dry matter intake than the fill characteristics of NDF. Other researchers suggest NDF as a better index to predict maximum intake of dry matter. Their reports were based on the fact that NDF contains all the fibrous cell-wall portions of the plant. Therefore, NDF should be related to the depressive effect of fiber on voluntary intake.

An additional study was conducted at this station to determine the accuracy of the intake prediction model developed in the earlier study. This study suggested that the model consistently over estimated dry matter intake of confinement-reared heifers consuming rations with varying forage bases. While rations in this study were balanced for .68 kg/day gain, heifers gained in excess of .8 kg/day. It was also concluded that higher gains were caused by excess energy density of rations and not by variation in ration ADF.

Both studies emphasize problems inherent to intake prediction model development and confinement reared heifers. The model in the initial study was developed using rations based primarily upon one forage (corn silage). In the latter study, forage base was varied between corn silage and alfalfa haylage, possibly influencing the prediction of dry matter intake. In both studies, heifers were housed in total confinement where energy expenditure may be greatly reduced and/or growth in body weight may be more efficient, thus affecting metabolic mechanisms of intake control. Rations were formulated to vary in energy density (ADF) with little regard to total fiber or NDF content. Variation in ration fiber content allows for confusion between physical and metabolic mechanisms of intake control.

The following study was conducted as an attempt to reduce confounding between ration NDF and TDN levels. It was also of interest to determine which of these parameters aids more in the prediction of dry matter intake of growing dairy heifers. Objectives of this study were to: 1. Determine the effect of varying levels of NDF and TDN on DMI of two different weight groups of growing dairy heifers, while attempting to eliminate confounding between ration NDF and TDN. 2. Use additional information provided by this and the previous model development study to improve the predictive ability of the existing prediction equation over a wider range of body weights.

Heifer Management

Nutritional management of dairy heifers is probably the most neglected area in dairy herd management. The goal of a dairy heifer management program should be to rear mature heifers capable of producing to their genetic potential at the lowest possible cost. As non-income producing animals, this group tends to be neglected nutritionally resulting in inadequate growth prior to breeding, thus delaying calving.

Growth management

To achieve optimal production potential the dairy heifer should be 40-45% of mature weight at time of breeding (101). Etgen et al. (41) indicated that large breeds (Holstein, Brown Swiss) should weigh 354-400 kg, Ayrshire and Guernsey breeds 290-336 kg, and Jerseys 250-282 kg at time of breeding. Others (31, 51) make similar recommendations for these breeds and ages. These weights correspond with the recommended age of 14-17 months at breeding (41, 55, 73) and provide for calving between 23 and 26 months of age. Current age at first calving in Virginia DHI herds is 29 months. This age reflects problems with heifer nutrition and management, and is well above the standard of 24 to 26 months for optimal lactational potential and economic return (48). Norman et al.(77) reported that first lactational milk yield increased substantially with increased calving age to 26 months. Beyond 27 months production increases were lower and would not be great enough to justify later calving under intense management conditions.

Holding replacements so that they calve at an older age and greater weight can greatly affect profitability of the replacement enterprise. Researchers (41) estimate that increased age at first calving, past the optimum, costs $20-$40/heifer/month for confinement reared heifers. Others (2) estimate the increased costs to be $60-$70/heifer/month. Miller and Amos (71) suggest that heifers be raised on permanent pasture and be permitted to calve at a later age. Their study reports a reduction in feed costs by 50% due to reduced feeding of concentrates and stored forages. They also indicate that good pasture management should provide ample forage, thus allowing heifers to gain adequately and calve at 25 months. When pasture was not of sufficient quantity or quality, heifers were allowed to grow more slowly and thus reach mature size and calve at 31 months. Even though heifers were permitted to calve at 31 months, cost of this type of management was still only 65% of a conventional program.

Effect of feeding level

Swanson (99, 100) and Garner (47) reviewed the effects of growth rate on lactational ability of dairy heifers. Swanson (99), using seven pairs of identical twins, determined that rapidly grown heifers produced less milk than conventionally grown heifers in first, second, and third lactations. Average fat corrected milk production of fattened heifers was 84.8% and 93% of control animals for the first and second lactations. Gardner (47) presented similar results suggesting rapid growth and fattening was uneconomical, produced animals with lower lifetime production, yet had no adverse affects on herdlife or reproduction.

Effect of feeding level on age at which animals reach puberty has been addressed by Foldager (42), Sejrsen (92), and Gardner (47). Studies (47, 91, 100) indicate that appearance of puberty is directly and positively related to rate of growth and is dependent on size more than age. Heifers within a breed tend to reach puberty at similar body size regardless of feeding level (91). Gardner (47) reported heifers reached first estrus at 8.3 and 10.2 months when on control and accelerated growth programs, respectively. These findings suggest plane of nutrition as the most important factor in determining age of first estrus.

Increasing proportions of concentrates in the ration can reduce age at first calving to less than 20 months (47). Feeding this type of ration causes overconditioning (47, 101), decreased milk production (31, 99, 101), and calving problems (31, 101). Others (42) suggest ration energy density or composition have no influence on mammary development and later lactation, when plane of nutrition is the same. When plane of nutrition is increased, so that heifers gain more than .60 kg/d in the prepubertal period, mammary development is impaired (42). Swanson (99, 100, 101) reported the decrease in milk production in rapidly grown, or fattened heifers, may be due to fat infiltration into the mammary gland. A critical period for mammary growth has been suggested to occur during the prepubertal period between 90 to 325 kg for large breeds (92, 105). For smaller breeds the critical period is 60 to 230 kg. During this, the allometric phase (3 to 9 mos.), growth of mammary parenchyma is as much as 3.5 times faster than body weight growth. It is during this phase that ductular development is most critical. Sejrsen et al.(92) and Tucker (105) indicated heifers raised on a high plane of nutrition, during the allometric phase of mammary development, had less secretory tissue in their mammary glands than heifers raised at a normal rate of growth. In the pre-pubertal period hormonal basis of the animal is affected by plane of nutrition (92). Heifers on a high plane of nutrition were found to have decreased mammary growth due to decreased secretion of somatotropin and corticoids. This study indicated a positive relationship between parenchyma growth and somatotropin production, and a negative relationship with prolactin. Administration of exogenous somatotropin, to heifers on high planes of nutrition, has been found to increase mammary parenchyma growth and decrease extraparenchymal tissue and total mammary weight (42). Thus animals with higher circulating levels of somatotropin and corticoids may have greater potential for secretory tissue growth on high planes of nutrition.

Reports (92, 101, 105) indicate that growth of secretory tissue is inversely related to extra-parenchymal adipose tissue in the allometric phase. Therefore animals on high planes of nutrition (gaining > .60 kg/d) may have greater production of adipose tissue, and increase growth of mammary fat pad thus reducing secretory tissue growth. Kertz (61) determined that heifers in the 3 to 12 month age group can be fed high energy diets (those supporting >.8 kg/day gain) without adverse affects, when protein levels are also increased. These heifers grew at .9 to 1.0 kg/day and showed greater skeletal growth without fattening. Effects on mammary development and subsequent milk production were not available.

At onset of puberty, and until pregnancy, growth rate of the mammary gland decreases to a level similar to the rate of body weight gain. Plane of nutrition during this period does not influence hormone levels or mammary growth (42). Presence of adipose tissue in this, the post-pubertal isometric phase, is unrelated to growth of mammary tissue.

During pregnancy the fat pad and ducts again begin to grow at a rate faster than the body, with plane of nutrition being less critical. Foldager et al.(42) studied heifers gaining .40, .60, and .80 kg/d, from 325 kg live weight to three months prepartum. They concluded heifers gaining .40 kg/d had lower mammary gland weights than those gaining .60 or .80 kg/d, but no differences in parenchyma were found. Based on these results, heifers with higher live weights at calving tend to produce more milk due to greater bodily stores, lower growth requirements, and higher feed intake, rather than due to greater parenchymal growth. It can be concluded that feeding regimes should support ample growth in weight and stature without overfattening of the animal so that development of mammary secretory tissue is maximized. While over-fattening during the pre- and postpubertal periods has proven to be detrimental to overall productivity (47, 91, 99, 101), underfeeding can also depress lactation performance. Heifers fed nutritionally inadequate diets tend to lack mature size by first calving (56, 101). Swanson et al. (99) studied the effects of feeding animals at 75% of normal intake and were bred to calve at 2 years. They determined underfed animals to have increased dystocia, and 13% lower milk production in the first lactation. Underfeeding of heifers can be corrected by the feeding of supplemental concentrates in the first lactation (56, 101).

From these studies it can be concluded that plane of nutrition during the pre-pubertal critical period has lasting negative effects on lactation performance. Growth rates during the pre-pubertal period affect levels of circulating hormones more than rates in the isometric phase. Circulating levels of somatotropin, insulin, and corticoids is reduced by a high plane of nutrition. A plane of nutrition supporting .40 kg/d has been suggested as providing for optimal secretory tissue growth during the allometric phase (42). Mammary development between puberty and pregnancy is not affected by nutrition. A plane of nutrition during pregnancy resulting in daily gains of .70 kg/d, will result in increased secretory tissue growth and improved lactation performance. This suggests that growth standards be established so that heifers are raised to achieve maximum secretory tissue growth, body weight gains and growth in stature providing for maximal lactation performance.

Growth Standards

Standards for determination of adequate rates of growth are presented in table 1. Proper rates of gain and growth in stature are important to ensure maximum productivity of dairy heifers. Swanson (101) recommends that for optimal growth, performance, and age at first calving, heifers be fed in three stages of gain; .55 kg/d weaning to breeding, .68 kg/d breeding to 20 months, and .91 kg/d until calving. He suggests that under such a scheme animals will grow successfully to breeding age and size without problems associated with fattening. Post breeding growth rates will allow for growth to mature size by 24 months, and prepare the animal for lactational levels of intake. Etgen et al. (41) suggests higher rates of gain at .73 to .82 kg/d for large breeds, and .45 to .64 kg/d for small to medium breeds, for the period between weaning and breeding. They too stress that overconditioning should be avoided.

It has been suggested (71, 82) that rearing heifers at a slower rate with compensatory growth periods can optimize use of cheap feeds, increase growth and feed efficiency, and produce an animal with high lactational potential. Park (82) fed heifers averaging 7.6 mos. of age and 205 kg (BWT) on a 4 stage schedule. Animals were fed 5 months at 85% of (74), 2 months at 140% of (74), 5 months at 85% of (74), and 2 months at 140% of (74). Treatment animals were compared to control heifers gaining .45 kg/day. Heifers within the treatment regime gained more, and consumed less feed resulting in substantial improvements in growth and feed efficiency. Growth during the maintenance phase was .25 kg/day, while growth was 1.9 kg/day during the compensatory phase. Results for the first lactation showed improved performance of 10% by heifers raised on the compensatory regime.

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

Age mo.	Clapp	Etgen	Heinrichs	NRC
		---------- kg	----------	
1	42	42		30
2	54	52	62	49
4	127	123	123	106
6	182	177	169	144
8	235	232	209	183
10	280	277	256	221
12	323	318	303	259
14	366	354	344	297
16	408	386	380	336
18	450	414	420	374
20	488	445	448	412
22	525	477	496	450
24	575	514	515	489

Regression Equations:

Clapp (31) : BWT(kg) = 42.30 + 22.52 * AGE (mos.)
Etgen (41) : BWT(kg) = 51.21 + 20.17 * AGE (mos.)
Heinrichs (51) : BWT(kg) = 47.66 + 20.30 * AGE (mos.)
NRC (74) : BWT(kg) = 29.74 + 19.12 * AGE (mos.)

To achieve goals of heifer growth, a program should be implemented that provides for maximal weight, stature, and mammary secretory tissue growth. To achieve these goals the dairyman or nutritionist must apply published standards of growth, accurate analysis of forages and concentrates, and prediction of dry matter intake to balance rations to meet nutrient requirements. Evaluating feedstuffs for use in animal diets requires many procedures. These procedures should answer questions such as: nutrient composition, digestibility, productive value, and physical characteristics.

Nutrient Content of Feeds

Availability of nutrients in a feed is determined by the chemical composition of the feed with respect to the concentrations of digestible and indigestible nutrients, and through organic structures and inhibitors that may limit availability of the nutrients (112). Characterization of the availability of energy and protein in a feed requires a system of analysis that allows for estimation of digestibility and other parameters of nutritional value. Laboratory analysis to measure these parameters must be rapid and economical so that the prediction of animal response in different feeding situations can be achieved.

Two types of analysis exist: in vivo or in vitro digestion with rumen bacteria or enzymes and chemical evaluation. The in vivo method of digestion gives direct estimation of digestibility but requires surgically altered animals, is lengthy, and is greatly affected by animal variation. The in vitro method gives indirect estimation of digestibility, is lengthier, more expensive, less reproducible and may not represent in vivo digestibility. Cheaper, more rapid, chemical analyses do not give a direct estimate of nutritive value, yet are reproducible. This method depends on statistical association between the content of analyzed components and feed value (112). Although many factors have been suggested and evaluated as indicators of forage quality, most have been discarded or found to be of limited use when used as the sole index of forage nutritive value (70).

Chemical analysis of feeds is valuable in accounting for nutritional phenomena and for describing feed characteristics important in ration formulation. Since this method of analysis is much cheaper and quicker than animal feeding trials, its use in assaying feed quality is indispensable.

Proximate System

This system has been in use for more than 120 years. Developed in the 1860's by Henneberg and Stohmann it has remained unchanged as the primary means of feedstuff analysis (21, 109, 112). This procedure is probably the most generally used chemical scheme for describing feedstuffs. It consists of the following steps; 1. Dry matter. A sample is heated to a constant weight at 100 C. The loss in weight is water, but can also be a loss of materials which are volatilized such as silage or fermentation products. 2. Ether Extraction. The dry residue is extracted with ether for 4 or more hours. This extraction gives an estimation of lipid content. 3. Carbohydrates. After removal of ether extract and water from the sample, the residue is refluxed 30 min. with 1.25% sulfuric acid followed by 30 min. reflux with 1.25% sodium hydroxide. The insoluble residues are dried, weighed, burned at 600 C and the insoluble organic matter reported as crude fiber. 4. Crude Protein. Determination of nitrogen by the Kjeldahl method requires a sample which has been digested in concentrate sulfuric acid. The digestion process converts the nitrogen into the ammonium sulfate form. The digest is then neutralized with sodium hydroxide, distilled, driving the ammonia into standard acid and titrated. This determines the amount of nitrogen in the sample. As protein contains an average of 16% nitrogen, nitrogen content x 6.25 equals crude protein. 5. Nitrogen Free Extract. The determination is found by difference, not by actual analysis. This component consists of the dry matter not accounted for by the sum of ether extract, crude fiber, ash and crude protein (112).

This system is the basis on which total digestible nutrients (TDN) is calculated, using the following assumptions: 1. Ether extract recovers lipids and fats which contain 2.25 times the energy/gram of carbohydrate. 2. All nitrogen is in protein form which contains 16% nitrogen. 3. Crude fiber recovers the least digestible fibrous and structural matter of the feed. 4. The NFE represents highly digestible carbohydrates. None of these assumptions are totally true and the degree of error is highly variable between feeds, especially with forages.

The NFE term has been chiefly criticized because it does not represent a single constituent, but is a residual of numerous undetermined substances of variable nutritive value such as hemicellulose and lignin. Calculation of NFE by difference is further weakened by errors involved in determining the fat, fiber, protein, and ash contents (21). In that the NFE fraction contains the cumulative errors of all the other determinations, a considerable amount of error in any one fraction makes this value nearly useless. Errors determined critical to this estimation are; ether extract contains waxes and pigments that are of little nutritional value to the animal. Lipid estimation of forages is inflated as they contain no triglycerides, and leaf galactolipids contain less than the 2.25 factor of energy found in carbohydrates. Nitrogen content of plant proteins is 15 to 16%. This aids in the accuracy of crude protein estimation. However, true protein accounts for only about 70% of forage nitrogen and little of the fecal nitrogen, thus the error in using the 6.25 factor is reflected in the NFE fraction.

The largest of these errors tends to be created by partial solubilization of lignin and hemicellulose, and variable recovery of cellulose in the crude fiber extraction. The NFE fraction is meant to represent the highly digestible carbohydrates (36), while the crude fiber is characterized as being the indigestible part of a feedstuff (109). The effect of this error is to cause the apparent digestibility of the NFE to be less than that of the crude fiber. This occurs most often in cases where the feedstuff has high hemicellulose and moderate lignin content. For example: poorest recovery of cell wall components in crude fiber occurs with grasses. Legumes, which are lower in hemicellulose but higher in lignin, are intermediate for crude fiber. Therefore one can see that the most fundamental error of the proximate system of analysis is the division of the carbohydrates into simple (digestible) and complex (indigestible) forms represented by NFE and crude fiber respectively.

Because of the errors involved in determination of the digestible and indigestible fractions by the proximate system, various workers developed a new system for more definitive separation of the carbohydrate fraction. In development of such a procedure, Van Soest et al. (107) designed a system which would fractionate forages into relatively digestible and indigestible fractions, called the Detergent or Van Soest system.

Detergent System

The detergent analysis of feedstuffs were most recently improved by Van Soest in 1963 (106, 107). He determined that the use of both acid and neutral detergents would be superior in separation of carbohydrate and protein fractions. Similar methods were proposed which made use of acid and alkaline solutions for digestion (14, 45, 58, 87, 119). Results from these procedures were less accurate than those obtained by the crude fiber method. With very long digestion times similar results were obtainable, but were not practical.

The Van Soest method of analyses consists of separate extractions of plant tissues by slightly alkaline solutions of sodium lauryl sulfate or strongly acid solutions containing cetyl trimethylammonium bromide (CTAB). These digestions yield a low nitrogen residue containing the major cell wall components of lignin, cellulose and hemicellulose (49, 106, 107, 112). The use of sodium lauryl sulfate in the alkaline solution divides the dry matter of feeds very near the point that separates the nutritively available and soluble constituents from those that are incompletely available and dependant on microbial fermentation. The residue from this digestion, neutral detergent fiber (NDF), contains all the cell wall components including the hemicellulose (49). The acid extraction of the sample relies primarily upon the ability of the CTAB to dissolve proteins in the solution to yield predominantly lignin and cellulose. This fraction is commonly called acid-detergent fiber (ADF). These rapid analyses have been designed to separate and fractionate feed dry matter into three classes as represented in Figure 1.
The classes in the figure represent: 1. Total availability, 2. Incomplete availability, 3. Total unavailability. The totally available class's actual extent of digestion is determined by the competition between rate of digestion and passage. Extent of digestion of class two is regulated by rate of microbial breakdown as controlled by rate of passage, availability of protein for growth of bacteria, solids passage rate, and biochemical inhibitors (lignification). Class three contains those fractions which are indigestible by the enzymic and microbial digestive processes (112).

Because of the complete availability of the non cell wall components, the problem of estimating forage digestibility is essentially that of estimating cell wall digestibility. The

Fraction	Components	Availability
	Class I	
Cell Contents (Fiber soluble in neutral detergent)		
	Lipids Sugars, organic acids Pectin, starch Non-protein N Soluble protein	Almost completely digestible - not lignified
Cell wall constituents (Fiber insoluble in neutral detegent)		
	Class II	
1. Soluble in acid detergent	Hemicellulose Fiber bound protein	Partially digestible according to degree of lignification.
2. Acid-detergent fiber	Cellulose	
	Class III	
	Lignin Lignified N	Totally unavailable

Figure 1. Fractionation of feed by the Van Soest (107) method of analysis.

source of variability in fiber digestibility has long been regarded as being mainly plant maturity, but other sources such as environmental and genetic differences among plants also exist (111). Estimation of fiber digestibility with fiber fractions works best when the variation in maturity is emphasized and the other factors are small. When environmental and genetic factors are minimal the association between lignin and cellulose is greatest. As lignin is the most unavailable feed fraction it is used as an indicator of the digestibility of feedstuffs. The ADF fraction has the advantage in that it divides the cell wall fraction into the major indigestible components. This procedure divides components, indigestible without rumen bacteria, into those which are soluble and insoluble in acid detergent. The acid-soluble fraction contains primarily hemicelluloses and cell wall proteins, while the residue or insoluble fraction recovers cellulose and the least digestible non-carbohydrate fractions (lignin, lignified N). ADF has proven to be a good indicator of feedstuff digestibility as it contains the lignin fraction. It is the lignified matrix in ADF which is the most unavailable feed fraction. Since ADF does not contain the total complement of cell wall components, it is better correlated with digestibility than with intake. The ADF fraction is more accurate in predicting the indigestibility of feeds than crude fiber or NDF. ADF is most reliably related to digestibility because ruminants are able to digest much of the fibrous cellulosic carbohydrate, and are limited in this ability only by lignification and capacity of their digestive tract (111).

Compositional studies by Van Soest (107) show the correlations of the acid detergent fiber method to digestibility to be $r = -0.79$, which is somewhat improved over the use of crude fiber $r = -0.73$ in estimating nutritive value. The correlation of the ADF lignin content, as determined using permanganate analysis, and digestibility was $r = -0.90$ when grass and legume were separated. Separation of species removes the bias involved with differences in lignification, cell wall content and their changes associated with maturity.

The NDF fraction has been proposed (67, 68) as a good predictor of dry matter intake because it contains all of the bulkier and less digestible portions of the feedstuffs (3). The NDF value should be inversely correlated with dry matter intake. As indicated with ADF, fiber content of the ration and digestibility are inversely related. Therefore, fiber content of the ration affects intake. Since NDF contains the full complement of fibrous plant components it is best associated with the physical factors limiting intake, such as bulk density or volume, rumination time, chewing time, and rate of particle size reduction for passage. Intake of feedstuffs influences digestion by increasing the rate of passage. This in turn, causes a decline in digestibility of the more slowly digesting feed components through competition between digestion and passage. These slowly digesting feed components are cellulose and hemicellulose contained in the NDF fraction. Feeding trials utilizing NDF to predict intake have shown that rations containing 36% NDF resulted in the highest fat corrected milk production (68). Research with dairy heifers indicated that maximal dry matter intake occurs between 40 and 44% NDF (84). This study also reported NDF to be negatively correlated with intake $r = -.42$ and $-.03$ when above and below 42% NDF. Van Soest (108) reported results from 82 forages (6 plant species) showing that cell wall content was best related ($r = 0.65$) to intake. He suggested that cell wall content influence on intake was depressed when below 50% of the dry matter. Above 55 - 60 percent intake was limited by the total fibrous part of the forage (NDF). Studies conducted to validate optimal levels of NDF for intake and fat corrected milk production have shown that a constant optimum across roughage sources is not possible (17). Feeds that are alike for NDF content may have widely varying differences in bulk density and caloric density. Such feeds are cottonseed hulls and sugarcane bagasse. Cottonseed hulls are higher in bulk and caloric density. These researchers suggest that NDF may best predict intake and production when used within roughage sources. Others (114, 115) have shown that rate and extent of NDF digestion affects fat corrected milk production and is negatively correlated with NDF content. They formulated diets containing components of high and low rates of NDF clearance, speculating that diets of high rate of clearance would yield greater dry matter intake and production. Results from this study indicated that dry matter intake did not differ between rations and that cows controlled intake by chemostatic mechanisms when fiber level was not limiting.

Improvements in assiciation of the cell wall fractions to digestibility and intake are created by an increased ability, by the detergent system, to recover the major cell wall components with only minor quantities of protein, bound nitrogen, minerals and cuticle. Common contaminants in the NDF residue include starch, animal keratin, and soil minerals. The interference of starch is commonly removed by the use of amylases (88). Failure to remove these contaminants leads to difficulty in filtration of the fiber and increased analytical error. The elimination of the other contaminants is not critical to the NDF estimation of the feedstuff, unless they are uncommonly high. The animal proteins (keratin) can be removed by the use of sodium sulfite, but doing so also removes some of the lignin, thus if the cell wall preparation is to be used for other purposes this step must be avoided (112). Another cell wall component removed by neutral detergent is pectin. As it is easily digested by the process, and is the most rapidly fermentable carbohydrate by the animal, it would be erroneous to include this in the indigestible fraction of NDF. Removal of pectin does, however, decrease the estimation of hemicellulose, as hemicellulose is determined by difference between NDF and ADF. The error occurs as the acid detergent does not remove pectin. Concern regarding this error is greatest with legumes as they contain substantial pectin, while corn silage and grasses contain very little. Therefore, estimation of hemicellulose, by difference, may be under estimated in legumes. Other contaminants of fiber estimation are soil minerals. Their presence reflects the amount of soil contamination of the sample and are generally not a problem.

The advantage of the ADF procedure is that the residue is free of protein and other acid-soluble material. This provides a residue is useful for the estimation of lignin, cellulose, cutin, indigestible nitrogen and silica (112).

Current use of the detergent method of analysis or more specifically the ADF and NDF fractions over crude fiber analysis has been seated in the more specific fractionation of fiber components and reduced error. While the detergent method has advantages in division of feedstuff components, it requires considerable amounts of laboratory equipment and time. Thus, the Near Infrared Reflectance Spectroscopic method of analysis was devised. Its advantages are seated in the savings of time, expense, reduce problems associated with sample preparation and handling, and provide a method of feedstuff analysis is portable.

Alternative Systems

Near infrared reflectance spectroscopy (NIRS) is one of the newest methods of assaying nutrient composition and feeding value of feedstuffs (59). Major advantages of the NIRS system are speed, simplicity of sample preparation, multiplicity of analysis in one operation, nonconsumption of sample, and reduced cost of reagents (80). Disadvantages include cost of instrumentation, dependence on calibration procedures, complexity of data treatment, and lack of sensitivity for minor constituents. NIRS analysis is based upon the principle that each major chemical component in a feedstuff has near infrared absorption properties. These properties are created by vibrations arising from the stretching and bending of H bonds associated with C, O, and N. These vibrations give the sample absorptive properties in the near infrared region specific to a component. The summation of these absorption properties, combined with the radiation-scattering properties of the sample, determines the diffuse reflectance of a sample. Compositional information is therefore extracted from the near infrared diffuse reflectance signal by correlation to the concentration of the component in the sample. Through correlation between known compositional values and reflectance, an equation is developed which is used to predict the composition of other samples of similar species, cutting, storage method, and sample preparation. It is imperative that samples be of similar species, cutting and/or maturity, geographic location, method of handling (baled, ensiled, green chop), and be prepared in similar methods to the sample on which the equation is developed. Otherwise, analyses may be completely inaccurate and useless for diet formulation or estimation of productive function.

Analysis of a sample using this method requires as little as one second and only minimal sample preparation. Preparation consists of grinding to a mean particle size of 100 to 500 um to ensure sample homogeneity. This method of analysis is able to analyse a feed sample for the same nutrient components as the chemical methods. Jones et al. (59), Norris et al.(79), and Shenk et al.(94), found that NIRS could predict the crude protein, ADF, NDF, and lignin content of forages and grains with nearly the same accuracy of chemical methods but at a much faster rate. The use of NIRS to predict animal response to various forage bases was conducted by Norris et al. (79) and Eckman et al. (40). These researchers used sheep to determine the dry matter digestibility, dry matter intake, and digestible energy intake of grass and legume forages. They found that the scanning monochromator could predict digestibility and intake as accurately as fiber or in vivo digestibility assays using sheep. The scanning monochromator is more effective than filter instruments for analysis of chemical constituents. Improved effectiveness, by this instrument, lies in its ability to utilize the entire spectrum within the near-infrared region. The scanning monochromator is able to scan all wavelengths within the 1000 to 2600 nm region in less than 3 minutes. By scanning a greater number of times, this instrument is able to better determine the spectral properties of the sample with reduced error from extraneous reflectances.

Potential for application of NIRS is considerable. Combining the capabilities of high-volume forage testing and minimum sample preparation with a computerized ration balancing program gives nutritionists the ability to make rapid corrections to rations during farm visits, using mobile units. The lag time associated with sampling and waiting for laboratory test results is therefore eliminated. NIRS can aid the researcher by allowing daily monitoring of forage quality in animal nutrition trials. Diets can quickly be altered to compensate for changes in forage quality thus maintaining desired nutrient levels in treatments. Use of this method to analyse wet forage samples has shown promise for determination of dry matter, nitrogen, and insoluble nitrogen. Accuracy of this method for determination of CP, ADF, NDF, and ADF-N is poorly documented (1). Potential for analysis of fat and water-soluble vitamins and fat composition of individual and complete feeds is present with NIRS. Analysis for macro minerals is moderately accurate, while analysis for trace minerals has shown little promise due to their low levels. Due to recent recommendations concerning the use of by-pass protein sources, NIRS may also find application in analysis of proteins for their fractionation into digestible and indigestible fractions (32). Application of this method of analysis for the compositional determination of total mixed rations has been less than desirable. Determination of nutrient composition of mixed feeds is quite complicated due to heterogeneity. Mixed feed fractionation complicates equation determination due to the variable reflectance of combined ingredients. Differences in bulk density, energy density, mineral content, and variability in fiber fraction, make it difficult to develop accurate equations due to low correlations with mixed sample reflectance and composition.

With further development in this area, and improved accuracy in analyses of individual ingredients through validation with chemical methods, this method may become more attractive. Development of equations for NIRS analysis of the cellulose, hemicellulose, and lignin fractions will prove to be valuable in prediction of intake and digestibility characteristics of feeds. Possibly through determination of specific fibrous fractions, the rate and extent of digestion of feedstuffs can be determined allowing for better estimation of animal utilization and performance.

Cellulose and Hemicellulose digestion

Introduction

The major carbohydrate constituents occuring in forages are cellulose, hemicellulose, and pectin. Cellulose comprises the largest proportion of this polysaccharide complex, approximating 40 to 60%, while hemicellulose and pectin constitute from 30 to 40% of the total carbohydrate (38). Due to the complexity and similarity in structure of pectin and hemicellulose, they will be treated as a single entity in this discussion. The availability of native celluloses to cellulolytic organisms varies from zero to 100%. This availability depends on the inherent factors such as crystallinity of the cellulose and its association with lignin, cutin and silica (110). The association of cellulose with lignin content in the growing plant is not as regular as one would predict. Studies have shown that environmental temperature is dominant over light, fertilization, and water supply (factors affecting the maturation process) in its effect on plant composition. Increased temperature promotes more rapid metabolic activity which decreases the pool size of metabolites in the cellular contents. Photosynthetic products are thus being more rapidly converted to structural components. Temperature is positively associated with lignification and increased cell wall material. Therefore, temperate zone grasses and legumes have a negative correlation between lignin, cellulose, and digestibility (110). The effect of light is exerted directly upon metabolism of the plant through photosynthesis. Factors involved include total light received, light intensity, and daylength. Added light promotes the accumulation of glucose and the metabolism of nitrogen. Cell wall content is decreased by increasing light through dilution by non-structural carbohydrates, amino acids and organic acids. Fertilization tends to decrease digestibility of forages due to greater lignification. This effect is, however, offset by a decrease in total cell wall content. Water stress tends to retard the development of plants and thus retard maturity. The result is an increase in digestibility with a reduction if dry matter yield. Under normal growing conditions effects due to changes in temperature, light, fertilization, and water are interrelated making identification of individual effects quite difficult.

Ratios of hemicellulose to cellulose in the plant cell wall vary widely among different species. Grasses have a distinctly higher proportion of hemicellulose and lower lignin - to - cellulose ratios. Legumes tend to be highly lignified while containing a low proportion of hemicellulose. Lignin is the main factor limiting digestibility in forages. Because of the differences in total cell wall content and lignification, grasses and legumes tend to differ in voluntary dry matter intake and rate of digestion. Grasses, having higher cell wall content, tend to have lower voluntary intake due to a longer rate of digestion even though they are less lignified. Legumes, while being more lignified, have lower cell wall content and faster rates of digestion thus increasing volun tary dry matter intake.

Van Soest (112) indicates that there are two possible theories for lignin's effect on fiber digestibility. The oldest theory is that of physical incrustation and entrapment of nutrients within lignified cell walls. A more recent theory is the formation of lignin-carbohydrate linkages resistant to cellulolytic enzymes. Breakage of these linkages with alkali increases the digestibility of the sample without changing the lignin content. This suggests that the lignin fraction does not encrust the carbohydrate fraction, but bonds to it forming an ester linkage yielding it indigestible (112). While levels of cellulose and hemicellulose, as well as their availability, vary with plant species, it is important to realize that utilization of cellulose and hemicellulose by the ruminant depends on the synergistic action of rumen microorganisms.

Cellulose digestion

Cellulose is comprised of B-1,4 pyranosidic chains of glucose (110). Because of the B-1,4 linkage, animals which do not contain cellulase enzyme are unable to utilize cellulose. The main agents essential for the utilization of cellulosic materials by the ruminant are certain species of anaerobic bacteria. These bacteria produce the cellulase enzyme which hydrolyses the insoluble cellulose to soluble cellulodextrins and/or sugars (22). The digestion of cellulose in the rumen involves effective interaction of cellulolytic and noncellulolytic bacteria. The final products of cellulose digestion, i.e., acetate, propionate, butyrate, carbon dioxide, methane, and microbial cells, are not produced by the cellulolytic bacteria alone (22). This composite of products is dependent upon the interaction of A) cellulolytic species, B) carbohydrate-fermenting species, C) species utilizing succinate, formate, and lactate, and D) methanogenic bacteria. Four major species of bacteria are responsible for cellulose digestion; Ruminococcus flavefaciens, Ruminococcus albus, Bacteriodes succinogens, and Butyrvibrio fibrisolvens (22). These species seem to obtain their energy for growth only via carbohydrate fermentation. Leatherwood (63) reports that cellulose degradation involves at least two different proteins acting in a synergistic manner. One of these proteins is known to have hydrolytic enzyme activities, while function of the other protein is less well known. This protein is felt to be involved in enzymatic conversion of native cellulose to a reactive form which can be solubilized by the hydrolytic enzyme. This second enzymatic function is referred to as an affinity factor. Presence of the hydrolytic and affinity factors are necessary for formation of a complete cellulase complex, and thus cellulose digestion.

Production of the affinity and hydrolytic factors is known to exist in the four main bacterial species, thus giving them the ability to digest cellulose (63). As indicated earlier, resistance of cellulose to digestion is increased by the presence of lignin and silica, as well as by the amount of crystallinity of the cellulose. Crystallinization of cellulose tightens the structure making it less easily digested resulting in a depression in rate, but not extent of digestion. It is the presence of inert substances which blocks the cellulose binding sites for the cellulase complex, and hence the depression in fiber digestibility (63).

There are, however, other factors which affect cellulose digestion through regulation of enzyme synthesis and activity. Moderate levels of readily available carbohydrates must be present to meet nutritional requirements for growth of the rumen bacteria (22). Physical form of the diet is also of importance. Finely ground forages may pass out of the rumen too quickly, and result in a lowering of rumen pH. Inadequate amounts of fiber greater than .64 cm in length may reduce rumination, and thus buffering of the rumen contents through ensalivation (120). Rapid passage and lowered pH tend to reduce digestion of cellulose, and other structural carbohydrates, due to changes in microbial populations.

Proper maintenance of the rumen environment is essential to maximize cellulose digestion. This condition can be quite easily controlled by management of feeding regimes and provision of rations containing adequate amounts of available protein, carbohydrates, vitamins, and minerals.

Hemicellulose digestion

Hemicellulose is the most complex of fiber components of common forages. It is made up of several monosaccharides, including xylose, arabinose, rhamnose, galactose, mannose, glucose, galacturonic acid, and glucuronic acid, linked by a B 1-4 linkage in the main xylan core polymer (117). This complex mixture of polysaccharides varies a great deal between plant species (112). Wedig et al. (117) reported that alfalfa has lower concentrations of hemicellulose and cellulose and a higher lignin content than orchardgrass. This study indicated that hemicellulose of forages occurs in close association with cellulose and lignin. It is this close association between the hemicellulose and lignin which affects its digestibility.

Burdick et al. (24) used acid solubilization and hydrolysis to determine that hemicellulose is digested at a rate similar to that of cellulose. Using bromegrasses of two maturities, he determined that more mature grasses were higher in lignin (3.4% boot stage vs. 5.6% flower stage). He and Sullivan (24) reported that hemicellulose of the more mature forage was less digestible, suggesting that lignin depresses digestibility of hemicellulose. In alfalfa, Sullivan (98) indicated that the correlation between lignin and digestibility of hemicellulose is greater than the correlation between lignin and the digestibility of cellulose (-.83 vs. -.57, respectively). This response in digestibility of alfalfa may largely be due to the fact that lignin has a greater effect on the digestibility of hemicellulose, than on the digestibility of cellulose. This effect is thought to be caused by a tight ester linkage between lignin and hemicellulose which does not occur with cellulose (98).

Bacterial digestion of hemicellulose is similar to that of cellulose. Dehority (38) presented results which indicate that many of the bacterial species involved in cellulose digestion are also involved in digestion of hemicellulose. Two species are, however, more active in hemicellulose digestion: Bacteriodes ruminicola and Butyrivibrio fibrisolvens. Breakdown of hemicelluloses requires a synergism between rumen bacterial species occuring as two stages in the fermentation of this fiber fraction. The first stage involves the degradation, or more specifically, the solubilization or depolymerization of the hemicellulose into oligosaccharides. In the second stage, these digestion intermediates are utilized for bacterial growth. Herein lies the cooperative relationship between the bacteria which degrade and those which utilize. Some species of bacteria are only able to perform one of the two stages, and are thus dependent upon other species to initiate the process or remove products of hemicellulose fermentation.

Research by Dehority (38) indicates that both species of bacteria are generally present in the rumen, and are able to digest hemicellulose. These polysaccharide digesting bacteria are usually in great enough numbers to support optimal fiber digestion. Thus utilization of hemicellulose by the animal should not be restricted by availability of active bacteria.

As previously mentioned, lignin plays an integral part in hemicellulose digestion. Lignin apparently becomes closely attached to hemicellulose in the maturing plant. In this close association, the hemicellulose becomes blocked or protected from action by the solubilizing bacteria, and also by the presence of cellulose. Sullivan (98) found that grasses tend to have higher cellulose and hemicellulose concentrations. He also reported that in grasses the concentration and digestibility of one fiber fraction is positively correlated with the other. Herein lies an interesting phenomena. The greater quantity of a less digestible component (hemicellulose) is associated with higher digestibility of itself, of cellulose and of total dry matter. In support of this phenomena, Sullivan (98) found that the hemicellulose and lignin contents of grasses are negatively correlated. This means that grasses with higher hemicellulose contents will be lower in lignin, and should have greater digestibility.

Application of these digestion principles is important to the understanding of digestion rates of grasses and legumes. Dry matter intakes tend to be higher for those animals consuming rations based on legume forages. This response is most likely the result of greater proportion of cell contents to cell walls. While alfalfa tends to contain 50% more lignin than grasses, its level of hemicellulose is substantially less (117). Due to the lower level of hemicellulose in alfalfa, the higher lignin content has less of a depressive effect on fiber digestion. Higher rate of fiber digestibility could also be attributed to the lower total fiber content of legumes as opposed to grasses (74).

It can be concluded that plant species vary widely in make-up of their carbohydrate fibrous fractions. While differences in composition exist, variation in digestibility and intake is affected by the indigestible lignin and silica fractions within cell walls. Degredation of the carbohydrate components is dependent upon the cooperative effort of various species of rumen bacteria. Lignin and silica block binding sights on the cellulose and hemicellulose thus making it more difficult for rumen bacteria to make available an energy source which, otherwise, would be indigestible. While formulating rations to meet the productive requirements of an animal it is imperative that the diet not only meet the nutritional needs of the animal by also provide an environment conducive to fiber digesting bacterial growth. Due to differences in structural carbohydrate content and digestibility of feedstuffs, voluntary dry matter intake will be affected by the type of feedstuff. Intake is not, however, controlled only by the digestibility and intake charateristics of the forage. It is also controlled by physical, physiological, and psychogenic factors unique to each animal.

Regulation of intake

Introduction

Feed intake of ruminants is regulated by many highly complex mechanisms. Three hypotheses have received the greatest focus in the past two decades. These include physical effect of gut disten tion in limiting voluntary intake, chemostatic or physiological mechanisms,and psychogenic inhibition of intake (60). Freer and Campling (43) suggest it is possible that the voluntary intake of some roughages might be regulated more by the limited capacity of the reticulo-rumen, during a meal, than by their rate of disappearance from this organ. This is supported by the findings of Campling and Balch (27) that the amount of ingesta in the rumen at feeding time and at the end of the feeding period has some form of control on voluntary intake of forages. Montgomery and Baumgardt (72) found that ruminants adjust voluntary intake in relation to a physiological demand for energy as long as fill or rumen load is not limiting. Similar results were found (16, 39, 121) when proportions of concentrates in the rations, or energy density was increased, voluntary intake decreased so that available energy consumption was relatively stable. Psychogenic inhibition of intake involves the animal's response to environmental effects. These effects include the stresses associated with social interactions among animals, different feeding situations, and the animal's preference for specific feeds due to sight, smell, taste, physical form, or possibly location of the feed.

Physical regulation

The theory of physical limitation is that some restriction of capacity limits intake. It was suggested by Balch (7) that voluntary intake of forages is related to the amount of digesta in the reticulo-rumen, which is a function of the rate of digestion of food particles and their rate of passage out of the rumen. Blaxter et al. (15) found that within the limits controlled by quality of the roughage used, the amount of forage consumed by sheep is determined by the capacity of the digestive tract, and physical factors. Conrad, Pratt, and Hibbs (34) using trials with 114 lactating dairy cows determined that intake begins to decrease when rations contain greater than 67% digestibility, suggesting metabolic control of intake. Intake of rations below this value is controlled by the amount of undigested residue per unit body weight and the animal's body capacity (physical control). Montgomery and Baumgardt (72) using dairy heifers found that maximal dry matter intake was achieved at the point of 56% digestibility in the ration. Above this value heifers began to reduce intake to maintain a constant energy balance. They, as the previous authors, suggest that these digestion coefficients are arbitrary and should not be confused as being fixed maximal points where physical factors no longer limit intake. Differences in the digestion coefficients could be caused by differences in physical form of rations used in the studies. Conrad et al. (34) used rations composed primarily of alfalfa or timothy hays in the long or ensiled form, whereas the rations fed by Montgomery and Baumgardt (72) contained dehydrated alfalfa meal and ground shelled corn in the form of pellets. These results are in agreement with (23) who found lower digestibility but similar intakes between rations containing pelleted and chopped roughages. Studies conducted by Freer and Campling (43) using diets of hay, dried grass and concentrates concluded that cows ceased eating when the reticulo-rumen contained about 35 pounds of dry matter. When roughages had a slower rate of disappearance from the reticulorumen than 18 lb. of dry matter/day, eating ceased. Thus intake was regulated to maintain an amount of digesta in the rume which could be reduced to 18 lb. of dry matter matter immediately before the next meal. It was evident that the amount of digesta in the reticulo-rumen did not approach these limits before or after feeding when concentrates were offered ad libitum (43).

There is some evidence that on some diets animals do not eat to a constant rumen fill. When cows were offered hay and oat straw ad libitum, hay was consumed to contain 35 percent more dry matter in the reticulo-rumen than straw (27). Montgomery and Baumgardt (72) found similar results feeding long and chopped hay and straw to heifers. These results suggest that intake is not only controlled by the physical capacity of the rumen, but also by the structural carbohydrate components which affect rate and extent of digestion. Comparisons of hay and silage showed that more digesta was present in the reticulo-rumen with hay than silage suggesting that silage intake was not restricted by rumen capacity, but by factors inherent to the silage (116). Other workers (43) concluded that rumen fill was less and not limiting dry matter intake when rations consisted of highly digestible concentrates. Makela indicated that rumen size is limited by the abdominal cavity (12). He and Blaxter (15) suggest that space required by the growing fetus places limits on the voluntary intake of the pregnant animal. Forbes' (44) studies with pregnant ewes determined that until about the 120th day of gestation there was little change in rumen volume. After this time rumen volume appeared to be depressed and may have caused a depression in roughage intake in late pregnancy. Forbes (44) also observed a negative relationship between volume of rumen contents and the volume of the uterus plus abdominal fat and abdominal organs. Others (25) indicated tha volume of the reticulorumen of the lactating cow in mid-lactation is considerably greater than that of the non-lactating animal. They suggest that these differences in cattle are not due to restriction by fetal growth, but by endocrine differences associated with onset of lactation.

Tayler (25) observed the amount of abdominal fat to be important in restricting the intake of herbage by grazing cattle, possibly by restricting rumen capacity. The limits within which physical regulation of intake occurs are not yet clearly defined. Voluntary intake of poor quality forages with a low protein content such as straw is controlled partly by physical factors, and especially by the rate of digesta breakdown in the rumen, and by some metabolic factor arising from the nitrogen status of the rumen. Huber (53) reported that rations containing less than 12% protein had depressed dry matter digestibility, lower intake, and poorer energy utilization. In young ruminants which have less ability to digest large quantities of bulky, highly fibrous feeds, physical limitations on intake are more pronounced as the diet becomes less digestible (25).

It is evident that control of intake is not solely regulated by physical factors controlling the rate and extent of reticulorumenal digestion. While physical factors do affect the rate of microbial digestion and mechanical disintegration, voluntary intake is also controlled by various metabolic factors unique to the physiological state of the animal.

Metabolic regulation

The concept of physiological or metabolic regulation of intake is based on the theory that the force controlling intake is the maintenance of energy balance. Baumgardt (12) used the term set point to describe the body weight and composition that the animal attempts to attain and maintain at all times. Simply stated, an animal eats to meet its energy requirement. First, is the energy requirement for maintenance. This is influenced by the inherent genetic metabolic efficiency of the animal to use energy to maintain body functions (69). This requirement can, however, be affected by ambient temperature. As temperature decreases energy required to maintain body temperature increases. In addition is the energy needed for basal activity. This requirement varies depending on the feeding system amd the environment of the animal. Intake of energy to meet energy needs for maintenance, production, and maintenance of tissue reserves can be affected by many factors. The first of these is the energy density of the ration.

When concentrates or high quality forages make up a large portion of the ration it appears that intake is regulated by factors other than rumen load or fill. Researchers (16, 39, 121) have found that as the amount of concentrate increased in the ration, voluntary intake decreased so that the available energy intake was relatively constant. This suggests that voluntary intake of diets of this type are probably controlled by chemostatic or homeothermic regulatory mechanisms acting as satiety signals (72). Baumgardt (12) described a receptor system involved in the regulation of energy balance. Receptors, which exist in various tissues of the animal, are responsible for detection of feedback signals (e.g., physical distention, changes in metabolic concentrations of volatile fatty acids, free fatty acids, pH and temperature). These signals are relayed to the hypothalamus, which then regulates feed intake so that energy homeostasis occurs. Baile and Della-Fera (8) reported that a central nervous system (CNS) peptide, cholecystokinin octapeptide (CCK-OP), is a neural signal responsible for energy homeostasis. This peptide signal is produced by the hypothalamus when its receptors are activated. The CCK-OP then travels via the CNS to receptors within the digestive tract sensitive to CCK. The receptors are therefore responsible for the initiation of satiety and related digestive changes. Extensive research with rodents using chemical and electrical stimulation or lesioning of various hypothalamic areas has identified the ventromedial and lateral hypothalamus as important centers in the control of intake and regulation of energy balance. Lesions in the ventromedial hypothalamus (VMH) of goats had an effect on feeding, resulting in hyperphagia and obesity (9). The lateral hypothalamus (LH) seems to be associated with the initiation of feeding, and lesions in this area result in aphagia and weight loss (8). Injections of neural depressant drugs into the cerebrospinal fluid have been successful in blocking the inhibitory action of the medial hypothalamus. Neural depressants caused feeding when injected directly into the medial hypothalamus of goats and sheep (10). Satiated goats, sheep, and calves eat vigorously during perfusion of the cerebrospinal fluid with pentobarbital. Therefore it can be concluded that there are neural signals transferred from the neural centers to the digestive system which may affect intake. While the exact sources and compositions of these signals is not yet known, the control they elicit on the animal is quite definite.

Metabolites

In ruminants blood glucose concentration, arteriovenous differences of glucose, and glucose utilization rates show little relationship to feeding (8). In non-ruminants the glucostatic theory is represented by the response of satiation when there is an increase in glucose utilization in the ventromedial nucleus of the hypothalamus. Workers (12) have shown that intravenous injections of glucose do not depress intake in ruminants. Glucose utilization rates increased after intraperitoneal infusions of glucose into dairy heifers but had no effect on feed intake (95). Because ruminants have relatively low blood sugar levels, relative resistance to insulin, and lack of an alimentary hyperglycemia following feed intake, one would expect that glucose levels are not an important satiety signal (95).

In contrast, volatile fatty acids (acetate, butyrate, propionate, and branched forms) are important in the energy metabolism of ruminants. During and after feeding the concentration of VFA's in rumen and blood increase (29). Infusion of acetate, propionate, and butyrate at 15% of the animal's estimated digestible energy requirement and a VFA mixture (60, 20, 20% of calories from acetate, propionate, butyrate) reduced the voluntary intake of a pelleted ration in dairy cows (95). These findings are supported by Baile et al.(10) who observed depressed intake when solutions of acetate and propionate were injected intraruminally. Injections of acetate made in the dorsal area had a greater effect on intake than those made into the ventral rumen, reticulum, or abomasum (11). Exposure of as little as 5% of the rumen to high concentrations of acetate was sufficient to decrease feeding (66). In goats, injections of sodium acetate into the jugular vein depressed intake less than injections into the rumen. This suggests that chemoreceptors on the luminal side of the rumen are not as sensitive as those in blood vessels to VFA concentrations. Receptors are probably not the same for all the VFA's. Injection of propionate into the dorsal rumen, ventral rumen, reticulum, or abomasum depressed feed intake similarly. However, propionate injected into the ruminal vein was more effective in depressing intake than injections into the lumen of the rumen, or the mesenteric or portal veins, or carotid artery (11). This suggests that propionate receptors may be present in the walls of the ruminal vein as well as the luminal side of the rumen. It can be concluded, that while blood glucose concentrations have little effect on intake, acetate, propionate, and butyrate can act as satiety signal compounds in the regulation of intake. Presence of chemoreceptor sites in the ruminal lumen as well as the walls of the rumen vein act in the monitoring VFA concentrations in the rumen as well as the rumen vein. Signals from these receptors probably act upon the hypothalamus which then regulates feed intake to maintain energy balance.

Psychogenic inhibition or stimulation

The environment under which the animal is fed can be an inportant factor in altering intake. Stresses (in addition to disease or parasites) usually will reduce intake. Such stresses as crowding, noise and disturbances, and excessive hauling tend to keep animals excited and reduce feed consumption. Social interactions among animals may affect intake in certain feeding situations (69). Coppock et al. (35) reported that cows fed in groups ate 7% more of a complete feed than did individually stanchioned cows, although there was no effect on milk yield or composition. Social interactions do not necessarily facilitate feeding especially if there is insufficient feeding space for all animals in a group to eat at once. When space is limiting, dominant animals will have first selection of feed and greatest opportunity for feed intake. This situation probably alters intake of less dominant animals due to reduced time allowed to eat and composition of feed remaining in the bunk after selection is usually more fibrous (69). In addition to social interactions, the overall stress on the animal associated with management of the operation, feeding facilities, and the feeding situation can depress intake. Proper design of feed bunks, mangers and water supplies can encourage increased intake.

Palatability characteristics are related to the animal's perception of a feedstuff and the relish with which an animal consumes the feed. Palatability is essentially the result of many different factors sensed by the animal in the process of locating and consuming food. Consumption depends upon appearance, odor, taste, texture, temperature, and in some cases, auditory properties of the feedstuff (30). These factors are probably most pronounced in the intake inhibition associated with wet or fermented feeds that is not a function of moisture content. Such things as off flavors and aromas, mold or deterioration of the feeds all have an effect on palatability which may result in lower voluntary intake of feeds (69). Voluntary intake problems may gain partial or complete correction through improvements in feeding management. Such improvements as frequent feeding, overfeeding by 5-10% to allow for selection, and regularly cleaning of bunks and waterers may stimulate intake to achieve maximal performance (69).

In summary, social facilitation encourages feeding in dairy cattle, and animals eat more when kept in groups than when penned individually. Other psychogenic effects controlling intake are palatability of the feedstuff as well as their amounts and facilities in which they are provided.

Temperature

Enviromental temperature is known to have an effect on dry matter intake of dairy heifers (75). This effect is most likely the result of changes in feedstuff digestibility due to differences in ruminal motility during thermal stress. Highest energy utilization occurs between 13-18 C, with little change in feed intake recognized within the range of 5-25 C (75). Magnitude of effect of extremes above or below the 5-25 C range is dependent upon feed type, quality of feed, humidity, hair coat, and growth rate.

Feed intake. The National Research Council (75) indicates that normally growing dairy heifers need not have diets adjusted for extremes in heat or cold. Quigley (83) reported that dairy heifers appear to adjust their dry matter intake when temperatures are above or below the thermoneutral zone. When ambient temperature was greater than 30 C heifers probably switch eating schedules to night feeding so that dry matter intake remained constant. Lactating dairy animals on a 60:40 roughage to concentrate ration increased intake 35% when subjected to constant temperatures of -20C. This intake response to cold is likely the result of increased reticulorumen motility and rumination activity. These digestive changes result in increased rate of passage and decreased apparent digestibility of feeds (75).

Nutrient utilization. Reduction of metabolizable energy (ME) values of feeds when fed to cold-stressed cattle and sheep has been reported (75). These reductions in ME values are apparently the result of increased fecal and urinary losses (75). Similarly, increases in feed utilization are associated with warmer temperatures, suggesting digestibility factors are related to changes in rumen motility associated with thermal stress. Animals may reduce daily gain during cold periods, but will compensate during warmer periods of the year. Increases in energy density of the ration is recommended for beef animals (during cold periods) to maintain gain, but increases in protein, vitamins, and minerals are not required (75).

It is suggested (75) that high and low ambient temperatures can have mild to marked influence on feed intake and growth rate of heifers. Further studies (75) indicate that short-term growth suppression from high temperatures is compensated for during times of more moderate temperatures. It is probable that dairy heifers are able to regulate intake to adjust for changes in ambient temperature, and rely upon compensatory growth to account for losses due to thermal extremes.

Ration factors affecting intake

Moisture

It has been found that heifers fed most silages voluntarily restrict their rate of intake below that of contemporaries fed hay. It has been suggested that differences in dry matter content and/or other chemical constituents of the silages may be factors in determining their rate of voluntary intake (103). Factors inherent in the moisture content of the ration are known to influence dry matter intake (50, 62, 89) Researchers (50, 62, 89) indicate that factors causing reduction of dry matter intake include moisture content, organic acid content, fermentation products, and silage pH. High moisture (< 60% DM) in diets may be advantageous for a variety of reasons. Adequate moisture in complete feeds (DM >40 and <60%) may prevent or reduce separation of ingredients. Silages or high moisture grains may be favored over drier feeds because of ease of preservation, reduced harvest losses, and increased quality. Increased moisture content may increase palatability by improving texture or may dilute undesirable flavors (62). In contrast, dairy cattle consuming high moisture diets may be unable to achieve maximum intake and production. Several researchers (50, 89, 103) reported that cattle consume more dry matter from hay than from wilted haylage (27 - 33% DM). Others (50, 52, 89) fed rations containing high-moisture silage (<65% DM), low-moisture silage (>65% DM), and hay (85% DM) to lactating dairy cows. Their studies conclude that method of preservation influences the chemical composition of the forage when fed. Forages preserved as hay were lower in protein, ether extract and ash than those preserved as silage. Wilted silages generally contain a greater total acid content then low-moisture silage. Roffler reported that butyric acid was the predominant acid present in wilted silages, while lactic acid predominated in low-moisture silages. From these trials it can be concluded that variation in dry matter intake may be attributed more to organic acid, pH, and fermentation products, than to moisture content of the feed.

Silage quality. It is generally agreed that high-quality silage i characterized by low pH, low contents of butyric acid, acetic acid, and ammoniacal nitrogen and by high levels of lactic acid (50). Many studies (50, 52, 89, 103) have observed wilted or high-moisture silages to be higher in butyric acid and ammoniacal nitrogen. Ammoniacal nitrogen constituted a greater proportion of the total nitrogen in wilted silage than in low-moisture silage. This suggests more extensive protein breakdown occurs during the fermentation of wilted silage, as compared to low-moisture silage (50, 89). Total silage acid content is markedly higher in high-moisture silage, suggesting a more complete carbohydrate fermentation than occurs with low-moisture silage and may affect dry matter intake in dairy animals.

Forage intake. Reports (50, 52, 89, 103) indicate that cow fed low-moisture silage usually consume more forage dry matter than cows fed high-moisture or wilted silages. Thomas et al. (103) found that heifers consumed more dry matter from haylage (43-50 % DM) than direct-cut silage (20-25% DM) when forages were harvested from similar fields and cuttings. They also found that addition of water to wilted silage, haylage, hay or intraruminally did not change trends in dry matter intake. The addition of silo effluent to dry hay reduced dry matter intake by 2.9 lb./heifer/day (103). Addition of similar effluent directly into the rumen, via small fistulas, also depressed voluntary intake of hay. Lahr et al. (62) concluded that diets containing less than 60 - 65% dry matter depressed intake in lactating cows. This response occurred regardless of whether the ration dry matter content was reduced by ensiled feeds or the addition of water.

It is therefore concluded that the moisture content of the forage at time of ensiling results in differences in fermentation. The relationship between dry matter content and intake may be more a reflection of the fermentation process and quality of fermented product than its actual dry matter content. Thus, animal intake responses are most-likely controlled by quality of fermented product which is a direct reflection of pre-storage dry matter content and proper storage rather than influence of moisture on animal intake.

pH

Variations in the dry matter content of silages prior to ensiling changes not only the organic acid content, but also the silage pH. Intake depression associated with ensiling of forages ranges from 4 to 50% (50, 52). Shaver et al. (93) suggests that silage moisture content is not the limiting factor in dry matter intake, but that low intake of silages is more likely due to end products of silage fermentation common to silages with low dry matter contents.

Fermentation products. Two major compositional changes occur during ensiling: degradation of plant proteins to nonprotein nitrogenous compounds and conversion of water-soluble carbohydrates to organic acids (104). Although ammonia and amines can be found in large quantities in silages, a direct correlation between their content and dry matter intake has not been established. Direct addition of ammonia and amines to ether hay or silage was not found to depress intake (81).

Addition of lactic and acetic acids to reduce pH of the diet has resulted in reduced dry matter intake (50, 118). Shaver et al. (93) conducted studies to determine if the response to addition of organic acids was due to their presence or a change in diet pH. Addition of sodium bicarbonate to neutralize corn silage, increased silage pH from 3.79 to 7.11 and increased dry matter intake by .78 kg/day. Acidification of fresh whole corn with hydrochloric acid reduced pH from 5.20 to 3.66 and depressed organic matter intake 0.29 to 3.62 kg/day. Wilkinson et al. (118) conducted similar experiments involving addition of lactic and acetic acids to fresh corn plants. Their studies indicate that dry matter intake is a direct reflection of diet pH and titratable acidity. They suggest the depression of voluntary intake is caused by the acid load created by feeding of ensiled feeds. This acid load affects the acid-base balance and nitrogen balance, thus causing acidification of the urine and increasing urinary ammonia excretion.

A trend toward decreased live weight gain, and reduced feed efficiency was found to exist when silage pH was reduced. Studies with heifers indicate that gain was maximized when diet pH was increased to 5.78 with sodium bicarbonate (93).

It can be concluded that forage pH affects voluntary intake of corn silage and alfalfa haylage. It seems likely that total hydrogen ion content and not specific organic acid content is responsible for differences in voluntary intake of ensiled forages. This premise is supported by the facts that addition of sodium bicarbonate increased pH and intake, while hydrochloric acid addition decreased pH and voluntary intake of forages.

Protein

Protein nutrition in ruminants is a complex, dynamic process. Nitrogen is a critical nutrient in the ruminant, since it is the primary component in protein (amino acids) (76). Availability of protein (nitrogen) is dependent upon microbial intervention and a readily available carbohydrate source. Microbial bacteria convert dietary protein (nitrogen) and nonprotein nitrogen into bacterial protein. Bacterial protein is subsequently digested by the animal and used as a supply of amino acids. It is this amino acid supply, along with the lesser amount of protein which is able to by-pass the rumen, which is used for production of milk, and animal or fetal tissues.

Various researchers (6, 20, 53, 54) have indicated that varying levels of protein in the diet of growing dairy heifers may affect DMI, gain, and skeletal growth. In two trials involving 44 dairy heifers, Bagg et al. (6) fed three levels of dietary protein (80%, 100%, 120% of (74)) to animals between 71 and 295 days of age. In the first trial animals were fed according to requirements from 85 to 182 days. Animals were then assigned to rations containing one of the three protein levels and maintained on this ration to 295 days of age. Weight at 295 days was found to increase linearly with level of protein. Wither height and dry matter intake were unaffected by the level of protein in the diet. In the second trial, he assigned the animals to treatment diets for the period of 71 to 182 days of age. Animals were then rerandomized to either a medium or high protein diet and maintained on this diet till 295 days of age. At 181 days a quadratic effect was determined to represent the weight and wither height response with the greatest response occurring from the medium protein (100% of (74)) diet. A wither height interaction between period one and two treatments indicated a response to high protein levels by those heifers previously receiving the low or medium protein diets. These authors summarized that level of dietary protein linearly increased protein digestibility, but had no effect on dry matter intake. Gains appeared to be more closely associated with dry matter and energy intake than the amount of protein in the ration.

These findings are in agreement with Brown and Lassiter (20), and Gardner (46) in that they too found no significant effect of dietary protein on DMI. However, low protein diets tend to depress dry matter intake (6). Protein concentrations less than 12% were reported to depress dry matter digestibility, lower intake, and cause poorer energy utilization (53). This response is likely the result of inadequate nitrogen availability for bacterial growth and thus a subsequent depression in fiber digestion is realized. Brown (20) indicated that dairy calves grow at comparable rates on protein levels between 12 and 24%. However, calves fed 16% protein diets had slightly faster rates of gain than those fed higher or lower levels of protein. This therefore suggests an optimal level of dietary protein may exist. These studies indicate that protein levels greater than 12% should be sufficient to maintain bacterial growth. Feeding higher levels of dietary protein may exceed the amount required to maximize skeletal growth, and should therefore be avoided for economic reasons when formulating rations.

Within the normal range of dietary protein contents, voluntary intake should not be affected by protein content (44). These findings suggest that dairymen feeding low protein forages to heifers can stimulate intake and digestibility of the forage by addition of supplemental protein. Supplemental protein can be in the form of high protein grains or urea as both will successfully increase digestibility of DM and accelerate fiber digestion.

Digestibility and Fiber

It is often assumed that intake and digestibility of forages are directly related. Although they are somewhat interdependent, intake and digestibility of forages are separate parameters of quality. Intake is dependent upon the 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 discussed earlier.

Digestibility is dependent upon two factors: the proportion of the total forage made up by the soluble part, and the lignification of the fibrous residue (108). In terms of chemical composition, the only consistent effect that can be observed for all forages is that of the total fibrous fraction, i.e. NDF. As this fraction increases, voluntary intake declines with an increasing negative slope. In forages with low NDF, digestibility and intake apparently are not related. Legumes are characterized by a rapid burst of fermentation followed by a plateauing as the soluble cell contents are exhausted. Thus, due to a high cell content fraction legumes tend to have shorter fermentation time resulting in lower dry matter digestibility yet higher voluntary intake. In forages with a high NDF fraction intake is highly correlated with both chemical composition and digestible dry matter. This suggests the relationship between digestible dry matter and voluntary intake depends on the proportion of digestible energy from cell-wall constituents. In contrast to legumes, grasses are observed to have a slower initial fermentation due to lower cell contents, yet fermentation continues steadily to yield equal or higher dry matter digestibility. For these reasons dry matter digestibility and voluntary intake of grasses are closely associated.

Van Soest (108) presented data which support the theory of fibrous mass inhibiting intake in forages with high NDF. He suggests the point at which fiber mass appears to become limiting occurs when NDF is between 50 and 60% of the forage dry matter. It should be noted that level of NDF was based on all forage rations using 121 different types of forage. Mertens (68) sought to validate these levels by comparison of rations based on alfalfa hay, Bermudagrass hay, and corn silage, balanced with concentrate to the same NDF content. The alfalfa diets while containing lower amounts of concentrate and thus having lower TDN (65%) or NEl (1.50 Mcal/kg) resulted in higher production of 4% fat corrected milk. Highest production of fat corrected milk for all rations occurred when rations contained 36% NDF. Cows consuming the 36% NDF rations based on alfalfa produced an average of 7 pounds per day more 4% fat corrected milk than cows on the corn silage or Bermuda grass hay diets. This study suggests that while an optimal level of NDF may be possible, differences in digestibility of the NDF fraction affect animal performance. Research with dairy heifers indicated that when ration NDF content was above 42% it was negatively correlated (r = -0.42) with dry matter intake, while below this level correlation was very low (r = -0.03) (85). This study suggests that NDF is more important in regulation of voluntary intake of heifers when rations contain more NDF. Variability in rate and extent of NDF digestion sparked investigations into feasibility of using NDF to formulate rations varying in fill characteristics.

Using polyester bags suspended in the rumen of cannulated dairy cows, rate and extent of fiber degradation was determined for 22 feedstuffs (114). Varga et al. (114) determined that for forages, rate of NDF degradation was negatively correlated (r = -0.98) with NDF content and extent of degradation. For all other feeds a low negative relationship (r = -0.50) existed between NDF content and extent of degradation. This suggests that physical and chemical factors limiting rate and extent of cell-wall digestion of forages may not be similar to those associated with grains. This study also found that grouping of feeds into like characteristics (protein and/or energy sources) based on NDF was not possible because feeds within the same group differed in NDF content as well as rate and extent of degradation.

In a feeding trial, based on NDF rate and extent of degradation information, two diets with 39% NDF but varying in rate and extent of NDF degradation were used. Diets were formulated to be isonitrogenous, isocaloric, and sililar in ADF and soluble protein content. Results indicate that dry matter intake, fat corrected milk, daily fat production, and solids not fat did not differ between diets. Cows fed low fill (faster estimated NDF degradation) produced more milk (30.3 vs. 26.3 kg/d) and milk protein (0.97 vs. 0.78 kg/d) than diets with slower estimated rates of NDF disappearance. However, the slower rate of disappearance diets had higher milk fat content (3.92 vs. 3.54%) than low fill diets. They concluded that due to low ruminal pH and/or other physiological mechanisms such as higher VFA production may have prevented cows on the low fill diet from consuming more dry matter than cows on the high fill diet. In addition, while similar in chemical composition, ingredient composition was different between diets. This also may have contributed to differences in nutrient utilization resulting in differences in milk production and composition.

In a recent study, researchers pooled data from 20 experiments using early to midlactation Holstein cows (17). Objectives of the trial were to determine relationships between NDF content of the diet and milk yield and dry matter intake. Results indicate NDF has a greater effect on dry matter intake than on milk yield, and its use in formulating diets is limited to within roughage sources. This limitation is due to a lack of a constant optimum value for maximum dry matter intake and milk yield across all roughage sources. Feeds similar in NDF content may differ in bulk and caloric density and due to these differences may differ in rate and extent of degradation.

In summary, intake and digestibility are separate parameter estimates of quality or feed value of a feedstuff. Intake is dependant upon the volume, or fibrous cell wall components and is therefore directly related to the NDF fraction. Digestibility is dependent upon amount of cell wall lignification as well as physical form, rate of passage, and NDF content. Maximum dry matter intake occurs when mixed rations contain between 34 and 40% NDF. Maximum digestible energy intake occurs between 34 and 36% with maximum 4% fat corrected milk also occuring within this range. Rations designed to vary in rate and extent of NDF degradation resulted in no differences in dry matter intake, yet varied in fat and protein content. While feeds may be similar in NDF, differences in bulk and caloric density affect their nutrient utilization and voluntary intake. For these reasons an optimal ration NDF level is not possible, suggesting NDF may be most applicable in formulating rations within roughage sources. This type of application would require development of predictive equations within each forage type, and be dependent upon accurate intake prediction models.

Predicting dry matter intake

It is imperative that intake prediction models produce accurate estimates of dry matter intake. Accurate estimation of intake is important because of its direct impact on productive function, as well as being an important variable in formulating balanced rations. In the tradition of step by step method of formulating rations, dry matter intake must be estimated before the amount of forage and concentrate can be determined and the content of protein, vitamins and minerals in the mixture can be calculated (69). Nutrient requirements are often reported in grams of Mcal/day then corrected factorially to a percentage basis. This conversion, therefore assumes a known level of dry matter intake. Due to management schemes commonly used in dairy replacement heifer operations involving the grouping of animals, individual dry matter intakes are very difficult to measure. These situations put great emphasis on predictive equations to provide useful estimates of dry matter intake for ration formulations. The goal is that the quantity eaten times the percent of the nutrient per unit will equal the quantity required by the heifer for maintenance and growth.

Accurate prediction of intake is very difficult under varying management schemes. As mentioned, intake is controlled by both physical and metabolic factors. These factors are expected to change as ration formulation and physiological state of the animal change; therefore variables descriptive of both systems of intake control must be included in a prediction model.

Equations to predict dry matter intake in lactating dairy cows range from a low degree of confidence (12, 37, 97) to those explaining 80 to 84% of variation in dry matter intake (28, 34, 122). Brown and coworkers (18) utilized 4135 Holstein and 704 Jersey 28-day records of 492 cows at 11 cooperating university herds to predict dry matter intake and milk yield. Factors found to influence dry matter intake were: season, days in milk, log days in milk, log milk (kg/d), milk fat (kg/d), body weight (kg), crude fiber (% of DM) and crude fiber squared. Milk yield was determined the most important determinant of total intake of dry matter, and accurately reflected physiological state of the animal and its need for metabolizable energy. In a review of nutritional modeling, Brown et al. (19) reported the following parameter s were important in equations to predict intake of dry matter in lactating cows: stage of lactation, milk or FCM yield, fat yield or percent, are of parity, body size or weight, weight change, feed type, energy density, genetic ability, season, location, digestibility, and ration dry matter (%).

Yungblut and coworkers (122) used regression of daily intake of dry matter on thirteen independent variables to explain 84% of the variation in intake. Independent variables were: lactation number, days in lactation, milk, fat percent, vat yield, FCM yield, ADF

% in ration, dry matter % in ration, wither height, body weight, metabolic body weight (BWT $kg^{.75}$), weight change, and heart girth. Quigley et al. (85) conducted a study to determine factors affecting intake of dairy heifers in confinement housing fed total mixed rations. Variables important in prediction of dry matter intake were: body weight, gain, and polynomial terms of ration fiber or ration energy to account for changing metabolic systems controlling intake. The equation selected was: DMI (kg) = - 29.8637 - 1.5425E -.05 * body weight squared + .1575 * metabolic body weight + 2.0895 * gain - .1177 * gain squared + .7296 * TDN - 0.0048 * TDN squared - .0014 * body weight * gain interaction - 0.0191 * TDN * gain interaction. This model explained 59% of the variation in intake.

Sniffen utilizes two equations to predict intake of heifers; under 600 lbs., DMI (lbs.) = .6 + .024 * body weight (lbs.). Over 600 lbs. DMI (lbs.) = 9.7 + .0102 * body weight (lbs.). These equations are based on NRC data, and simply divide heifers into two groups without regard to rate of gain or ration digestibility (83). Equations using gain as a variable affecting dry matter intake of heifers are few or non-existant. Conrad et al. (34) reported that physical and physiological factors regulating intake change in importance with increasing digestibility. At low digestibility (<66 %) factors were: body weight (reflecting roughage capacity), undigested residue per unit body weight per day (reflecting rate of passage), and dry matter digestibility. At higher digestibilities intake appeared to be dependent on metabolic size (Bwt $kg^{.73}$),

production and digestibility. These findings are in agreement with Baumgardt et al. (13) which indicated the need for separate intake prediction equations depending on fill characteristics represented by bulk density, NDF, NDF digestibility, and percent dry matter. Their equations included quadratic terms which illustrate the curvilinear relationships between NDF and dry matter intake and bulk density and dry matter intake.

Present equations in use for predicting dry matter intake of heifers (74, 96) give only crude estimates of dry matter intake. Those in use by NRC (74) and Virginia (96). (DMI = -.417 + .03335 (BW) - 2.66154E-05 * (BW^2) are based on data obtained from 1943 to 1964, and may not reflect requirements of today's animals. While the equation does adjust intake for differences in body weight, if metabolic factors contribute to regulation of intake, then body weight alone is inadequate as the sole estimator.

As previously mentioned dry matter intake is controlled by both physical and physiological mechanisms within the animal. This suggests that intake prediction equations must include variables which not only explain differences in intake due to energy required for maintenance and growth, but also those variables which affect the physical control mechanisms. This translates to an equation which includes factors such as body weight, gain, NDF, TDN, ration dry matter, and possibly interactions of these variables. Quadratic terms would meed to be included to adjust for curvilinear relationships between fiber and energy terms as well as their possible interaction with body weight and gain.

Accurate prediction of dry matter intake is essential in formulation of dairy heifer rations. Most requirements are presented on a percentage basis therefore requiring a known level of intake. Determination of variables predictive of intake is dependent upon accurate collection of data such as body weight, rate of gain, and dry matter intake, as well as reliable analysis of roughages, concentrate ingredients, and minerals, for use in estimation of fiber and energy characteristics. This information could then be used to predict dry matter intake over a range of body weights, gains, and variations in ration composition with the goal of producing a model applicable to situations present in industry. With an acceptable prediction model available, dairymen could improve management of replacement heifers through improvement in feeding schemes for growth and maturation thereby reducing costs associated with the replacement enterprise.

Materials and Methods

Objectives of this study were to: 1. determine if varying levels of neutral detergent fiber (NDF) and total digestible nutrients (TDN) would affect dry matter intake and gain in heifers between 125 and 400 kg body weight, 2. use information from this and a previous study to improve the predictive ability of an existing intake prediction equation over a wider range of body weights.

Heifers were divided into two weight blocks, light (<182 kg) and heavy (>270 kg), based on beginning weight, to determine if heifer responses in intake and gain differed by body size. Heifers with body weights falling between weight blocks were assigned to the nearest weight block as number of animals was limited. Therefore, a certain amount of overlap in body weights was created between weight blocks. Treatments consisted of three levels of NDF (35%, 45%, 55%) at 100% of NRC (74) TDN recommendations and three levels of TDN (85%, 100%, 115% of NRC) at 45% NDF for light heifers with anticipated gain of .68 kg/day. Treatments for heavy heifers, with similar gain, consisted of three levels of NDF (40%, 50%, 60%) at 100% of TDN requirement and three levels of TDN (85%, 100%, 115% of NRC) at 50% NDF. Classification of experimental rations is given in Table 2. Treatments 2 and 7 were duplicate treatments as the mid-point level of NDF was formulated to 100% of NRC recommendation for TDN, and the mid-point level of TDN was formulated at the mid-point NDF for each weight block. These two treatments were to serve as control diets. Treatment levels were selected to provide estimates of nutrient content at practical feeding levels for all animals on study while attempting to minimize amount of confounding between NDF and TDN on dry matter intake. Selection of ration NDF and TDN levels were based on deviations from customary levels and those recommended by NRC (74). Upper and lower limits were based on those levels which may represent conditions where either physical or metabolic mechanisms control intake.

Experimental Model

Previous work has shown the following ration compositional measurements may be related to control of voluntary dry matter intake: 1) nutrient density (kcal DE/ml), 2) energy concentration (% TDN), 3) physical form ration, 4) plant cell wall content, 5) ration moisture content, 6) ration pH content, and 7) ration protein content. The relationship of these factors can be stated in the following model: DMI (kg/d) = μ + (β) nutrent density + (β) nutrient concentration + (β) physical form + (β) cell wall content + (β) moisture + (β) pH + (β) protein content + random effects.

Variables used in model development were those which were easily, objectively measured and readily available to dairymen in practical situations. Nutrient concentration of feeds was included in the model as total digestible nutrients (TDN). NE_m and NE_g (Mcal/kg DM) terms were not included as estimates of energy requirements because of low accuracy of determination, and the fact that they have not been widely adopted by the dairy industry.

Presently, no quantitative measurement of physical form or palatability is available. The assumption was made that total mixed rations were acceptable to all animals within the study, and intake was not affected by form or palatability of treatments. It should be noted that grinding or chopping of hay increases intake and decreases fiber digestibility

Table 2. Classification of experimental rations.

	Light	Heavy
Body weight[a]:	208	292
% NDF	----(treatment number)----	
35	1	
45	2	
55	3	
40		6
50		7
60		8
% of NRC[b]	45% NDF[c]	50% NDF[c]
85	4	9
100	2	7
115	5	10

[a] Mean body weight, kg.

[b] Percent NRC recommendation for TDN.

[c] Dry matter basis.

of rations fed dairy heifers (25). Because chopped hay was used in this study, care must be taken when applying these results to situations where long hay is fed separate from other forages and concentrates.

Researchers (18, 84) have indicated that voluntary intake of dry matter by growing dairy heifers can be affected by changing environmental conditions. Brown et al. (18) determined season to affect dry matter intake of lactating dairy cattle. However, Quigley et al. (84) utilizing ambient temperature as an estimate of seasonal effects, determined ambient temperature did not improve predictive ability of an intake model. Therefore, this variable was not included in model development in this study. Ability of heifers to adjust intake to periods during which temperatures are more acceptable, as well as their ability to make compensatory gain may be reasons this variable explains little of the variation in DM intake.

Variables associated with body weight (BWT, $BWT^{.75}$, wither height) and gain were included in model development as they represent estimates of energy requirements for basal metabolism and growth. A model containing these variables may be written:

$DMI_i = \beta_0 + \beta_1(TDN)_i + \beta_2(NDF)_i + \beta_3(\text{Body weight})_i$

$+ \beta_4(\text{Dailygain})_i + \beta_5(\text{Dry matter }\%)_i + \beta_6(\text{pH})_i + \beta_7(\text{Protein})_i + \varepsilon_{i,}\ i = 1....n.$

Experimental Procedure

Preliminary

Heifers born at V.P.I. and S.U. dairy facilities were raised under accepted management practices in calf hutches until weaning. After weaning animals were in group pens of 6 to 10 heifers and fed corn silage-based rations. In the preliminary phase of the experiment, heifers were placed in groups of 6 to 10, according to body weight. Total mixed rations containing 75% of fermented forage (DM basis) as corn silage and 25% as alfalfa haylage were fed. Other ingredients included ground orchardgrass hay,[1] ground shelled corn, soybean meal, and a mineral mix.[2] Heifers were fed once daily with rations formulated to provide nutrients according to NRC (74) recommendations for .68 kg/day gain. At the beginning of each experimental period, heifers within each group were weighed and assigned randomly to a treatment within their weight block, light (<182 kg BWT), heavy (>270 kg BWT). Heifers falling between weight blocks were assigned to the closest respective weight block. Heifers were assigned to treatment groups consisting of 8 to 10 animals and moved to the total confinement counter-slope facility, each group having access to a pinpointer feeder.[3]

The study was divided into three sets in which 4 treatments were assigned randomly per set. Sets were required as the pinpointer facility contained only 4 pens. Treatment assignments were random from either the light or heavy heifer block of treatments with order determined randomly prior to initiation of the trial.

Experimental

Heifers entered the pinpointer facility 10 to 14 days, prior to the trial, to allow for

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

[2] Mineral mix: 20% Ca, 5% P, 5% Na, 2% Mg, 2% S, 1% K, on DM basis.

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

Treatment #	Set Assignment
2, 3, 5, 9	Set One
4, 6, 7, 10	Set Two
1, 2, 7, 8	Set Three
1, 4, 9, 10	Set Four

1. Heifers were randomly assigned to treatment within weight block when entering pinpointer facility.

2. Treatments 1...5, light block heifers.
   Treatments 6...10, heavy block heifers.

3. Heifers were assigned to treatments in groups of 8 - 10.

4. Groups were moved into the pinpointer facility 14 days prior to the 5 week trial.

5. At trials end heifers were returned to the heifer barn facility or rerandomized to into another treatment depending on animal numbers.

6. Treatments 1, 4, 9, and 10 were duplicated due to computer failure and ration formulation problems.

Figure 2. Assignment of treatments to sets within the study.

acclimation to the facility and feed. Following acclimation, daily as-fed intakes[4] were obtained during the 35 day feeding trial. Heifers were weighed once during the acclimation period, 3 days consecutively at the beginning of the trial, at the beginning of weeks 3 and 5, and 3 days consecutively at the end of the trial period, as recommended by Lush (65). Wither heights were recorded at each weighing to assess height growth.

Diets were formulated using ingredients similar to those used in the preliminary period. High moisture corn was used instead of dry shelled corn due to availability and ease of use. Soybean hulls were used in treatments 3 and 5 in the first set of treatments to increase NDF and energy concentration, but were not used in sets 2 through 4 because of difference in rate of fiber digestibility compared to the forages. Due to low feeding rates of soy hulls and their limited effect on ration fiber and energy density at these levels, it was assumed that lack of further use would not be detrimental in comparisons of diets between sets.

Diets were mixed daily in a Uebler mix cart[5] and transported to the pinpointer facility. Samples were obtained 3 times per week and stored at 4° C prior to analysis. Subsamples were analyzed for pH[6] by mixing 100 ml of distilled H_2O with a 20g sample of the diet and allowing it to equilibrate for 15 min prior to analysis. Orts were also analyzed for pH, during the first set of treatments, to determine if secondary fermentation occurred within the pinpointer feeders. Weekly composite samples were analyzed for DM (convection oven, 60 - 65° C), crude protein by macro-kjeldahl, acid detergent fiber

[4] Ibid

[5] Uebler 780-80 Weight Mix Machine, Ferris Industries Inc., Vernon, N. Y.

[6] Orion Ion Analyser Model 407 A/F, Cambridge, Mass. Research grade glass combination electrode, American Scientific.

(ADF) and neutral detergent fiber (NDF) (49) by the V.P.I. & S.U. Forge Testing Laboratory.

Total digestible nutrients was predicted from ADF and CP using the following equations (Carr, S. B., Dept. of Dairy Sci. V.P.I. & S.U. Personal communication. 1988. Originating from Penn. State Univ., State College, Pa.):

All concentrates except soyhulls: TDN = 89.8 -.768 * ADF%

Soyhulls: TDN = .0789 * CP% + 78

Corn silage: TDN = 80.4 - .4810 * ADF%

Alfalfa haylage:TDN = 93.79 - .9 * (ADF% - 1)

Grass hay: TDN = 100.32 - 1.118 * ADF%

Ingredients were analyzed for calcium, magnesium, and potassium by atomic absorption.[7] Phosphorus was determined by colorimetric procedures.[8]

Samples of feed ingredients were collected 3 times per week, stored at 4° C, composited into weekly samples, and analyzed for DM, crude protein, ADF and NDF as described. Rations were formulated prior to the trial based on ingredient samples collected during the acclimation period and average body weight per treatment group. Diets were reformulated as ingredients changed or at the beginning of week 3 and 5 to adjust for weight gain. Following the 35 day intake period, heifers were either re-randomized to a treatment in the heavy weight block or returned to the preliminary phase facility. Attempts

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[7] Perkin-Elmer 370 atomic absorption spectrophotometer, Norwalk, Conn. 06856.

[8] Spectronic 20 spectrophotometer, Bausch & Lomb, Rochester, New York 14602.

were made to limit number of heifers involved in sequential treatments to minimize possible carryover effects.

Analysis

Statistical analysis of data was conducted by least squares regression procedures as outlined in (64, 90). Sets were analzed to determine differences in intake and gain which may have been associated with seasonal differences. Body weights and wither heights were regressed on day using mean values of the 3 observations at the beginning and end of the trial. Model used to predict body weight between days 1 and 35 was:

$Y_{ij} = \beta_0 + \beta_1(D_j) + e_{ij}$, where:

Y_{ij} = Body weight of heifer i on day j.

β_0 = Intercept.

β_1 = Linear regression coefficient of daily gain on body weight.

D_j = Day of study on which body weight is predicted, j = 1....35.

ε_{ij} = Random residual.

Measured weights and heights during weeks 3 and 5 were eliminated due to high variability associated with single observations. These weights were, however, used in reformulation of rations within the set.

Analysis of treatments was conducted using Bonferroni tests on contrasts of least squares means from the General Linear Models procedure (90). This method of testing was required as the number of contrasts desired was greater than the treatment degrees of freedom. This method of analysis is conservative by inflating the critical value thereby reducing the chance of rejecting the null hypothesis. Differences were tested for dry matter intake and gain within body weight blocks. The model used in the analysis of variance procedure was:

$Y_{ijk} = \mu + W_i + T_j + H_k(_j) + (WT)_{ij} + E_{ijk}$, where:

Y_{ijk} = Intake of heifer k receiving treatment j for week i.

μ = population mean.

W_i = Fixed effect of week i, i = 1...5.

T_j = Fixed effect of treatment j, j = 1...10.

$H_k(_j)$ = Random effect of heifer k in treatment j.

$(WT)_{ij}$ = Fixed effect of interaction between week i and treatment j.

E_{ijk} = Random residual.

Differences among treatments in mean ration component analysis were alsoo analysed using Bonferroni contrasts by the following model:

$Y_{ij} = \mu + W_i + T_j + E_{ij}$, where:

Y_{ij} = Value of ration variable for week i and treatment j.

μ = population mean.

W_i = Fixed effect of week i, i = 1...5.

T_j = Fixed effect of treatment j, j = 1...5, 6...10.

E_{ij} = random residual.

Pearson product-moment correlation coefficients between DM intake and independent variables were computed to determine degree of colinearity among independent variables. Importance of colinearity was determined by regression procedure according to (90) using colinearity diagnostics.

Model development

Backward stepwise regression (90) on the full model was conducted on the data-set from only this study to determine those variables which may be of interest in future model development. Full expansion of independent variables (i.e., quadratic and interaction terms) are listed in Table 3.

Development of a simplified prediction model was fit to a data-set composed of this and a previous data-set from this station. Backward stepwise procedures were also utilized

Table 3. Independent variables used in development of full model.

Independent Variable	Description
1. BWT / MBWT	Body weight, kg / Metabolic body weight, kg.
2. TDN	Ration total digestible nutrients, % of DM.
3. NDF	Ration neutral detergent fiber, % of DM.
4. GAIN	Daily gain, kg.
5. WH	Wither height, cm.
6. DGROW	Daily increase in wither height, cm.
7. DM	Ration dry matter, 100% basis.
8. CP	Ration crude protein, %.
9. pH	Ration pH, 0 - 14 scale.
10. BWTSQ	Body weight squared.
11. TDNSQ	Total digestible nutrients squared.
12. NDFSQ	Neutral detergent fiber squared.
13. GAINSQ	Body weight gain squared.
14. WHSQ	Wither height squared.
15. DGROWSQ	Daily growth squared.
16. DMSQ	Ration dry matter squared.
17. CPSQ	Crude protein squared.
18. pHSQ	Ration pH squared.
19. BWTTDN	BWT * TDN.
20. BWTNDF	BWT * NDF.
21. BWTGAIN	BWT * GAIN.
22. BWTWH	BWT * WH.
23. BWTDGROW	BWT * DGROW.
24. BWTCP	BWT * CP.
25. BWTpH	BWT * pH.
26. TDNNDF	TDN * NDF.
27. TDNGAIN	TDN * GAIN.
28. TDNWH	TDN * WH.
29. TDNDGROW	TDN * DGROW.
30. TDNDM	TDN * DM.
31. TDNCP	TDN * CP.
32. TDNpH	TDN * pH.
33. NDFGAIN	NDF * GAIN.
34. NDFWH	NDF * WH.
35. NDFDGROW	NDF * DGROW.
36. NDFDM	NDF * DM.
37. NDFCP	NDF * CP.
38. NDFpH	NDF * pH.
39. GAINWH	GAIN * WH.
40. GAINGROW	GAIN * DGROW.
41. GAINDM	GAIN * DM.
42. GAINCP	GAIN * CP.
43. GAINpH	GAIN * pH.
44. WHGROW	WH * DGROW.
45. WHCP	WH * CP.
46. WHpH	WH * pH.
47. DGROWCP	DGROW * CP.
48. DGROWpH	DGROW * pH.
49. DMCP	DM * CP.
50. DMpH	DM * pH.
51. CPpH	CP * pH.

in development of the simplified model. This regression procedure began by fitting a model containing all independent variables. Variables were then deleted from the model one by one until all variables remaining in the model significantly contributed to explanation of variation in the data producing a calculated F statistic with an α level less than .05. Model building ended when no variables outside the model had an F statistic significant at the .05 level and every variable in the model had an F statistic significant at .05 level. All possible regression analysis was conducted on independent variables selected by the stepwise procedure, producing r^2, Cp, and PRESS statistics for each model. The Cp statistic is an estimate of the amount of bias in prediction created by variables not included in the full model. When Cp is at its lowest point (Cp = number of parameters) bias in estimation should be minimal. This assumption of bias is based on the full model containing parameter estimates which are unbiased and reflect a Cp value near the number of parameters in the model (90). Also included in model analysis was the PRESS statistic. PRESS gives an estimate of residuals with the influence of individual observations removed from the prediction. Selected models were then tested using an independent data-set from a protein and energy study conducted at this station. Selected models were evaluated by comparison of calculated sum of squared residuals [Σ(Y actual - Y predicted)^2]. Absolute differences between actual and predicted DM intake were also calculated. Final model selection was based on r^2, Cp, PRESS, sum of squared residuals and absolute difference between predicted and actual DM intake.

Results and Discussion

Nutrient analyses of ingredients used in preliminary and experimental rations are in Tables 4 and 5. It should be noted that all analyses are presented on a dry matter basis. Forages were of relatively good quality as compared to Virginia state averages. Corn silage was similar to NRC (74). Alfalfa haylage was slightly higher in CP (21.5%) and NDF (49.1%) than NDF (74) for late vegetative state. Ground orchardgrass hay was higher in CP (11.45%) with similar NDF and TDN to NRC (74).

Concentrate ingredients were less variable than forages, and were of high quality. NRC values for TDN of soybean hulls were used instead of values based on prediction from CP due to obvious underestimation of energy content (71% vs. 50.9%, NRC vs. lab prediction). Mineral analysis of ingredients used in preliminary and experimental rations is reported in Table 6. Mineral composition of ingredients was in accordance with NRC (74).

Ingredient composition of rations fed during the preliminary periods is in Table 7. A basal ration was formulated for the heaviest group ($\bar{x}$ = 575 kg) with the fermented forage dry matter consisting of 75% corn silage, and 25% alfalfa haylage. Remaining nutrient needs were met with orchardgrass hay and a mineral pre-mix. Groups with lower body weight received supplemental soybean meal and high moisture corn, as a top-dress to the basal ration. Rations were formulated to support an anticipated gain of .68 kg/day. Basal ration averaged 45% DM, 13.4% CP, 54.6% NDF and 63% TDN, on a dry matter basis. Nutrient concentrations were consistent with NRC (74) rec-

Table 4. Mean plus standard error (SE) of Dry Matter, Crude Protein, Neutral Detergent Fiber, Total Digestible Nutrients in feed ingredients of all rations. (n = 5)

Component	Set							
	1	SE	2	SE	3	SE	4	SE
	% DM Basis							
Corn Silage								
DM	36	3.3	36.6	4.0	33.6	1.9	38.3	1.1
CP	9.5	0.5	9.4	0.9	10.1	0.6	8.1	0.7
NDF	49.4	1.6	48.5	1.9	50.6	1.9	47.9	4.3
TDN	67.3	1.3	67.8	1.2	68.8	1.6	68.6	0.5
ADF	27.2	1.3	26.2	1.2	24.1	1.6	24.5	0.5
Alfalfa Haylage								
DM	50.8	2.0	56.3	2.9	65.7	1.4	47.2	1.0
CP	22.1	1.4	21.1	1.2	20.2	2.1	22.7	0.64
NDF	55.2	3.4	54.0	1.8	48.6	4.6	38.6	0.55
TDN	62.1	3.1	62.4	2.5	64.0	1.9	65.5	2.9
ADF	35.2	3.1	34.9	2.5	33.1	1.9	31.4	2.9
Orchardgrass Hay								
DM	91.5	0.9	92.6	0.8	89.2	3.4	90.8	3.1
CP	11.9	1.3	13.5	1.5	11.0	1.5	9.1	0.3
NDF	69.6	4.7	64.1	0.9	70.1	2.6	70.6	1.5
TDN	57.9	3.1	60.2	1.2	54.8	2.5	54.3	1.9
ADF	37.9	3.1	35.9	1.2	40.7	2.5	41.2	1.9

Table 5. Mean plus standard error (SE) of Dry Matter, Crude Protein, Neutral Detergent Fiber, Total Digestible Nutrients in feed ingredients of all rations. (n = 5)

Component	Set							
	1	SE	2	SE	3	SE	4	SE
	% DM Basis							
High Moisture Corn								
DM	66.8	1.3	71.4	1.9	72.9	2.0	75.1	1.3
CP	12.1	0.2	13	1.6	13	1.4	12.6	1.6
NDF	18.2	1.2	17.4	1.2	18.2	3.0	17.9	.45
TDN	85.5	0.7	86.6	0.5	86.4	0.8	86.6	0.5
ADF	5.6	0.7	4.2	0.5	4.4	0.8	4.2	0.5
Soybean Meal								
DM	82.6	0.9	85.1	3.5	86.5	2.5	NA	
CP	54.2	0.5	50.2	0.2	51.3	1.5	NA	
NDF	16.1	0.2	17.8	0.3	17.3	0.3	NA	
TDN	87.0	0.1	83.4	1.9	84.3	2.4	NA	
ADF	3.6	0.1	8.3	1.9	7.2	2.4	NA	
Soybean Hulls								
DM	87.6	1.9	NA		NA		NA	
CP	11.3	0.2	NA		NA		NA	
NDF	72.3	0.3	NA		NA		NA	
TDN	71.0	1.6	NA		NA		NA	
ADF	46.1	1.2	NA		NA		NA	

NA, Ingredient not used in this set of treatments.

Table 6. Mineral analysis of ingredients used in preliminary and experimental rations.

	% of DM			
Ingredient	% Ca	% P	% Mg	% K
Corn Silage	0.38	0.31	0.25	1.16
Alfalfa Haylage	1.46	0.36	0.33	2.19
Orchardgrass Hay	0.39	0.25	0.27	1.34
Soybean Meal	0.54	0.72	0.36	1.89
Soybean Hulls	0.64	0.17	0.37	0.97
High Mois. Corn	0.19	0.39	0.19	0.43

ommendations except that CP was slightly higher than recommended due to a higher CP (14.8%) for orchardgrass hay than original analysis indicated.

Composition of experimental rations (Tables 8, 9) show that variation of level of NDF and TDN was achieved by shifting the forage base from corn silage to alfalfa haylage. Rations requiring lower NDF and TDN concentrations contained predominantly alfalfa haylage. Haylage was used as it was of high quality with a relatively high TDN content, while also having a low level of NDF. Treatments requiring higher levels of NDF (>45 %) consisted mainly of corn silage and ground orchardgrass hay with additional high moisture corn. Soybean hulls were included in rations 3 and 5 during the first set of treatments to increase ration NDF and energy concentration. Soy hulls were, however, discontinued in the study due to concern over their rapid rate of NDF digestibility and lack of effective fiber when compared to other fiber sources (114).

Rations in both the preliminary and experimental phase were not formulated with trace mineralized salt, however salt was present in adequate quantities in the mineral pre-mix. Heifers were provided free access to trace mineralized salt in the block form. It was assumed requirements would be met from both these sources.

Component analysis of experimental rations is reported in Table 10. CP and TDN levels were similar to NRC (74) recommendations for an anticipated gain of .68 kg/day. It should be noted that treatments 2 and 7 served as control treatments for testing of other treatments withing their respective block. Analysis of experimental rations by weight block (Tables 11, 12) suggest treatments may not have represented a range in fiber and energy wide enough to reflect differences in intake due to physical or metabolic mechanisms of control. Researchers (54, 68, 83) indicate ration ADF and NDF levels need to be below 20 and 30%, respectively for metabolic mechanisms to affect voluntary in-

Table 7. Composition of preliminary rations.

Ingredient	Body Weight Group Light[a]	Medium[b]	Heavy[c]
	-----(% of dry matter)-----		
Corn Silage	49.5	58.4	66.0
Alfalfa Haylage	15.0	17.8	20.2
Orchardgrass Hay	15.0	17.8	13.5
Soybean Meal	3.1	1.2	–
High Mois. Corn	16.7	4.1	–
Mineral	0.7	0.7	0.7

Mean body weight of heifers in group.

a $\bar{x}$ = 265 kg.

b $\bar{x}$ = 385 kg.

c $\bar{x}$ = 575 kg.

Table 8. Composition of experimental rations, light heifer block.

Ingredient	Ration Classification 1[a]	2[b]	3[c]	4[d]	5[e]
	----(% of dry matter)----				
Corn Silage	15.0	77.6	59.0	–	75.0
Alfalfa Haylage	80.0	17.6	12.2	86.0	17.7
Orchardgrass Hay	–	–	15.9	13.0	2.5
Soybean Meal	–	–	4.1	–	–
Soybean Hulls	–	–	8.1	–	2.5
High Mois. Corn	4.0	4.3	–	–	1.6
Mineral	1.0	0.7	0.7	0.7	0.7

Treatment.

[a] 35% NDF, [b] 45% NDF, [c] 55% NDF } At 100% of NRC TDN.

[d] 85% TDN, [e] 115% TDN } At 45% NDF.

Table 9. Composition of experimental rations, heavy heifer block.

	Ration Classification				
Ingredient	6[a]	7[b]	8[c]	9[d]	10[e]
	----(% of dry matter)----				
Corn Silage	8.4	65.4	39.0	14.3	68.7
Alfalfa Haylage	72.4	34.0	34.5	62.3	13.7
Orchardgrass Hay	–	–	25.8	22.6	10.0
Soybean Meal	–	–	–	–	–
Soybean Hulls	–	–	–	–	–
High Mois. Corn	18.5	–	–	–	6.9
Mineral	0.7	0.6	0.7	0.8	0.7

Treatment.

[a] 40% NDF, [b] 50% NDF, [c] 60% NDF — At 100% of NRC TDN.

[d] 85% TDN, [e] 115% TDN — At 50% NDF.

take of dry matter in dairy heifers. Based on the observed minimum and maximums, it was assumed ranges were sufficient to observe differences in dry matter intake. It should be noted; due to design of the experiment it was nearly impossible to create conditions when either physical or metabolic mechanisms would control intake without affecting the amount of confounding between NDF and TDN.

Trends in energy concentration (TDN), fiber levels (ADF, NDF) and pH were consistent between the heavy and light heifer blocks. Heavy block rations were lower in protein and higher in DM, fiber, and pH than were light block rations. These trends would be expected as rations for the heavy heifers contained more ground orchardgrass hay and less fermented and concentrate feeds, thus fiber and pH were higher while energy was lower. Minimum and maximum values were similar for both weight groups, therefore factors associated with variation in intake and gain should be reflected in both weight blocks.

Analyses of parameters for each treatment classification are reported in Tables 13 and 14. Changes in DM and pH between rations were due to varying concentration of fermented feeds, high moisture corn, and orchardgrass hay. Crude protein varied from 9.9 to 21.7. Treatments 1 and 4 contained CP levels greater than 16% due to high alfalfa haylage content. Average composition of these diets reflect the effect of haylage by increasing CP, DM, and pH, while TDN and ADF remained relatively constant as compared to the control and high TDN diets.

Energy in rations (TDN, NEm, NEg) was fairly consistent with ration formulation. Range of energy concentration between rations was not as wide as anticipated due to variation in forage analysis and confounding with NDF levels. Lag time between collection and analysis of ingredients influenced ration formulation. Pooled trial ration

Table 10. Analysis of experimental rations.

All Rations[a]:	Mean[b]	SE	MIN	MAX
% of DM				
Dry Matter	51.20	0.82	36.0	68.0
Crude Protein	15.01	0.37	9.9	23.7
ADF	30.97	0.47	20.6	40.7
NDF	45.93	0.69	31.5	58.4
TDN	66.19	0.36	59.0	74.0
pH	4.55	.04	3.90	5.25

[a] Treatments 1...10.

[b] n = 75.

Table 11. Analysis of experimental rations, light heifer block.

Light block[a]:	Mean[b]	SE	MIN	MAX
% of DM				
Dry Matter	49.37	1.27	36.0	68.0
Crude Protein	15.15	.65	10.1	23.7
ADF	30.45	.75	20.6	37.7
NDF	44.17	1.04	31.5	56.0
TDN	66.47	.58	61.0	74.0
pH	4.41	.06	3.90	5.00

[a] Treatments 1...5.

[b] n = 35.

Table 12. Analysis of experimental rations, heavy heifer block.

Heavy block[a]:	Mean[b]	SE	MIN	MAX
% of DM				
Dry Matter	52.35	1.04	36.0	62.0
Crude Protein	14.46	0.39	9.9	19.7
ADF	31.90	0.54	24.8	40.7
NDF	48.10	0.79	38.9	58.4
TDN	65.53	0.43	59.0	71.0
pH	4.66	0.05	4.03	5.25

[a] Treatments 6...10.

[b] n = 40.

Table 13. Mean and standard error (SE) of ration variables by treatment, light heifer block.

	Treatment Classification									
Trial variable	1	SE	2	SE	3	SE	4	SE	5	SE
DM	53.0	3.4	45.7	1.8	55.5	0.7	50.8	1.7	45.5	0.9
CP[a]	18.7	0.4	13.3	0.3	12.6	0.4	21.7	1.0	11.5	0.7
ADF[a]	26.1	1.1	29.4	1.4	35.9	0.8	32.2	0.8	29.7	0.6
NDF[a]	39.1	1.5	44.9	1.4	53.8	0.7	38.8	1.5	43.4	0.7
TDN[a]	69.8	0.9	67.3	1.0	62.2	0.6	65.2	0.7	67.0	0.4
NE_m[bc]	1.37	.02	1.32	.02	1.24	.01	1.29	.01	1.32	.01
NE_g[bd]	0.65	.10	0.60	.02	0.52	.01	0.57	.01	0.60	.01
pH[a]	4.64	0.1	4.21	.07	4.46	.07	4.83	.04	4.07	.05

[a] Percent of dry matter, n = 5.

[b] Megacalories per kg of dry matter, n = 5.

$NE_l = 0.0234 + TDN\% - 0.106$ (Carr, S. B., 1988. Personal Comm.)

[c] $NE_m = NE_l * 1.716 + .31$

[d] $NE_g = NE_l * 1.716 - .41$

Table 14. **Mean and standard error (SE) of ration variables by treatment, heavy heifer block.**

	Treatment Classification									
Trial variable	6	SE	7	SE	8	SE	9	SE	10	SE
DM	52.1	5.4	48.2	1.6	60.4	0.7	55.3	1.2	49.6	1.0
CP[a]	16.6	0.4	13.6	0.5	13.6	0.1	16.8	0.7	12.3	0.5
ADF[a]	30.0	0.9	31.1	0.5	34.5	0.5	35.8	0.7	28.7	0.7
NDF[a]	41.4	0.9	46.9	1.2	54.5	1.0	51.2	1.3	46.4	0.8
TDN[a]	67.0	0.6	66.1	0.4	63.2	0.4	63.0	0.9	67.9	0.5
NE_m[bc]	1.32	.01	1.30	.01	1.25	.01	1.25	.01	1.33	.01
NE_g[bd]	0.60	.01	0.58	.01	0.53	.01	0.53	.02	0.61	.01
pH[a]	4.83	.07	4.39	.07	4.69	.03	5.01	.04	4.47	.07

[a] Percent of dry matter, n = 5.

[b] Megacalories per kg of dry matter, n = 5.

NE_l = 0.0234 + TDN% − 0.106 (Carr, S. B. 1988. Personal Comm.)

[c] $NE_m = NE_l * 1.716 + .31$

[d] $NE_g = NE_l * 1.716 - .41$

analysis for net energy for maintenance and gain averaged 1.29 and .58 Mcal/kg DM, with a range of .25 Mcal/kg DM for each. These levels were probably sufficient to meet net energy requirements for maintenance and gain of growing dairy heifers. While NEm and NEg terms were not used in formulation of trial rations, they are presented to give clarification of energy partition within the trial diets. Treatments 3 and 8 tended to contain lower TDN concentrations when compared to other treatments. This depression in energy concentration is a reflection of higher orchardgrass hay content. The confounding effect of a high NDF requirement in these treatments also played a role in depression of energy concentration.

Treatment differences between variables associated with intake and gain were determined by least squares regression procedures using the model outlined in Table 15. Analysis of variance indicated there were significant differences in DM intake between weeks, treatments, and between heifers within treatments. Intake differences between weeks were expected as growing animals were expected to increase DM intake as they increase in body weight. Addition of sets, to the model, to determine if seasonal changes in day length and temperature affected dry matter intake showed no significant differences between treatments.

Differences between treatment effects were tested using Bonferroni contrasts. Differences in ration variables were tested using contrasts on least squares means. Contrasts of ration variables are presented in Tables 16 and 17. These analyses indicate that light heifer block rations designed to vary in NDF (tmts. 1 and 3), did so, while also being different in TDN. This suggests it was not possible to vary NDF levels in light heifer rations while keeping them iso-caloric. Rations formulated to be different in TDN (tmts. 4 and 5) were not different, nor were they different in NDF. Therefore, it was not possible to vary levels of TDN within this weight block and maintain common levels of NDF between rations. The high NDF ration was found to be significantly lower in TDN, NE_m, and NE_g than the low NDF, and the control diet. These results reflect the inherent problems associated with formulation of rations varying in NDF while maintaining an iso-caloric relationship.

Contrasts also indicate that rations differing in level of NDF tended to differ in CP. Such a trend is the result of varying the forage base to meet the criterion of ration formulation. Those rations which were different for CP, tended to also differ in pH. This relationship may be the result of not only a change in forage base, but also a reflection of animal size (BWT) within treatment. Therefore, treatments containing smaller animals required more CP, thus more supplements were incorporated in the ration replacing fermented forages with concentrates and subsequently decreasing ration pH.

Rations differed in pH from 3.90 to 5.25. It is difficult to determine the effect, if any, pH may have had on intake, as this range is quite narrow and rations differed in forage and concentrate components, dry matter %, and fiber and energy concentration. It should be noted that rations 4 and 9 (Tables 13, 14) had the highest pH (4.83, and 5.01) and lowest intake of DM/kg $BWT^{.75}$ (.095, and .091) of all treatments. These findings disagree with Shaver (93) who reported maximal DM intake by dairy heifers at pH 5.78. Results from this study must, however, be carefully interpreted as other factors within these treatments (TDN, NDF) may have had an effect on intake.

Heavy heifer ration analyses for differences in ration variables (Table 17) indicate the low and high NDF rations were different for NDF and TDN, results similar to those of the light heifer block. As both weight blocks indicate, it may not be possible to compose rations, with common feeds, to vary in either NDF or TDN while holding the other at

Table 15. Analysis of variance for dry matter intake, and daily gain.

Source	df	mean square	f value [b]
WK	4	6.52	20.75
TMT	10	58.42	8.02
ID(TMT)	107	7.28	23.15
WK*TMT	44	3.22	10.25

[a] Dry matter intake, % of body weight.

[b] $P<.05$

Table 16. Bonferroni contrasts of trial variables, light heifer block.

Contrast #[b]	Trial Ration Variable[a]						
	DM	pH	TDN	NDF	CP	NE_M	NE_G
1		*		*	*		
2			*	*	*	*	*
3			*	*		*	*
4		*		*	*		
5							
6		*			*		

[a] Significant differences in least squares means P<.05, *.

[b] Contrast of treatments by classification number,

Light block		Contrast
1	1 vs. 2	Low NDF vs. Control
2	1 vs. 3	Low NDF vs. High NDF
3	2 vs. 3	Control vs. High NDF
4	2 vs. 4	Control vs. Low TDN
5	2 vs. 5	Control vs. High TDN
6	4 vs. 5	Low TDN vs. High TDN

Table 17. **Bonferroni contrasts of trial variables, heavy heifer block.**

Contrast #[b]	Trial Ration Variable[a]						
	DM	pH	TDN	NDF	CP	NE_M	NE_G
1		*			*		
2			*	*		*	*
3	*	*		*			
4	*	*	*		*	*	*
5							
6		*	*	*	*	*	*

[a] Significant differences in least squares means P<.05, *.

[b] Contrast of treatments by classification number,

Heavy block		Contrast
1	6 vs. 7	Low NDF vs. Control
2	6 vs. 8	Low NDF vs. High NDF
3	7 vs. 8	Control vs. High NDF
4	7 vs. 9	Control vs. Low TDN
5	7 vs. 10	Control vs. High TDN
6	9 vs. 10	Low TDN vs. High TDN

mid-point levels. Such results may be possible using feeds less available to producers, yet under these conditions were not successfully achieved. Low and high TDN rations were also significantly different ($P<.05$) for both TDN and NDF. These results indicate that flexibility of ration formulation may be greater in larger heifers allowing for differences in TDN between the low and high TDN rations. There is, however, the same concern that these rations also varied in NDF content. Differences in other ration variables follow similar trends as were suggested in the light heifer block, and can be attributed to planned variation in ration formulation, variation in forage base, and to random error effects.

Dry matter intake, body weight and gain parameters pooled for all treatments (Table 18) reflect a sufficiently wide range of body sizes and growth rates to be reflective of most practical situations. Dry matter intake ranged from a minimum of zero to a maximum of 17.12 kg/day; a range much wider than reported by NRC (74) for growing heifers. Daily gain varied from .43 to 1.58 kg/day, which was also a range wider than NRC (74). Average daily gain (ADG) was 1.01 kg/day for all heifers on trial which was higher than expected as rations were balanced for .68 kg/day ADG. Average daily gain, above anticipated levels, may be a reflection of increased growth efficiency of confinement-reared heifers. It might also be possible that animals in total confinement eat more often or in greater quantities due to sheer boredom. Animal dominance could also play a role in level of voluntary intake depending on status within the pecking order. While domineering over the feeder, dominant animals may eat more often and thus increase intake and intake variability within the group. Intake should not have been affected by access to feeders as the number of animals per feeder was relatively low and ample amounts of feed were available. Greater range in intake and gain than reported by NRC would be expected as NRC table values are reflective of group means and do not reflect variation associated with experimental data.

Mean and standard error (SE), minimum and maximum dry matter intake (DMI), dry matter intake as a percent of body weight (DMI%), body weight (BWT), gain, wither height (WHT) and daily growth in wither height (GWTH), are reported for all animals in the trial (Table 18) and each weight block (Tables 19, 20). Mean DMI was 5.9 and 7.28 kg/day for the light and heavy blocks respectively. DMI by the light block heifers was 19% above NRC (77) prediction, while average DMI of the heavy group was only 3% above NRC predictions (77). Body weight gain was 1.07 and .96 for the light and heavy blocks, respectively. These levels of gain are 57 and 41% above the anticipated gain, suggesting energy intake was greater than projected.

Daily growth in stature, measured as wither height, is shown to be higher in the light block heifers .122 cm/day (Table 19) than the heavy .076 cm/day (Table 20). This response is expected as heifers in the light block are younger. Studies indicate that growth in wither height occurs at a higher rate for animals less than 10 to 12 months of age (31, 51, 56). Animals older than this grow in stature at a slower rate. Comparison of wither heights of all heifers within this study to Heinrichs (51) data is presented in Figure 3. This figure indicates heifers within this study were considerably shorter than those in the Pennsylvania study. One reason for initial differences in height may be attributed to the length of time to weaning in the Heinrichs study (ave. 8 to 12 wks.). Lower growth rates, by heifers in this study, could be attributed to a coccidiosis infection prior to entering the study and thus caused a depression in growth rate. It should be noted that the data does not represent multiple measurements of wither height on each animal over an extended period of time. Therefore, groups containing animals considerably smaller due

Table 18. Mean, standard error (SE), minimum and maximum of variables associated with DM intake, daily gain, and wither height of all heifers on trial.

ALL Blocks	N	Mean	SE	MIN	MAX
DMI[a]	595	6.63	.07	0.00	17.12
DMI%[b]	595	2.51	.02	0.00	4.43
BWT[c]	595	266.7	2.37	129.7	408.1
GAIN[d]	595	1.01	.01	0.43	1.58
WH[e]	595	109.7	.39	83.1	126.0
GWTH[f]	595	.098	.00	−.04	0.24

[a] Dry matter intake, kg/day.

[b] Dry matter intake, % of body weight.

[c] Body weight, kg.

[d] Daily body weight gain, kg/day.

[e] Wither height, cm.

[f] Growth in wither height, cm/day.

Table 19. Mean, standard error (SE), minimum and maximum of variables associated with DM intake, daily gain, and wither height of light block heifers.

LIGHT Block	N	Mean	SE	MIN	MAX
DMI[a]	280	5.90	.08	0.0	10.96
DMI%[b]	280	2.73	.03	0.0	4.43
BWT[c]	280	216.9	1.84	129.7	289.6
GAIN[d]	280	1.07	.01	0.43	1.51
WH[e]	280	104.5	.55	83.1	118.7
GWTH[f]	280	.122	.00	−.04	0.24

[a] Dry matter intake, kg/day.

[b] Dry matter intake, % of body weight.

[c] Body weight, kg.

[d] Daily body weight gain, kg/day.

[e] Wither height, cm.

[f] Growth in wither height, cm/day.

Table 20. Mean, standard error (SE), minimum and maximum of variables associated with DM intake, daily gain, and wither height of heavy block heifers.

HEAVY Block	N	Mean	SE	MIN	MAX
DMI[a]	315	7.28	.09	0.0	17.12
DMI%[b]	315	2.33	.02	0.0	4.31
BWT[c]	315	311.0	2.04	219.02	408.1
GAIN[d]	315	.96	.01	0.44	1.58
WH[e]	315	114.3	.39	97.6	126.0
GWTH[f]	315	.076	.00	−.04	0.15

[a] Dry matter intake, kg/day.

[b] Dry matter intake, % of body weight.

[c] Body weight, kg.

[d] Daily body weight gain, kg/day.

[e] Wither height, cm.

[f] Growth in wither height, cm/day.

to a coccidiosis infection or related health problems may have less growth in stature as indicated by wither height measurements. Lower height in older heifers was reflective of fever number of animals at this age. Older animals with body weights falling within the weight blocks stayed in the study, therefore these poor dooers were able to stay in the study.

Intake of DM, energy, and growth performance for heifers in the light block are in Table 21. Contrasts of intake and gain variables for the light heifer block are in Table 22. DM intake as a percent of body weight was significantly higher for the low NDF treatment when compared to the control (Med NDF tmt.). Highest DM intake as a percent of body weight occurred on the low NDF and high TDN rations (2.96 and 2.87 % of BWT respectively), suggesting these rations did not restrict intake of DM. Results from the low NDF and high TDN rations agree with reports by Baumgardt (12), Brent (16), Donefer (39), and Woods (121) who suggested DMI decreased as energy concentration increased. By design, treatments 1 and 5 were formulated to provide the animal with a ration which theoretically would allow maximal DM intake. While intake of these rations did appear to be maximal, it is not known whether intake was controlled by metabolic mechanisms or by rumen fill.

Contrasts indicate that treatments 2, 3 and 4 were not different for any of the intake variables. It is, however, puzzling that treatment 4 had the lowest DM intake, .095 kg/kg $BWT^{.75}$/day, lowest DEI (14.02 Mcal/day) and lowest average daily gain (0.8 kg/day). Treatment 4 (low TDN) contained energy and fiber densities which fell between densities of treatments 2 and 3, yet was higher in CP and pH. These findings suggest that intake was not affected by low TDN or high NDF, both of which are thought to affect intake of DM. Intake differences may have been the reflection of a low quantity

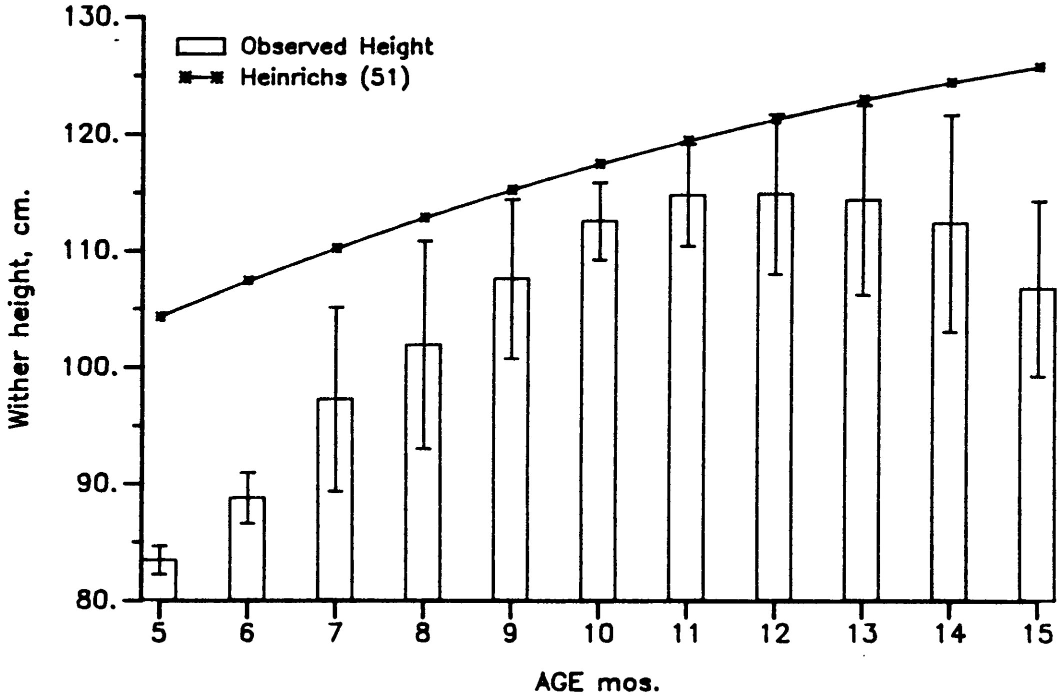

Figure 3. Comparison of observed wither height of heifers on trial to predicted wither height (51).

Table 21. Mean, standard error (SE), of variables associated with intake and gain, light heifer block.

Trial variable	1	SE	2	SE	3	SE	4	SE	5	SE
	Treatment Classification									
DMI%[a]	2.96	.04	2.56	.06	2.57	.04	2.57	.05	2.87	.07
DMI/BWT$^{.75}$[b]	.112	.002	.098	.002	.102	.002	.095	.002	.113	.003
Mcal DEI[c]	18.45	.33	15.67	.43	17.54	.30	14.02	.35	20.74	.64
DEI/BWT$^{.75}$[d]	.344	.005	.282	.007	.281	.005	.274	.006	.335	.009
Mcal DE/Gain[e]	16.11	.34	15.20	.37	17.81	.44	18.23	.70	16.57	.36
Kg TDNI[f]	4.18	.07	3.55	.09	3.98	.07	3.18	.08	4.70	.14
Kg NDFI[g]	2.38	.02	2.63	.02	3.44	.03	1.89	.03	3.04	.03
Gain[h]	1.16	.02	1.05	.02	1.01	.03	0.80	.03	1.25	.02

[a] Dry matter intake as a percent of body weight.

[b] Kg dry matter intake per kg body weight$^{.75}$.

[c] Megacalories of digestible energy = 4.409 * TDN%.

[d] Megacalories of digestible energy per kg body weight$^{.75}$.

[e] Megacalories of digestible energy per kg of daily gain.

[f] Intake of total digestible nutrients, kg/day.

[g] Intake of neutral detergent fiber, kg/day.

[h] Daily increase in body weight, kg.

Table 22. Bonferroni contrasts of trial variables associated with DM intake and daily gain in body weight, light heifer block.

Contrast #[b]	Trial Ration Variable[a]			
	DMI[b]	DMI%[c]	DMIMBWT[d]	GAIN[e]
1		*		*
2				*
3				
4				*
5	*			*
6	*			*

[a] Significant differences in least squares means P<.05, *.

[b] Contrasts of treatments by classification number,

Light block		Contrast
1	1 vs. 2	Low NDF vs. Control
2	1 vs. 3	Low NDF vs. High NDF
3	2 vs. 3	Control vs. High NDF
4	2 vs. 4	Control vs. Low TDN
5	2 vs. 5	Control vs. High TDN
6	4 vs. 5	Low TDN vs. High TDN

of readily available carbohydrate and high CP as provided by alfalfa haylage and orchardgrass hay. These nutrient levels may require animals to digest fiber more slowly and not be able to utilize readily available protein for bacterial growth, thereby lowering efficiency of ruminal digestion. Decreased DM intake by heifers in the control, low TDN, and high NDF diets may be attributed to ration compositional differences, yet differences in fiber and energy were not great enough to indicate trends associated with physical or metabolic contol of intake. Freer and Campling (43) suggested voluntary intake may be regulated by the limited capacity of the reticulo-rumen. Results from this study do not suggest these rations had reduced DM intake due to higher levels of fiber.

Tests for differences in intake of energy parameters are in Table 23. Energy intake parameters (Mcal DEI, Mcal DEI/kg $BWT^{.75}$, kg TDNI) all follow the same trends as were found with DMI (Table 21). It should be noted that DE content was determined by 4.409 x TDN kg as there are 4.409 Mcal DE/kg TDN. Treatments with lower DMI also had lower DEI. These results are to be expected as ration energy concentration did not differ greatly for the light block heifers. Therefore, as DMI decreased the response in decreased Mcal DEI and Mcal DEI/kg $BWT^{.75}$ was created. While no treatments were significantly different, megacalories of DE/kg gain (Mcal DE/kg gain) was used as an indication of the efficiency of conversion of DE to gain for each treatment. Highest conversion occurred on the control diets (mid-point NDF and TDN) with a response of 15.2 Mcal DE/kg gain. Poorest conversion of DE to gain occurred in the low TDN treatment (18.23 Mcal DE/kg gain). Reasons for these trends in efficiency were difficult to determine. It is postulated that heifers were best able to utilize rations consisting of primarily corn silage and alfalfa haylage. Greatest efficiency was on treatments 1 and 2, which were composed of corn silage, alfalfa haylage, and high moisture corn. Those treatments containing orchardgrass hay all responded with lower efficiencies of conversion than those not receiving the hay. These results suggest that intake and/or efficiency of DE conversion to gain was affected by ration composition within the light heifer block.

Treatments designed to vary for TDN were different from each other and the control diet for DEI (Mcal), kg TDNI, and kg NDFI. Treatments formulated to differ in NDF% were different for NDFI (kg) as expected. The significant differences in TDNI and NDFI between treatments 4 and 5 (low TDN, high TDN) is reflected by the wide variation in average daily gain between treatments. Response differences between these treatments were probably the result of variation in forage base, and not energy and fiber density as previously suggested.

Contrasts indicate that all treatments except the low and high NDF were different for daily rate of gain (Table 22). These differences are a reflection of DEI/kg $BWT^{.75}$ and DMI/kg $BWT^{.75}$. Rations with the highest gain (low NDF and high TDN) had the highest levels of DEI/kg $BWT^{.75}$ intake. Lowest daily gain occurred on the low TDN ration which also had the lowest DEI (14.02 Mcal DE/day). Ration differences may account for the greatest amount of this variation as low NDF and high TDN rations were composed of corn silage, alfalfa haylage, orchardgrass hay (high TDN only), soybean meal, and high moisture corn. The low TDN ration was composed of only alfalfa haylage and orchardgrass hay. These ration compositions indicate that differences in carbohydrate availability may have had a strong effect on average daily gain of heifers within the trial. Lower rates of average daily gain on the low TDN ration may also be a reflection of energy expenditure for removal of excess nitrogen in the presence of inadequate fermentable carbohydrates. For optimal preformance it is imperative that intake of energy and protein occur simultaneously. Rumen microflora are then able to

Table 23. **Bonferroni contrasts of trial variables associated with intake of energy (DEI, TDNI) and fiber (NDFI), light heifer block.**

Contrast #[b]	Trial Ration Variable[a]			
	Mcal DEI[b]	Mcal DE/G[c]	kg TDNI[d]	kg NDFI[e]
1	*		*	
2	*			*
3				*
4				*
5	*		*	
6	*		*	*

[a] Significant differences in least squares means P<.05, *.

[b] Contrast of treatments by classification number,

Light block		Contrast
1	1 vs. 2	Low NDF vs. Control
2	1 vs. 3	Low NDF vs. High NDF
3	2 vs. 3	Control vs. High NDF
4	2 vs. 4	Control vs. Low TDN
5	2 vs. 5	Control vs. High TDN
6	4 vs. 5	Low TDN vs. High TDN

use both sources for the coupling of the carbon structures and amine group for the production of amino acids which are used in their cell structures.

Differences in wither height can be attributed to differences in age and body weight of animals between treatments (Tables 24, 25). Treatments with lower body weight tended to also have lower wither height measurements as would be expected. Treatments differing in body weight tended to be the same treatments differing in wither height. Adjustment of intake variables by use of exponents i.e. $BWT^{.75}$ corrects for these differences between treatments allowing for testing to occur on a similar basis. Treatments differing in daily growth in wither height tended to mirror those which were also different for daily gain and wither height. The control and high NDF (0.141 and 0.116 cm/day, respectively), as well as the low and high TDN (0.055 and 0.135 cm/day, respectively) treatments were different for daily growth in wither height. Growth in height reflects differences in Mcal DE/kg gain. Results indicate that treatments with greatest DEI/kg $BWT^{.75}$ tended to have a greater response in stature, possibly reflecting a critical balance between energy and protein density and fermentability within treatments.

An index was calculated to represent change in body condition between the beginning and end of study. The index was determined as the difference between the ending body weight (kg) divided by ending wither height (cm) and the beginning body weight divided by beginning wither height. Change in index is represented in Figure 4 and Tables 24 and 25. Results indicate rations which were formulated to be either low in NDF or high in TDN had the greatest change in index. Significant differences for INDEX change were found between the low and high NDF treatments and between the low NDF and control. Greater changes by heifers on more energy dense rations represents an increase in body weight without the simultaneous growth in body structure. Growth of heifers

Table 24. Mean and standard error (SE) of variables associated with body weight (BWT), wither height (WH), daily gain in wither height (DGROW), and INDEX (BWT/WH), light heifer block.

	Treatment Classification									
Trial variable	1	SE	2	SE	3	SE	4	SE	5	SE
BWT[a]	203.1	.22	212.2	.21	248.9	.30	189.8	.30	244.4	.30
WH[b]	99.8	.05	108.7	.05	111.7	.07	89.9	.07	111.3	.07
DGROW[c]	0.133	.01	0.141	.01	0.116	.01	0.055	.01	0.135	.01
INDEX[d]	0.296	.01	0.234	.01	0.212	.02	0.244	.02	0.274	.02
GAIN[e]	1.16	.02	1.05	.02	1.01	.03	0.80	.03	1.25	.02

[a] Body weight, kg.

[b] Wither height, cm.

[c] Daily growth in wither height, cm/day.

[d] Index = Ending (BWT/WH) − Beginning (BWT/WH).

[e] Daily increase in body weight, kg.

Table 25. **Bonferroni contrasts of trial variables associated with body weight (BWT), wither height (WH), daily gain in wither height (DGROW), and calculated INDEX (BWT/WH), light heifer block.**

Contrast #	Trial Ration Variable[a]			
	BWT[b]	WH[c]	DGROW[d]	INDEX[e]
1		*		*
2	*	*		*
3	*		*	
4	*	*	*	
5	*	*		
6	*	*	*	

[a] Significant differences in least squares means $P<.05$, *.

[b] Body weight, kg.

[c] Wither height, cm.

[d] Daily growth in wither height, cm/day.

[e] Index = Ending (BWT/WH) − Beginning (BWT/WH).

on the high NDF and low TDN rations tended to be of more equal proportions between weight and height as indicated by a lower change in index. Change in index may serve as a measure of determining body condition scores in growing heifers. In this study those rations which were more energy dense or low in fiber tended to permit heifers to fatten rather than grow in proportion between weight and height.

Intake of DM, energy, and ration parameters for heifers in the heavy block are in Table 26. Contrasts indicate only the low and high NDF treatments were different for intake of dry matter (Table 27). Highest DMI as a percent of body weight or $BWT^{.75}$ occurred on the low NDF followed by the high TDN rations (2.45 and 2.42 % of BWT, respectively). Lowest DMI response was found on the low TDN ration (2.15% of BWT). Tests for treatment differences in DEI/kg $BWT^{.75}$, DEI/kg gain, TDNI, and NDFI indicate only the low and high NDF and TDN rations differed for DEI/kg $BWT^{.75}$ (Table 28). TDNI was different only between the low and high NDF treatments. Intake of energy (Mcal DEI, Mcal DEI/kg $BWT^{.75}$, kg TDNI) was less variable than was found in the light block heifers. Greatest intake of DE and kg TDNI were found on the low NDF ration (24.81 Mcal DE, 5.63 kg TDN). Greatest NDFI (kg/day) occurred on the low TDN ration. Lowest intake of DE and TDN occurred in the high NDF ration (17.5 Mcal DEI, 3.97 kg TDNI) and not in the low TDN ration as might have been expected. This suggests that DMI may have been restricted by rumen fill on the high NDF and not the low TDN rations.

When adjusting DE intake for differences in body weight (DEI/kg $BWT^{.75}$) the highest intake was found in the low NDF treatment (.312 Mcal DE/kg $BWT^{.75}$). Lowest DEI was found in the low TDN treatment (.247 Mcal DE/kg $BWT^{.75}$). Differences in the index of energy efficiency for gain (Mcal DE/kg gain), were a reflection of DE intake/kg

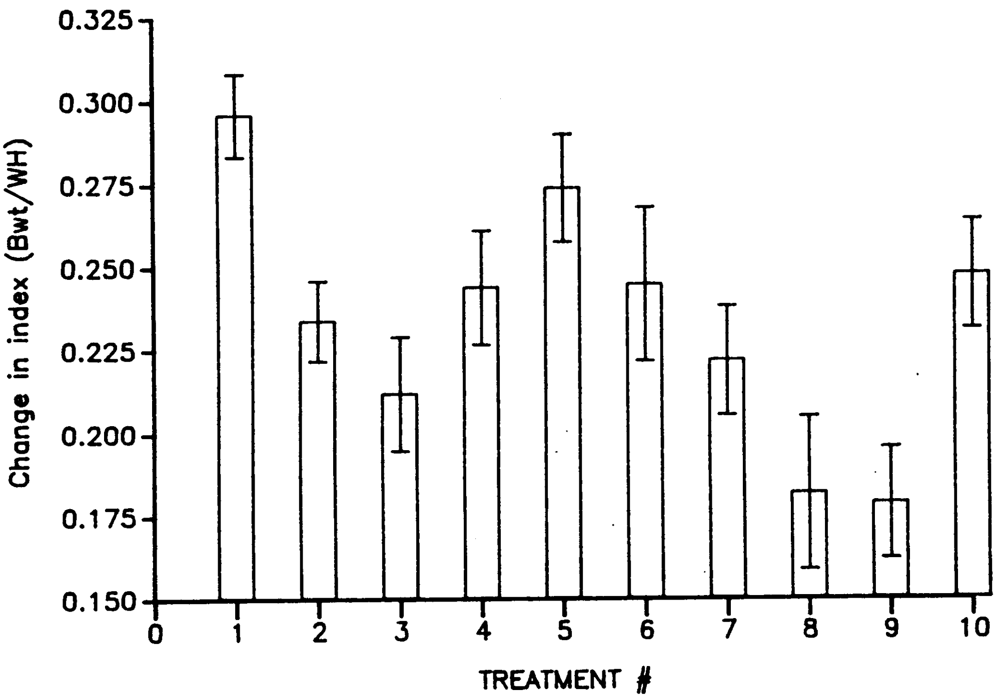

Figure 4. Change in body weight/wither height index between beginning and end of trial.

Table 26. Mean and standard error (SE) of variables associated with intake and gain, heavy heifer block.

Trial variable	Treatment Classification 6	SE	7	SE	8	SE	9	SE	10	SE
DMI%[a]	2.45	.07	2.40	.03	2.24	.05	2.15	.04	2.42	.05
DMI/BWT$^{.75}$[b]	.106	.003	.100	.001	.092	.002	.091	.002	.101	.002
Mcal DEI[c]	24.81	.56	20.98	.45	17.50	.58	18.95	.38	22.19	.74
DEI/BWT$^{.75}$[d]	.312	.009	.288	.004	.255	.006	.247	.005	.301	.007
Mcal DE/Gain[e]	21.42	.75	21.69	.68	21.95	.94	24.87	.73	22.33	.63
Kg TDNI[f]	5.63	.19	4.76	.10	3.97	.13	4.30	.09	5.03	.16
Kg NDFI[g]	3.45	.05	3.26	.04	3.41	.05	3.82	.04	3.49	.04
Gain[h]	1.18	.03	1.01	.02	0.83	.03	0.80	.02	1.02	.03

[a] Dry matter intake as a percent of body weight.

[b] Kg dry matter intake per kg body weight$^{.75}$.

[c] Megacalories of digestible energy = 4.409 * TDN%.

[d] Megacalories of digestible energy per kg body weight$^{.75}$.

[e] Megacalories of digestible energy per kg of daily gain.

[f] Intake of total digestible nutrients, kg/day.

[g] Intake of neutral detergent fiber, kg/day.

[h] Daily increase in body weight, kg.

Table 27. Bonferroni contrasts of trial variables associated with DM intake and daily gain in body weight, heavy heifer block.

Contrast #[b]	Trial Ration Variable[a] DMI[b]	DMI%[c]	DMIMBWT[d]	GAIN[e]
1				*
2	*			*
3				*
4				*
5				
6	*			*

[a] Significant differences in least squares means P<.05, *.

[b] Contrast of treatments by classification number,

Heavy block		Contrast
1	6 vs. 7	Low NDF vs. Control
2	6 vs. 8	Low NDF vs. High NDF
3	7 vs. 8	Control vs. High NDF
4	7 vs. 9	Control vs. Low TDN
5	7 vs. 10	Control vs. High TDN
6	9 vs. 10	Low TDN vs. High TDN

Table 28. Bonferroni contrasts of trial variables associated with intake of energy (DEI, TDNI) and fiber (NDFI), heavy heifer block.

Contrast #[b]	Trial Ration Variable[a]			
	Mcal DEI[b]	Mcal DE/G[c]	kg TDNI[d]	kg NDFI[e]
1				
2	*		*	
3				
4				
5				
6	*			

[a] Significant differences in least squares means P<.05, *.

[b] Contrast of treatments by classification number,

Heavy block		Contrast
1	6 vs. 7	Low NDF vs. Control
2	6 vs. 8	Low NDF vs. High NDF
3	7 vs. 8	Control vs. High NDF
4	7 vs. 9	Control vs. Low TDN
5	7 vs. 10	Control vs. High TDN
6	9 vs. 10	Low TDN vs. High TDN

$BWT^{.75}$ with the low NDF treatment being most efficient at 21.42 Mcal DE/kg gain. Lowest efficiency of conversion of DE to gain was found to occur on the low TDN ration (24.87 Mcal DE/kg gain). Trends in DMI and DEI were less variable between treatments in heavy block heifers than light block heifers. These findings suggest ration variability has less effect on voluntary intake of larger heifers.

Differences in gain between treatments were a reflection of DEI (Table 27). Those treatments with greatest DEI (low NDF and high TDN) had the highest average daily gains (1.18 and 1.02 kg/day, respectively). Rations containing greater quantities of corn silage or high moisture corn showed a response of greater gain than those containing primarily alfalfa haylage and orchardgrass hay, much the same response as occurred in the light heifer block but at a lower magnitude. This response is most likely the result of greater non-structural carbohydrate content in those rations containing corn silage and high moisture corn. These rations should have provided a better balance between energy and protein then was available on the haylage based rations.

Treatment differences in wither height and daily growth were less pronounced in this weight group (Tables 29, 30). The only treatments differing in wither height were the high TDN and control diets, yet all treatments except the control and high TDN were different for body weight. Differences in wither height may be a reflection of differences in ration formulation, but rate of daily growth was also different suggesting this as the cause. Daily growth for the control diet was 0.088 cm/day while daily growth, in wither height, for the high TDN treatment was 0.066 cm/day (Table 29). Growth in height was also different for the low TDN (0.057 cm/day) and the control diet (Table 30). These differences can be attributed to lower DMI/kg $BWT^{.75}$, lower DEI/kg $BWT^{.75}$, and higher Mcal DE/kg gain, when comparing the low TDN treatment to the control.

Table 29. Mean and standard error (SE) of variables associated with body weight (BWT), wither height (WH), daily growth in wither height (DGROW), and INDEX (BWT/WH), heavy heifer block.

	Treatment Classification									
Trial variable	6	SE	7	SE	8	SE	9	SE	10	SE
BWT[a]	340.7	.39	302.3	.27	278.3	.39	327.2	.28	306.1	.27
WH[b]	119.0	.07	116.8	.05	116.7	.07	112.3	.05	110.3	.05
DGROW[c]	0.095	.01	0.088	.01	0.086	.01	0.057	.01	0.066	.01
INDEX[d]	0.245	.02	0.222	.02	0.182	.02	0.180	.02	0.248	.02
Gain[e]	1.18	.03	1.01	.02	0.83	.03	0.80	.02	1.02	.03

[a] Body weight, kg.

[b] Wither height, cm.

[c] Daily growth in wither height, cm/day.

[d] Index = Ending (BWT/WH) – Beginning (BWT/WH).

[e] Daily gain in body weight, kg.

Table 30. Bonferroni contrasts of trial variables associated with body weight (BWT), wither height (WH), daily growth in wither height (DGROW), and calculated INDEX (BWT/WH), heavy heifer block.

Contrast #	Trial Ration Variable[a]			
	BWT[b]	WH[c]	DGROW[d]	INDEX[e]
1	*			
2	*			
3	*			
4	*		*	
5		*	*	
6	*			*

[a] Significant differences in least squares means P<.05, *.

[b] Body weight, kg.

[c] Wither height, cm.

[d] Daily growth in wither height, cm/day.

[e] Index = Ending (BWT/WH) – Beginning (BWT/WH).

It can be concluded from both weight blocks that rations containing lower quantities of corn silage and higher quantities of alfalfa haylage or orchardgrass hay showed a depression of DM intake, Mcal DEI/kg $BWT^{.75}$, kg TDNI, kg NDFI, daily gain, and daily growth in wither height. These differences in forage base may have caused a change in ration palatability, fiber digestibility, and nitrogen utilization, and thus were reflected in animal performance.

Comparison of observed intake and gain variables to NRC (77) are in Table 31. Due to the availability of National Research Council recommendations, to be published by fall of 1988, they were used as an up-to-date reference of nutritional requirements of growing dairy heifers. Due to lack of availability these requirements were not used in trial development nor were they used in analysis of the trial. Comparisons were made using least squares means of groups of animals falling into comparable weight groups as presented in NRC, not regressed responses of study heifers. Results from this study indicate that confinement-reared heifers may eat more DM as a percent of BWT than predicted by NRC. Greater levels of intake by confinement reared heifers may be due to; 1. Availability of properly mixed rations containing above average quality forages. 2. Availability of rations in sufficient quantities to provide ad libitum intake. 3. Group interaction between individuals stimulating eating frequency. 4. Human presence at various times of day also stimulating animals to commence eating. 5. Care and comfort provided by the counter-slope facility. These factors may be responsible for heifers reared under confinement situations to have a greater DEI/kg $BWT^{.75}$ and kg TDNI than NRC projects. Comparison of NE_g to NRC indicates heifers within the study had lower intake of NE_g,NE_g /kg gain, and Mcal DE/kg gain. These results suggest that heifers were more efficient in conversion of feed energy to gain then predicted by NRC. Results indicate that energy recommendations for confinement-reared heifers may be above levels required for .68 kg/day gain.

Effects of Fiber and pH on Intake

Intake response to changing levels of ration NDF and TDN was investigated in the interest of determining effect on DMI of growing dairy heifers. Effects of NDF and TDN on DM intake (kg/day) were estimated by second order polynomial regression and are shown in Figures 5 and 6, respectively. Equation generated was: Y = -171.7832 + 4.4151 * TDN - 0.0281 * TDNSQ + 1.1625 * NDF - 0.0039 * NDFSQ - 0.0125 * NDFTDN - 0.00317 * BWT + 4.68E-05 * BWTSQ. $r^2 = .57$. The equation was generated using observations of all heifers in the trial. Body weight was entered at the mean level for all heifers on trial. Figure 5 represents the intake response to TDN as NDF is increased at mean levels of the low, medium, and high NDF treatments. It should be noted that in all figures, response curves were limited to the range of observations within the data-set. Figure 5 indicates that as NDF content was reduced and TDN increased, DM intake also increased. The response appears to decline as TDN increased above 67 and 70% for the 45 and 40% NDF levels, respectively. This change in intake function may represent a shift from physical to metabolic control as rations increase in energy density and decrease in fiber. These levels of ration energy density and change in DM intake characteristics agree with findings of Conrad et al. (34). They reported a decrease in DM intake in dairy cows when rations were more than 67% digestible. Montgomery and Baumgardt (72) reported maximal DM intake with dairy heifers to occur at 56% digestibility. This wide discrepancy between studies was created by difference in physiogical state of the animal as well as age. Heifers tend to have slower rates of passage of fibrous material from the rumen and thus are able to utilize rations containing

Table 31. Comparison of observed DMI, DEI and efficiency measures to new NRC (77) recommendations.

	Body Weight, kg							
	200		250		300		350	
Trial variable	OB	NRC	OB	NRC	OB	NRC	OB	NRC
DMI%[a]	2.57	2.49	2.48	2.40	2.42	2.35	2.59	2.35
Mcal DEI[c]	18.45	14.71	17.54	17.32	17.50	19.95	24.81	22.64
DEI/BWT$^{.75}$[d]	0.344	0.277	0.281	0.275	0.255	0.277	0.312	0.280
Mcal DE/Gain[e]	16.11	18.39	17.81	21.65	21.95	24.94	21.42	28.30
Kg TDNI[f]	4.18	3.34	3.98	3.93	3.97	4.52	5.63	5.14
NE_m[g]	4.62	4.57	5.39	5.41	6.23	6.20	6.82	6.96
NE_g[h]	2.13	2.25	1.98	2.51	2.14	2.77	2.65	3.01
NE_g/kg gain	1.84	2.81	1.96	3.14	2.21	3.46	2.25	3.76

[a] Dry matter intake as a percent of body weight.

[b] Kg dry matter intake per kg body weight$^{.75}$.

[c] Digestible energy intake, Mcal/day.

[d] Digestible energy intake per kg body weight$^{.75}$.

[e] Digestible energy (Mcal) per kg of daily gain.

[f] Intake of total digestible nutrients, kg.

[g] Net energy, maintenance (Mcal/day) = 0.086 * $BWT_{.75}$

[h] NE, gain, Mcal/day= $.035 * BWT^{.75}(BWT/1000)^{1.119} + BWT/1000$

lower digestibility. Cows have higher rates of passage and therefore are dependent on rations containing greater digestibility so that energy needs are met. Variation between previous work and this study may be attributed to differences in ration composition, physical form, method of feeding, and animal variation and performance.

Relationship between intake of DM and ration NDF content is presented in Figure 6. This figure indicates that increasing ration NDF has a greater effect on high TDN rations than low. As NDF increased in the low TDN rations there was little effect on DM intake. Increasing NDF in the medium and high TDN rations was reflected by a decrease in DM intake by more than 1.5 kg/day as NDF increased from 35 to 55% of ration DM. These results indicate that ration fiber content has a greater depressive effect on DM intake as rations increase in energy density. It is difficult to determine if the decrease in DM intake is in response to change in NDF or change in ration TDN levels. Researchers Brent (16), Donefer (39), and Woods (121) found that as the amount of concentrate in the ration increased, voluntary intake decreased so that available energy intake was relatively constant. It is probable that heifers within this study were better able to regulate energy intake on higher TDN rations which were not limited by fiber content. Those rations with lower energy density and greater fiber content may have restricted intake due to the limitation of body capacity and thus show the response of depressed DM intake.

Light heifer response, measured in kg TDN/day, to increasing ration NDF is shown in Figure 7. As ration NDF was increased from 37 to 59%, intake of TDN decreased. Second order polynomial regression equation explaining this response was: Y = 0.49362 -0.043499 * NDF + 9.472E-04 * NDFSQ + 0.03282 * BWT + 2.619E-05 * BWTSQ - 5.055E-04 * BWTNDF. $r^2 = .45$.

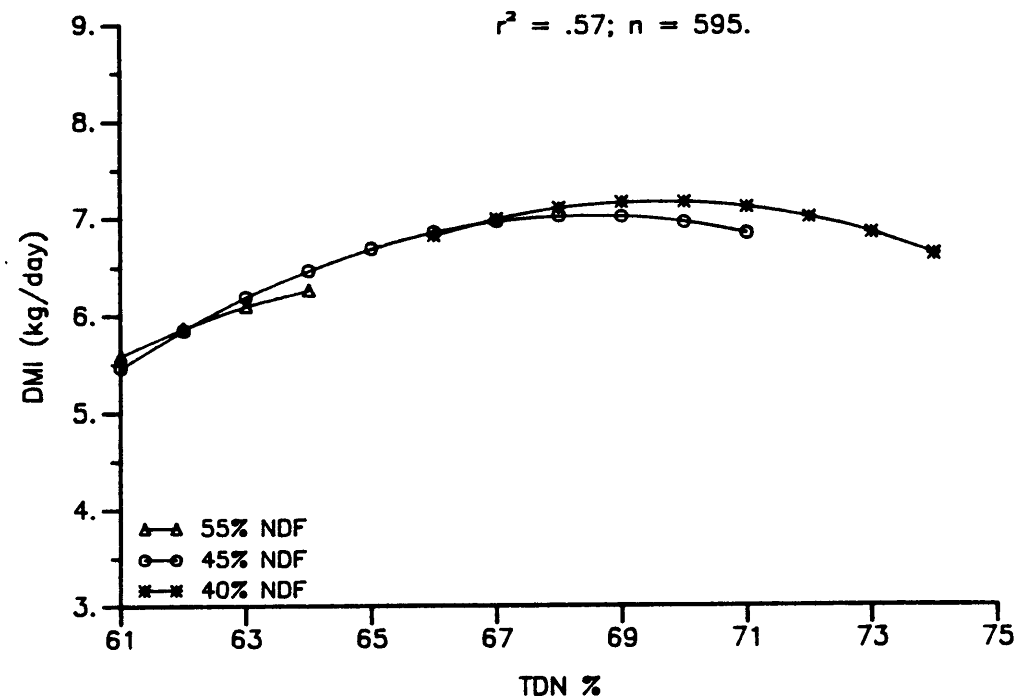

Figure 5. **Second order polynomial regression of dry matter intake (kg/day) on total digestible nutrients (% of DM) for all heifers on trial.**

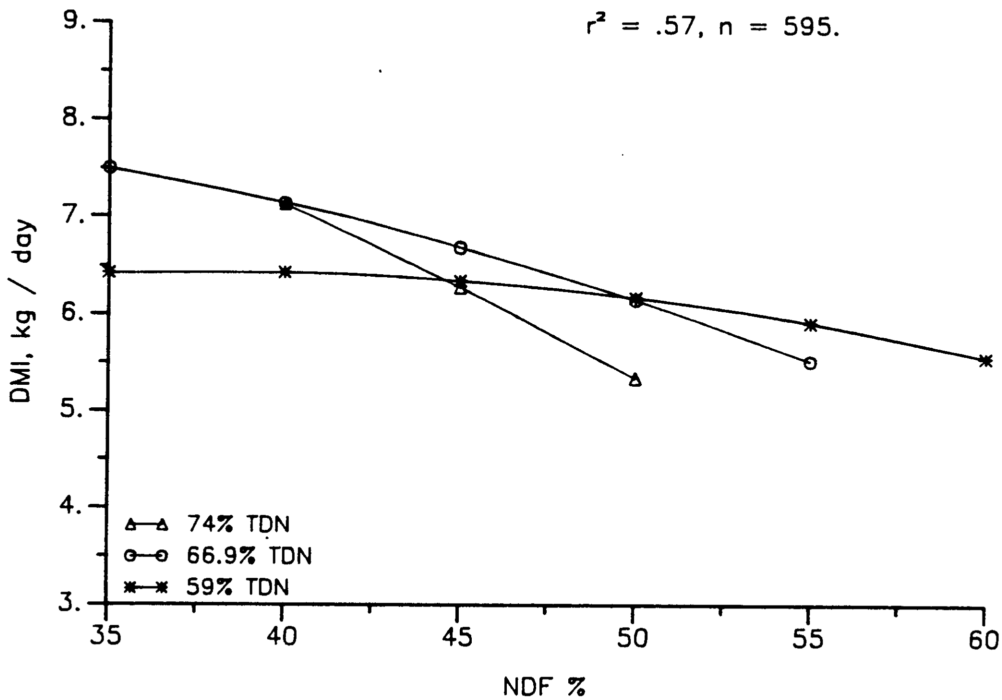

Figure 6. Second order polynomial regression of dry matter intake (kg/day) on neutral detergent fiber (% of DM) for all heifers on trial.

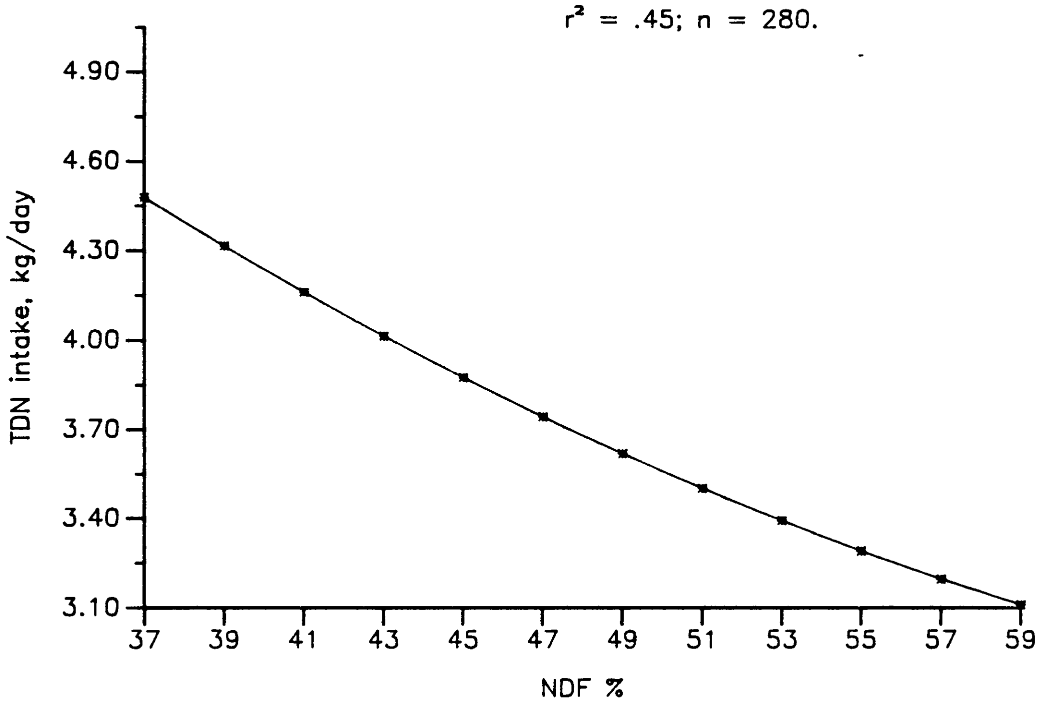

Figure 7. Second order polynomial regression of total digestible nutrients (kg/day) on neutral detergent fiber (% of DM) for heifers in the light block, mean BWT = 217 kg

This response may indicate that DM intake by smaller heifers ($\bar{x}$ = 217 kg) is possibly the result of limited physical capacity to increase DM intake with increasing NDF content, suggesting heifers are limited by physical factors (rumen distention, rate of passage, and rate of fermentation). Heavy heifer response (kg TDN/day) to increasing ration NDF is presented in Figure 8. Regression equation generated was: Y = -12.9632 + 0.7667 * NDF - 5.75E-03 * NDFSQ - 0.01477 * BWT + 1.2425E-04 * BWTSQ - 8.8809E-04 * BWTNDF. $r^2 = .57$.

TDN intake response to increasing NDF indicates that as NDF increased to 42.65% of ration DM, energy intake also increased. Above this level, intake of TDN began to decline and continued to do so to 59% NDF. This response possibly indicates that below 42.5% NDF, heifers controlled energy intake by metabolic mechanisms. Intake of TDN above 42.5% NDF was probably the result of increasing influence of fiber content and its filling effect on rumen capacity.

Intake of fiber (kg NDF/day) as a function of increasing levels of ration TDN is represented in Figure 9 for the light and heavy heifer blocks. Light heifer response is represented by the equation: Y = -4.4476 - 0.0135 * TDN + 9.8529E-04 * TDNSQ + 0.05761 * BWT - 6.1761E-04 * BWTTDN. $r^2 = .60$. The response curve in Figure 9 shows that intake of fiber (kg NDF) is somewhat depressed by increasing levels of ration TDN shown by a decline of 0.10 kg NDF/day. An alternative explanation is that as TDN decreases heifers attempt to increase DM intake but are limited by fill. This function may substantiate the earlier findings that increasing ration energy density had less effect on DM intake in light heifers than ration fiber content.

Figure 9 also presents the equation: Y = 25.4672 - 0.4845 * TDN + 1.3049E-03 * TDNSQ - 0.0433 * BWT + 8.6347E-04 * BWTTDN. $r^2 = .40$. As represented in the

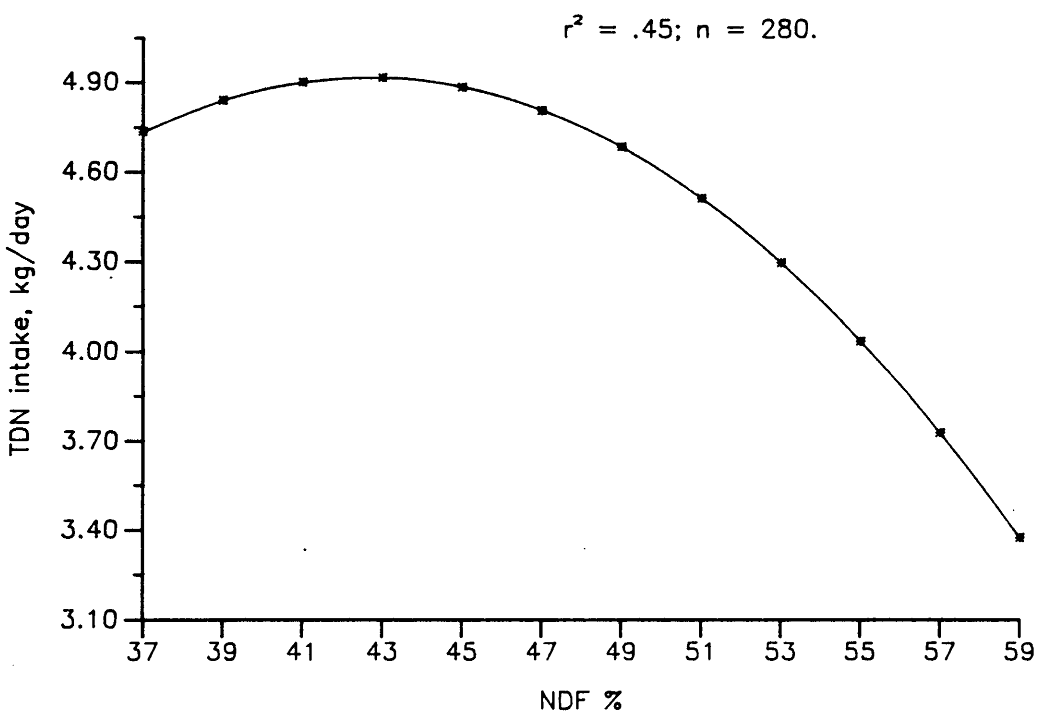

Figure 8. **Second order polynomial regression of total digestible nutrients (kg/day) on neutral detergent fiber (% of DM) for heifers in the heavy block, mean BWT = 311 kg**

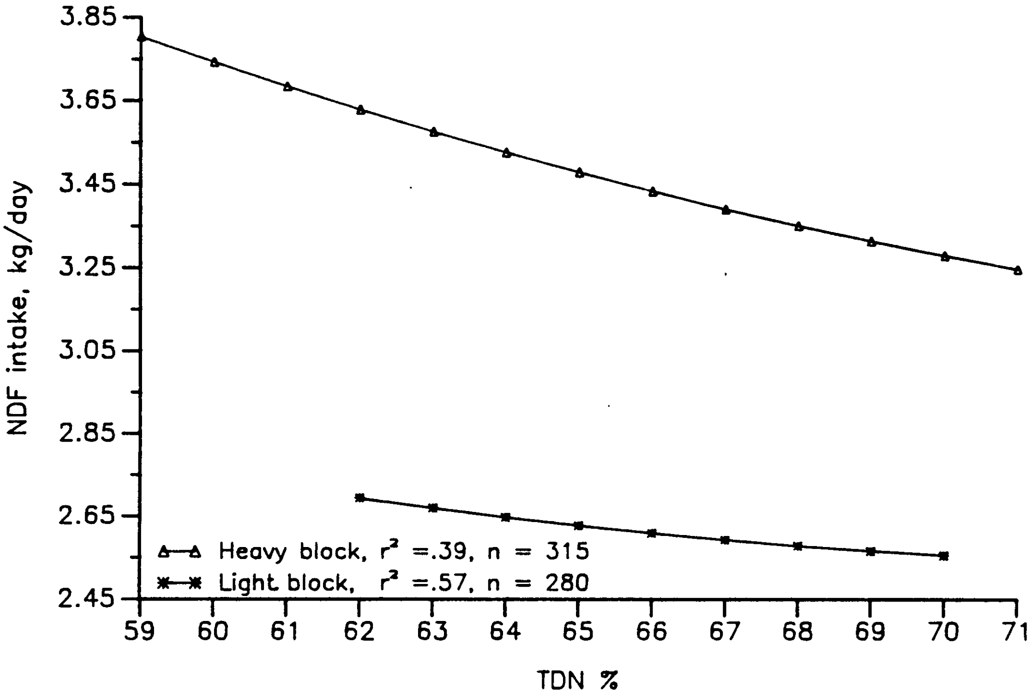

Figure 9. Second order polynomial regression of neutral detergent fiber (kg/day) on total digestible nutrients (% of DM) for heifers in both blocks.

figure, slope of TDN is more negative in the heavy heifer block than the lights. This greater decline in NDF intake accounts for a decrease of 0.45 kg NDF/day over the range of TDN. As indicated earlier, and supported by this figure, intake by the heavy heifers was more a function of ration energy density than fiber content. This figure suggests that as ration energy density increased, heifers decreased total fiber intake to maintain a level of energy intake without regard to daily fiber intake.

Change in DM intake (kg/day) with changing levels of ration pH are presented in Figures 10 and 11 for the light and heavy heifers, respectively. Intake response to changing levels in the light heifer block were quite minimal, Figure 10. Lack of intake differences may have been the result of the narrow range of ration pH's observed in this study. Response may also have been the result of similarities between treatments and their composition, there-by decreasing the amount of variation between treatments. It should be noted: it was not the intent of this study to have rations varying in pH content, and any information gained from this variation is secondary to planned ration variation in fiber and energy density. Heavy heifer response to changing levels of ration pH were more marked than light heifer response (Figure 11). The response curve indicates that as pH increased to 4.75, DM intake declined to about 6.90 kg/day. Above this pH level, DM intake began to increase toward levels comparable to intake below 4.75. It is difficult to determine if depression in DM intake was the result of changing ration pH, DM% or changing ration component content. Those rations with low pH and high DM intake were composed primarily of corn silage, high moisture corn, soybean meal, and orchardgrass hay, a very palatable ration. As rations increased in pH content they also increased in proportion of orchardgrass hay which would have a depressive effect on DM intake due to greater fiber content and lower palatability. The higher pH rations were composed predominantly of alfalfa haylage which is lower in fiber and more palatable than rations containing higher quantities of orchardgrass hay. These ration differences suggest that while differing in pH, their respective intake characteristics may be a reflection of composition and palatability, rather than pH or organic acid content and it is difficult to determine which.

The decline in DM intake (.9 kg/day) as ration pH increased from 4.05 to 4.74 disagrees with results of Shaver et al. (93) and Wilkinson et al. (118). Their results indicated that as rations became less acidic DM intake increased. As indicated earlier, results from this study are confounded with variation in ration composition making any tests associated with ration pH difficult to assimilate and draw conclusions. At best, this study gives some indication of DM intake trends associated with pH, but no concrete conclusions can be drawn from this information.

DM intake (g/kg $bwt^{.75}$) response to varying levels of ration ADF and NDF are presented in Figures 12 and 13. Second order polynomial regression equations generated are: ADF, $Y = 86.3192 + 2.4374 * ADF - 0.061 * ADFSQ$. $r^2 = .30$. NDF, $Y = -0.969\ 2 + 0.5616 * NDF - 0.00684 * NDFSQ$. $r^2 = .30$.

Prediction of maximal DM intake (g/kg $BWT^{.75}$) was determined by computation of the first derivative with respect to either ADF or NDF. Figure 12 indicates that maximal DM intake occurred at 19.98% ADF of ration DM. These findings are in close agreement with those of Jahn et al. (54) and Quigley et al. (85), who found maximal DM intake to occur between 20 and 23% ADF in ration DM. Below 20% both researchers suggest metabolic factors as control mechanisms of intake. Above 23% ADF in ration DM, intake of DM may be limited by physical factors associated with rumen distention, passage rate, and rate of fermentation. Results of this study must, however, be carefully interpreted as few observations occurred at ADF levels below 20% of ration DM.

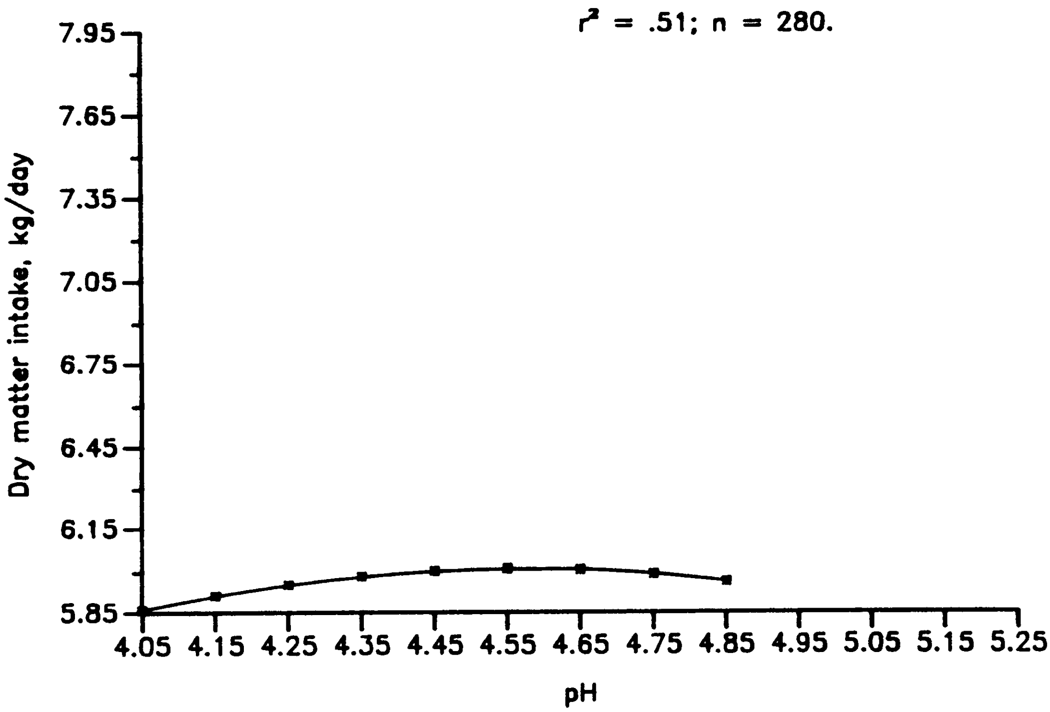

Figure 10. Second order polynomial regression of dry matter intake (kg/day) on ration pH, light heifer block.

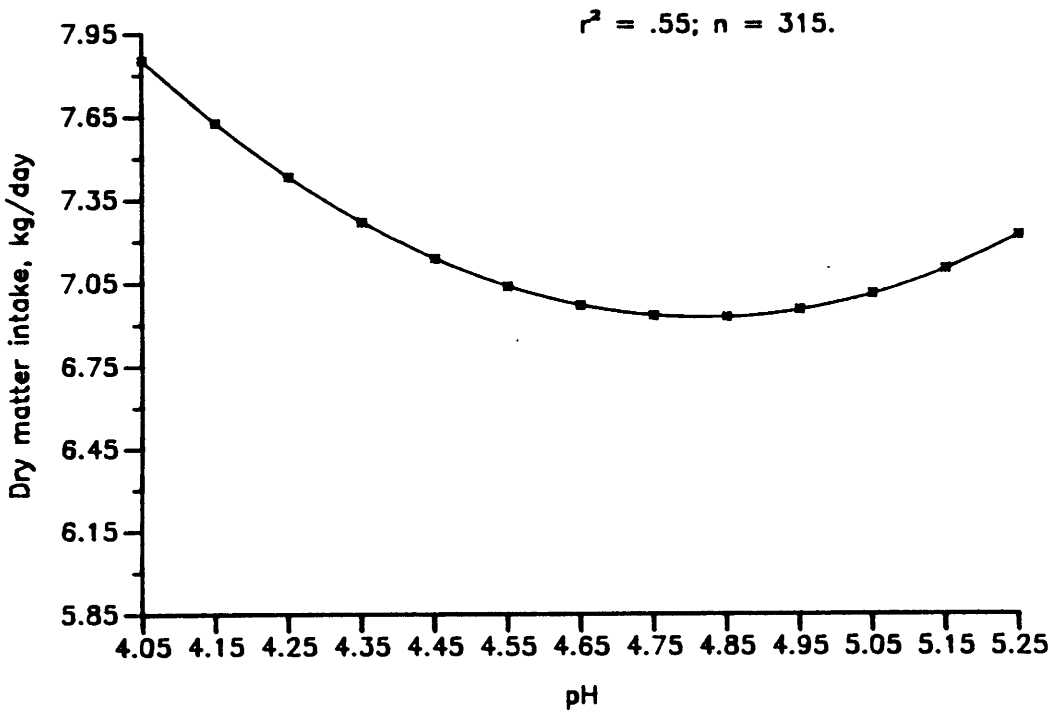

Figure 11. Second order polynomial regression of dry matter intake (kg/day) on ration pH, heavy heifer block.

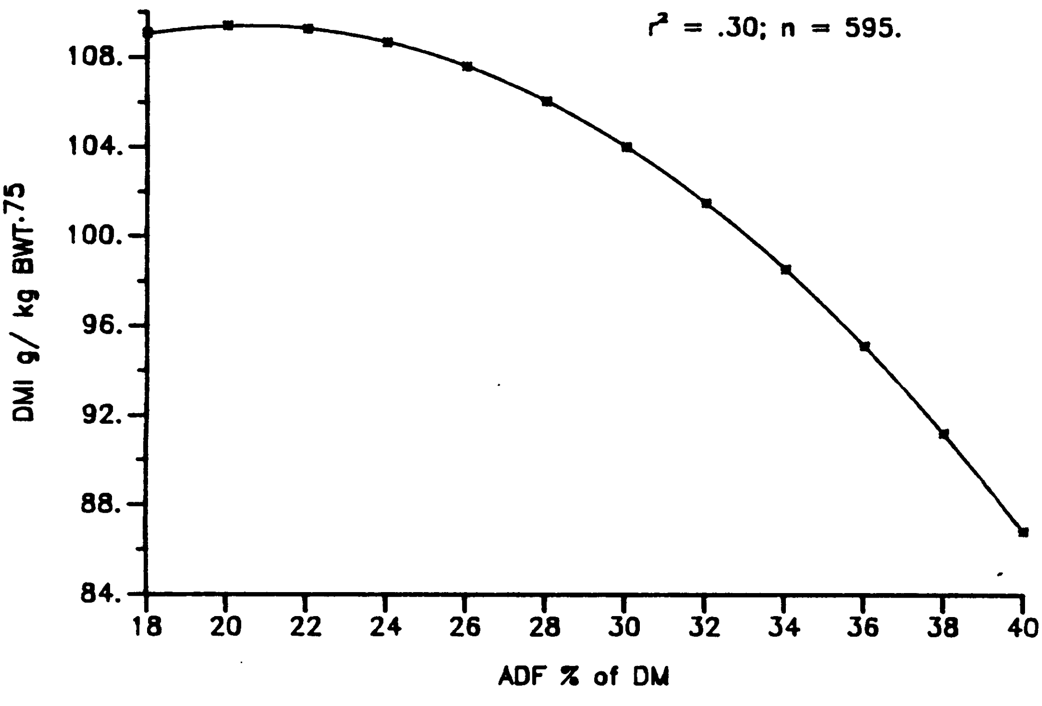

Figure 12. **Second order polynomial regression of dry matter intake (g/kg MBWT) on acid detergent fiber (% of DM) for all heifers on trial.**

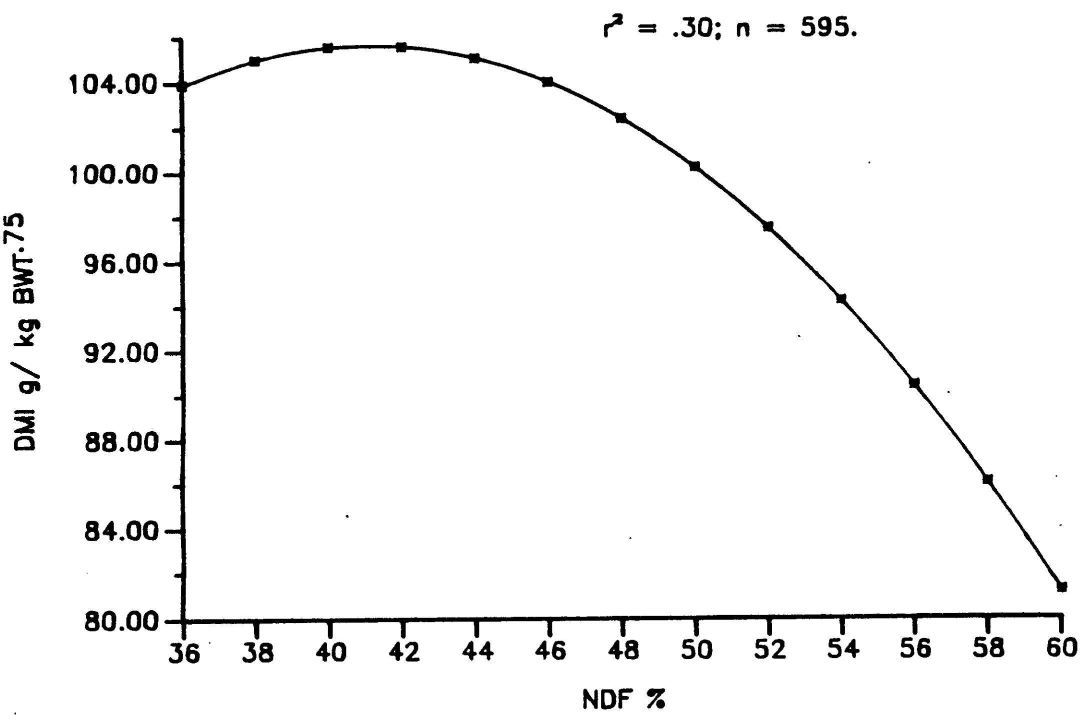

Figure 13. Second order polynomial regression of dry matter intake (g/kg MBWT) on neutral detergent fiber (% of DM) for all heifers on trial.

Response function of DM intake as a percent of metabolic body weight on NDF in ration DM is curvilinear (Figure 13). Maximal DM intake as determined by first derivative with respect to NDF occurred at 41.05% NDF in ration DM. Mertens (68) reported intake of DM was maximal for lactating dairy cows at 39% NDF in ration DM. Quigley (85) indicated DM intake by dairy heifers under confinement conditions was greatest between 38 and 43% NDF in total mixed ration DM. Even though rations varied in amount of concentrate ingredients as well as forage base, these findings indicate that even with varying forage base maximal DM intake occurs near 41% NDF in ration DM.

Correlation coefficients between intake of DM and independent variables are in Table 32. Correlation between intake of DM and body weight was highest (.67), and NDF was lowest (-.005). Due to the large number of observations in this data-set, biological significance of many coefficients may be questionable. Figures 5, 7, 8, 12, and 13, indicate that relationship between fiber and energy parameters and DM intake is actually quadratic, therefore, linear coefficients would be expected to be low.

Studies by Van Soest (107) and Quigley et al. (84) were in disagreement as to the correlation of NDF content and DM intake. Van Soest reported high correlations between NDF content of forages and voluntary intake. Quigley found that below 42% NDF in ration DM, correlation with DM intake was ($r = -.29$), above 42%, correlation was lower ($r = -.14$).

Due to findings of this study that intake of DM in response to ADF and NDF is curvilinear, it was of interest to determine correlation with DM intake above and below the point of maximal intake. Correlations between DM intake, ADF and NDF when NDF is above 41% (physical regulation) and below 41% (metabolic regulation) are in

Table 32. Correlation coefficients between DMI, BWT, GAIN, WH, TDN, NDF, ADF, ration dry matter (DM), CP, and ration pH (pH).

	BWT	GAIN	WH	TDN	NDF	ADF	DM	CP	pH
DMI	.67	.34	.42	.02	−.005[a]	−.01[a]	.05[a]	−.23	.06[a]
BWT		.004[a]	.66	−.29	.36	.30	.001[a]	−.38	.27
GAIN			−.02[a]	.36	−.33	−.36	−.16	−.07[a]	−.30
WH				−.24	.43	.25	.02[a]	−.55	−.05
TDN					−.72	−.99	−.31	.15	−.39
NDF						.73	.21	−.50	.14
ADF							.30	−.16	.39
DM								.17	.58
CP									.46

[a] coefficients nonsignificant, P>.0001.

Table 33. Correlation between NDF and DM intake at NDF less than and greater than 41% were r = .25 and r = -.13. These findings do not agree with those of Quigley (84) at less than 41% NDF. It is suggested, differences between observed values and those reported by Quigley may be the result of trial design differences and confounding between NDF and TDN. It is possible that ration compositional differences may be responsible for the differences in correlation between DMI and NDF at levels below 41%. In this study rations containing less than 41% NDF were composed of predominantly alfalfa haylage. Due to previously discussed factors within this treatment as NDF was increased heifers also increased voluntary DMI. This explains the positive correlation between NDF and DMI at NDF levels below 41%.

Removing variation of metabolic body weight changed the correlation between NDF and DM intake to -.18 and -.28 for below and above 41% NDF, respectively. Increase in correlation above 41% NDF and DM intake is a reflection of the effect of body weight. Removal of this variation increases the variation in intake explained by ration fiber content. Quigley reported very low correlations between fiber analysis and DMI when rations contained above 41% NDF. It is not evident to this author why correlations above 41% were so low as reported by Quigley. One would expect DMI to be depressed as fiber content increases. Coefficients between ADF and DM intake (g/kg $BWT^{.75}$) followed trends similar to those of NDF. In disagreement with findings of Quigley et al. (84), NDF was more highly correlated with intake of DM than ADF in most cases (Table 32). It was expected that ration parameters would be significantly correlated with intake of DM due to experimental design.

Correlation between NDF and ADF was .43 when NDF was below 41%, while it was .74 when above this level. This shift in correlation between the two fiber measurements reflects changes in ration composition due to varying forage type. High correlation be-

Table 33. Correlation coefficients between intake of dry matter and NDF and ADF when NDF in ration dry matter is less than (metabolic) or greater than (physical) 41%.

Variables[b]	Metabolic < 41% NDF		Physical > 41% NDF	
	Observed	Quigley(83)	Observed	Quigley
DMI : NDF	.25	−.29	−.13	−.14
DMI : ADF	−.18	−.30	−.02[a]	.11
DMIMBWT : NDF	−.16[a]	−.41	−.28	−.01
DMIMBWT : ADF	−.42	−.42	−.21	−.03
NDF : ADF	.43	.82	.74	.09

[a] coefficients nonsignificant, P>.05.

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

DMIMBWT = intake of dry matter, g/kg $BWT^{.75}$

NDF = neutral detergent fiber, % of ration dry matter.

ADF = acid detergent fiber, % of ration dry matter.

tween NDF and ADF (r=.74) was expected as ADF contains a major portion of the plant cell wall components found in NDF. Correlations between NDF and ADF were not in agreement with those reported by Quigley. It is postulated that these differences were caused by variation in forage base within this study. Forage base within the Quigley study varied only between corn silage and orchardgrass hay, thus limiting the variability in ADF and NDF ratios.

Estimation of TDN from ADF (Table 32) was shown to have high correlation and may be substituted for one another in intake prediction equations. Variability in correlation between these variables above and below 41% NDF indicate their variability associated with ration differences.

Correlations between body weight and ration energy and fiber parameters were significant due to experimental design. Rations were formulated in such a manner that body weight and gain should have resulted in a change in energy and fiber content as well as DM intake. Correlations between body weight and gain and DM intake were expected to be significant as these two parameters have a great effect on DM intake. Higher correlation (r=.36) between body weight and NDF, than body weight and TDN, suggests a greater influence of fill characteristics of a ration over its digestibility characteristics. Correlation between TDN and gain was higher (r=.36) than other ration parameters suggesting energy variables are more critical to gain in body weight than fiber or protein parameters.

Coefficients of correlation between independent variables are indicative of degree of colinearity, and suggest which independent variables, if any, may be substituted for one another in the data set (90).

Expanded Model Development

An expanded model was determined by backward stepwise elimination on the 51 independent variables in the original data set. Stepwise regression procedure eliminated all independent variables not contributing significantly to the model at the .05 level. Selection of dependent variables most predictive of dry matter intake was determined by backward stepwise regression of independent variables in Table 3 on DMI (kg/day), natural log of DMI, DMI as a percent of metabolic body weight, and DMI as a percent of body weight. Maximum r^2 obtained on the 4 dependent variables were .63, .59, .32, and .38, respectively. Yielding the highest r^2, DMI (kg/day) was selected for use in further model development. Maximum r^2 for the expanded model (Table 34) was similar to those reported by (18, 19, 83). As intakes were pooled on a weekly basis, it was expected that r^2 would be improved due to pooling's reduction of variation in daily intake. Full model development indicates variables which may not have otherwise been considered in predicting dry matter intake. Daily growth in wither height, and its interactions, may give an indication of the partition of energy to structural and tissue growth, as opposed to fat deposition. Dry matter and pH may act as measurements of the organic acid content of the ration. They may therefore serve as indicators of ration palatability or reflect ration palatability characteristics. Interactions between body measurements and ration parameters are very difficult to explain, yet they could be quite important in prediction of dry matter intake.

Due to size of data set and large number of error degrees of freedom, variables which may not have biological or practical significance were permitted to enter the model. While this model was not intended to be used in validation studies, it does add information on variables which may have significance for future model development. At this

Table 34. **Independent variables selected in expanded model development, parameter estimates and standard error (SE) of estimates for prediction of DM intake.**

Independent[a] Variables	Parameter Estimate	SE
Intercept	106.4868	
BWT	−0.8236	0.2276
MBWT	3.4261	1.1883
WH	0.7637	0.1478
TDN	−4.4735	0.9172
DGROW	−122.8651	39.1089
DM	−1.0323	0.3851
BWTSQ	3.6898E−04	1.0593E−04
TDNSQ	0.0288	0.0056
GAINSQ	2.6604	0.4139
WHSQ	−1.5700E−03	6.2356E−04
DMSQ	−5.5132E−03	9.5194E−04
BWTDGROW	0.1229	0.0233
TDNDGROW	1.3784	0.3685
TDNDM	0.0126	0.0046
NDFWH	−4.5239E−03	8.1994E−04
NDFDGROW	0.9029	0.2162
NDFDM	0.0109	0.0022
NDFPH	−0.0311	7.1325E−03
GAINPH	−0.7326	0.1797
WHDGROW	−0.7294	0.1265
WHCP	−9.3815E−03	1.6209E−03
DGROWPH	7.9156	2.8399
DMCP	0.0221	3.7153E−03

[a] See Table 2 for explanation of variables.

$n = 594$ $r^2 = .73$

time it is not conceivable that such a model would be implemented due to difficulty in variable procurement.

Simplified Model Development

A simplified model was developed to be predictive of DM intake using variables commonly available to dairy producers: body weight, daily gain, ration dry matter content, ration TDN, and ration NDF. Variables included in initial model development were the above, their squared terms, metabolic body weight ($BWT^{.75}$), and interaction of BWT, NDF and TDN with daily gain. Model development was conducted on the combined data sets of this study and data provided from Trial 1 (83) of a previous study conducted at this station. Data sets were combined in the interest of creating a larger data base with greater variation in ration composition for development of the DM intake prediction model. Backward stepwise elimination of independent variables on DM intake indicated that ration TDN and its squared term did not explain a significant amount of intake variation.

All possible regression analyses conducted on independent variables produced r^2, Cp and PRESS statistics for each model. The r^2 statistics ranged from a low of zero with NDF squared as the only independent variable to .67 with BWT, BWTSQ, $BWT^{.75}$, daily gain, GAINSQ, NDF, NDFSQ, and ration DM as variables in the model. Models were ranked by r^2, Cp, and PRESS statistics by the ALLPRESS procedure (90) with models in Table 35 selected as those most predictive of DM intake. Models containing more than 4 variables showed minimal increases in r^2 above .62.

The Cp statistic estimated the amount of bias in prediction created by variables not included in the full model. The Cp statistic decreased from 1028.87 with NDFSQ as the only independent variable in the model to 7.32 with 8 variables in the model. Cp decreased only slightly, from a level of 31.50 when more than 5 variables were included in the model. Minimum Cp statistics were consistently achieved when BWT, or $BWT^{.75}$ or BWTSQ, and GAIN, GAINSQ, NDF, and DM were included in the model, suggesting all are important in reducing bias.

Also included in the analysis was the PRESS statistic. PRESS gives an estimate of residuals with the influence of individual observations removed from the prediction. The PRESS statistic decreased as number of independent variables included in the model increased, with a reduction from 1475.56 with NDFSQ in the model, to 489.59 for model 1 (Table 35). Inclusion of TDN and/or its squared term (models 2, 3, Table 35) only slightly improved the predictability of the model and were therefore not included in the model for validation.

An independent data set from a protein and energy study conducted at this station was used in validation of predictive models. Models (Table 35) were evaluated by comparison of predicted DM intake to actual DM intake of each animal in the study using actual observations for the model parameters from the protein study. Comparison of each model was based on calculated sum of squared residuals [Σ(Y actual - Y predicted)^2]. Absolute differences between actual and predicted DM intake were also calculated. Differences in squared residuals, and absolute residuals were minimal between all models, suggesting any of these models would be adequate in prediction of DM intake.

Based on lower sum of squared residuals, similar r^2, lowest Cp, and PRESS statistics, and lowest standard deviation for predicted DM intake, model 1 (Table 35) was selected

Table 35. Diagnostic statistics of models selected from ALLPRESS procedure to predict dry matter intake.

Model[b]	r^2	MSE[a]	C_p	PRESS
1	.67	.967	7.32	489.59
2	.67	.948	7.37	509.67
3	.67	.950	9.37	511.62
4	.67	.950	9.37	511.62
5	.67	.977	11.00	517.88
6	.66	.980	20.61	519.55
7	.66	.981	24.53	521.50

[a] MSE = mean square error.

[b] 1. BWTSQ, GAIN, GAINSQ, NDF, NDFSQ, DM, BWTGAIN

2. BWT, BWTSQ, MBWT, GAIN, GAINSQ, NDF, NDFSQ, DM

3. BWT, BWTSQ, MBWT, GAIN, GAINSQ, NDF, NDFSQ, DM, TDNSQ

4. BWT, BWTSQ, MBWT, GAIN, GAINSQ, NDF, NDFSQ, DM, TDN

5. BWTSQ, GAIN, GAINSQ, NDF, NDFSQ, DM

6. BWT, GAIN, GAINSQ, NDF, NDFSQ, DM

7. BWTSQ, GAIN, GAINSQ, NDF, NDFSQ, DM, TDN, TDNSQ

as the simplified model. This model includes the variables: body weight squared (BWTSQ), daily gain (GAIN), daily gain squared (GAINSQ), ration neutral detergent fiber (NDF), ration NDF squared (NDFSQ), ration dry matter content (DM), and the interaction between body weight and daily gain (BWTGAIN). It was of interest if interaction terms between NDF and TDN with daily gain would significantly add to intake prediction. Results of inclusion of the interaction terms NDFGAIN, and TDNGAIN, were (r^2, Cp, and PRESS): NDFGAIN .67, 8.84, 493.07, TDNGAIN .67, 12.27, 496.25. These results indicate that addition of BWTGAIN to the simplified model aided more in prediction of DM intake and should not be replaced by other interaction terms.

Parameter estimates for the selected simplified model are presented in Table 36. Implementation of this model is dependent upon validation prior to distribution to dairy producers. It is imperative the model be tested to determine if DM intake predicted reflects those levels found under normal management conditions with less than superior feed quality, and less than ad libitum intake. The model must also be tested to ensure animal performance is adequate so that heifers achieve acceptable rates of gain and growth in body size, and capacity, prior to first lactation.

Table 36. Independent variables selected in simplified model development, parameter estimates and standard error (SE) of estimates for prediction of DM intake.

Independent[a] Variables	Parameter Estimate	SE
Intercept	−5.9781	
BWTSQ	2.2120E−05	5.86E−06
GAIN	−5.5527	1.3314
GAINSQ	2.7837	0.5829
NDF	0.4668	0.1273
NDFSQ	−5.3930E−03	1.3455E−03
DM	0.03285	5.6033E−03
BWTGAIN	7.7859E−03	2.9522E−03

[a] All estimates significant at $P < .001$, except BWTGAIN, $P < .01$

$n = 514$, $r^2 = .67$, CV = 14.59

BWT = body weight, kg.

BWTSQ = body weight squared.

GAIN = daily increase in body weight, kg/day.

GAINSQ = daily gain squared.

NDF = neutral detergent fiber, % of ration dry matter.

NDFSQ = NDF squared.

DM = dry matter content, % of ration.

BWTGAIN = interaction between body weight and daily gain.

Summary and Conclusions.

This study determined that factors which affect voluntary dry matter intake of growing dairy heifers may vary with physical size. Voluntary dry matter intake of heifers in the light block was possibly affected more by ration fiber content (NDF) than by ration energy concentratration (TDN)To support this premise, treatments designed to vary in NDF content differed in response for dry matter intake as a percent of body weight, as well as, in daily rate of gain. Treatments designed to vary in TDN also differed in voluntary intake and gain, but did not differ when intake was standardized as a percent of body weight. These findings suggest rations containing higher fiber contents (>41 % NDF) may restrict voluntary intake. It is probable that restriction is caused by physical limitations of size, lower fiber digestibility, slowed passage rate, and limited availability of a readily fermentable carbohydrate source. Intake of dry matter in treatments with varying energy concentration was probably confounded by fiber density, thereby masking any possible response to energy concentration. Lighter heifers may have attempted to increase intake as energy concentration decreased to maintain energy balance, yet were limited by these factors. Differences in dry matter and energy intake between treatments were reflected in growth performance. Growth performance was monitored through measurement of average daily gain, growth in wither height, and use of a body weight/wither height index. The BWT/WH index was calculated in the interest of determining the change in body condition of heifers within the trial. Heifers on treatments designed to be low in NDF or high in TDN responded with the greatest rates of daily gain, higher growth in stature and added more condition as indicated by the BWT/WH index. Heifers receiving treatments high in NDF or low in TDN were characterized by lower dry matter intake, daily rate of gain, energy intake, growth in wither height, and change in BWT/WH index. Heifers in these treatments tended to be leaner than their counterparts in the low NDF or high TDN treatments.

Trends in voluntary dry matter intake by heavy block heifers were similar to light block heifers. Heifers in treatments designed for low NDF or high TDN responded with higher intake of dry matter, daily gain, intake of energy, and change in BWT/WH index. Heavy block heifers differed in dry matter intake as a percent of body weight between treatments varying in NDF and those varying in TDN. Heifers receiving treatments varying in TDN showed a greater response difference in intake than those receiving NDF treatments. These findings suggest heifers with greater body size may be able to increase intake of rations containing low energy or high fiber to maintain adequate energy intake to support greater than .68 kg/day gain.

Heifers in treatments with higher change in index between beginning and end of trial probably did not apportion bodily growth equally between growth in muscle or bone mass and adipose tissue. Heifers in treatments low in NDF or high in TDN tended to have the greatest change in index suggesting greater deposition of adipose tissue. Heifers in treatments high in NDF or low in TDN responded with lower change in index. Differences in index change were greater in the heavy heifer block than the light suggesting heavy heifers became fatter on low fiber and high energy diets than smaller heifers. These differences between blocks may be the result of change in nutient partition with age, therefore indicating heavy heifers may apportion greater quantities of energy to fat than lighter heifers at similar ration energy densities.

Average daily gain of all heifers on trial was 1.01 kg/day, considerably higher than .68 kg/day. This rate of gain is above levels suggested for optimal growth of mammary tissue in the alometric phase (<9 mos. of age)(42, 47, 92). These conditions may produce animals prone to lower lifetime productivity due to fat infiltration of the mammary gland. It is recommended heifers be provided rations which do not create a large change in body condition index therefore giving the animal greater potential for higher lifetime milk production and reproductive performance.

Higher body weight gain and increased feed efficiency under total confinement conditions indicates that nutrient recommendations by NRC may underestimate efficiency of nutrient utilization. Results from this, and previous trials at this station indicate that heifers in confinement housing require less energy dense rations than recommended by NRC to perform at acceptable rates of gain. It is likely that recommendations should vary with housing type due to energy expenditure for animal maintenance.

Heifers consuming rations containing orchardgrass hay and alfalfa haylage responded with lower voluntary intake and rates of daily gain closer to levels rations were formulated. It is of interest to this author why rations containing greater quantities of these forages resulted in depressed response levels. It is postulated that availability of a readily fermentable carbohydrate source depressed growth of rumen bacteria thus slowing growth of those responsible for fiber digestion. Also possible is that metabolic energy expenditure was increased due to removal of excess ammonia as urea. Due to lack of a readily available energy source, heifers were forced to remove ammonia as urea as rumen bacteria are unable to handle the great ammounts provided by alfalfa haylage. It is possible that supplementation of readily fermentable carbohydrates will improve the efficiency of utilization of highly fibrous feeds thereby improving animal performance.

Development of dry matter intake prediction equations for dairy heifers indicate body weight affects intake more than any other variable. Other variables important in intake prediction are average daily gain in body weight, ration fiber (NDF) and dry matter content, and the interaction between body weight and daily gain. Curvilinear term of fiber was required to account for change in dry matter intake due to change from metabolic to physical controls.

Development of a simplified model using 8 variables indicated ration NDF content had a greater effect on intake prediction than TDN (or ADF). Under most conditions differentiation between the effect o these variables would be quite difficult. As discussed previously confounding between NDF, ADF, and TDN content is nearly impossible to control using forages readily available to dairy producers. In growing dairy heifers, ration fiber probably acts to limit voluntary intake hence causing reduced animal performance. In the opinion of this author, most dairy heifers tend to receive lower quality feeds than those provided the lactating herd. It would therefore be unlikely that heifer rations for growth would contain excess energy invoking metabolic controls of intake. In situations when ration energy is high, metabolic factors are considered to control voluntary intake of dry matter. Level of ration energy concentration invoking metabolic control of intake is not finite, nor is the level of fiber, yet under most conditions fiber will have greater influence on voluntary dry matter intake. For these reasons inclusion of a measure of ration energy concentration may not be as important in predicting voluntary intake as ration fiber content.

Prior to acceptance of equations developed in this study, it is imperative they be tested under field conditions. Voluntary intake of heifers in field conditions may vary widely from intake measurements provided under the controlled conditions of this study. It is also of importance to ensure that animal performance based on intake prediction be sufficient to provide dairy herd replacements prepared for maximal lifetime performance.

Bibliography

1. Abrams, S. M., J. S. Shenk, and M. O. Westerhaus. 1983. Capability of near infrared reflectance spectroscopy (NIR) to determine silage quality. J. Dairy Sci., 66 (Suppl. 1):183.

2. Appleman, R. D. 1978. Replacement economics. Page 512 In: Large Dairy Herd Management. H. H. Van Horn, and C. J. Wilcox, ed. University Press of Florida, Gainsville.

3. Aseltine, M. S. 1987. Neutral detergent fiber for formulating dairy rations appears to have merits. Feedstuffs. May 25.

4. Baumgardt, B. R., L. F. Krabill, J. L. Gobble, and P. J. Wangness. 1976. Estimating feed intake for cattle, sheep, and swine. Page 464 In : Proc. First Inter. Symp. Feed Comp., Anim. Nutr. Req., and Comp. of Diets. P. V. Fonesbeck, L. E. Harris, and L. C. Kearl, ed. Utah Agr. Exp. Sta., Utah State Univ., Logan.

5. Baumgardt, B. R. 1970. Control of feed intake in the regulation of energy balance. Page 234 In: Physiology of Digestion and Metabolism in the Ruminant. A. T. Phillipson, ed. Oriel Press, Newcastle, England.

6. Bagg, J. G., D. G. Grieve, J. H. Burton, and J. B. Stone. 1985. Effect of protein on growth of Holstein heifer calves from 2 to 10 months. J. Dairy Sci. 68:2929.

7. Balch, C. C., and R. C. Campling. 1962. Regulation of voluntary food intake in ruminants. Nutrition Abstrs., Revs. 32:669.

8. Baile, C. A., and M. A. Della-Fera. 1981. Nature of hunger and satiety control systems in ruminants. J. Dairy Sci. 64:1140.

9. Baile, C. A., and M. J. Forbes. 1974. Control of feed intake and regulation of energy balance in ruminants. Physiol. Rev. 54:160.

10. Baile, C. A., F. H. Martin, C. W. Simpson, J. M. Forbes, and J. S. Beyea. 1974. Feeding elicited by α and β adrenoceptor agonists injected intrahypothalamically in sheep. J. Dairy Sci. 57:68.

11. Baile, C. A., and C. L. McLaughlin. 1970. Feed intake of goats during volatile fatty acid injections into four gastric areas. J. Dairy Sci. 53:1058.

12. Baumgardt, B. R. 1970. Control of feed intake in the regulation of energy balance. Page 235. In: Physiology of Digestion and Metabolism in the Ruminant. A. T. Phillipson, ed. Oriel Press, Newcastle, England.

13. Baumgardt, B. R., L. F. Krabill, J. L. Gobble, and P. J. Wangness. 1976. Estimating feed intake for cattle, sheep, and swine. Page 464 In: Proc. First Inter. Symp. Feed Comp., Anim. Nutr. Req., and Comp. of Diets. P. V. Fonesbeck, L. E. Harris, and L. C. Kearl, ed. Utah Agr. Exp. Sta., Utah State Univ. Logan.

14. Bevenue, A., and K. T. Williams. 1959. Note on the use of detergents for removal of nitrogen from plant materials. J.A.O.A.C. 42:441.

15. Blaxter, K. L. 1957. The effects of defective nutrition during pregnancy in farm livestock. Proc. Nutr. Soc. 16:52.

16. Brent, B. E., D. Richardson, W. S. Tsien, and C. S. Menzies. 1961. Digestibility studies on levels of concentrates in complete pelleted rations for fattening lambs. J. Anim. Sci. 20:526.

17. Briceno, J. V., H. H. Van Horn, B. Harris, Jr., and C. J. Wilcox. 1987. Effects of neutral detergent fiber and roughage source on dry matter intake and milk yield and composition of dairy cows. J. Dairy Sci. 70:298.

18. Brown, C. A., P. T. Chandler, and J. B. Holter. 1977. Development of predictive equations for milk yield and dry matter intake in lactating cows. J. Dairy Sci. 60:1739.

19. Brown, C. A., C. C. Stallings, and S. W. Telega. 1981. Nutritional modeling and its impact on managerial goals in dairy production. J. Dairy Sci. 64:2083.

20. Brown, L. D., and C. A. Lassiter. 1962. Protein-energy ratios for dairy calves. J. Dairy Sci. 45:1353.

21. Browne, C. A., 1940. The origin and application of the term nitrogen-free extract in the valuation of feeding stuffs. J.A.O.A.C. 23:102.

22. Bryant, M. P. 1973. Nutritional requirements of the predominant rumen cellulolytic bacteria. Fed. Proc. 32:1809.

23. Buchman, D. T., and R. W. Hemken. 1964. Ad libitum intake and digestibility of several alfalfa hays by cattle and sheep. J. Dairy Sci. 47:861.

24. Burdick, D., and J. T. Sullivan. 1963. Ease of hydrolysis of the hemicelluloses of forage plants in relation to digestibility. J. Anim. Sci. 22:444.

25. Campling, R. C. 1970. Physical regulation of voluntary intake. Page 226 In: Physiology of Digestion and Metabolism in the Ruminant. A. T. Phillipson, ed. Oriel Press, Newcastle, England.

26. Campling, R. C., and C. C. Balch. 1961. Factors affect ing the voluntary intake of food by cows. I. Preliminary observations on the effect, of the voluntary intake of hay, of changes in the amount of the reticulo-ruminal contents. Brit. J. Nutr. 15:523.

27. Campling, R. C., M. Freer, and C. C. Balch. 1961. Factors affecting voluntary intake of food by cows. II. The relationship between voluntary intake of roughages, the amount of digesta in the reticulo-rumen and the rate of disappearance of digesta. Br. J. Nutr. 15:531.

28. Chandler, P. T., and H. W. Walker. 1972. Generation of nutrient specifications for dairy cattle for computerized least cost ration formulation. J. Dairy Sci. 55:1741.

29. Chase, L. E., P. J. Wangsness, J. F. Kavanough, L. E. Griel, and J. H. Gahagan. 1977. Changes in portal blood metabolites and insulin with feeding steers twice daily. J. Dairy Sci. 60:403.

30. Church, D. C., and W. G. Pond. 1982. Basic Animal Nutrition and Feeding. John Wiley and Sons, Inc. New York.

31. Clapp, H. J. 1982. Growth management of dairy heifers. Ministry of Agric. and Food Factsheet. 82-056. Ontario.

32. Clark, D. H., 1985. Near infrared reflectance spectro scopy (NIRS: Analysis of forage quality). USDA Agric. Handbook 643. USDA Washington D.C.

33. Conrad, H. R., J. W. Hibbs, and A. D. Pratt. 1966. Regulation of feed intake in dairy cows. 2. Association between digestible dry matter intake and cellulose digestibility in cows fed increasing levels of grain concentrate. J. Dairy Sci. 49:1038.

34. Conrad, H. R., A. D. Pratt, and J. W. Hibbs. 1964. Regulation of feed intake in dairy cows. 1. Change in importance of physical and physiological factors with increasing digestibility. J. Dairy Sci. 47:54.

35. Coppock, C. E., C. H. Noller, B. W. Crowl, C. D. McLellon, and C. L. Rhykerd. 1972. Effect of group versus individual feeding of complete rations on feed intake of lactating cows. J. Dairy Sci. 55:325.

36. Crampton, E. W., and L. A. Maynard. 1938. The relation of cellulose and lignin content to the nutritive value of animal feeds. J. Nutr. 15:383.

37. Curran, M. K., R. H. Wimble, and W. Holmes. 1970. Prediction of voluntary intake of food by dairy cows. 1. Stall-fed cows in late pregnancy and early lactation. Anim. Prod. 12:195.

38. Dehority, B. A. 1973. Hemicellulose degradation by rumen bacteria. Fed. Proc. 32:1819.

39. Donefer, E., L. E. Lloyd, and E. W. Crampton. 1963. Effect of varying alfalfa: barley ratios on energy intake and volatile fatty acid production by sheep. J. Anim. Sci. 22:425.

40. Eckman, D. D., J. S. Shenk, P. J. Wangsness, and M. O. Westerhaus. 1983. Prediction of sheep responses by near infrared reflectance spectroscopy. J. Dairy Sci. 66:1983.

41. Etgen, W. M., R. E. James, and P. M. Reaves. 1987. Dairy Cattle Feeding and management. 7th ed. John Wiley and Sons, Inc. New York.

42. Foldager, J., and K. Sejrsen. 1987. Mammary gland development and milk production in dairy cows in relation to feeding and hormone manipulation during rearing. Cattle Prod. Res. Danish Status and Perspectives. pp 102-116.

43. Freer, M., and R. C. Campling. 1963. Factors affecting the voluntary intake of food by cows. Brit. J. Nutr. 17:79.

44. Forbes, J. M. 1986. Dietary factors affecting intake. In. The voluntary food intake of farm animals. Butterworth and Co. Ltd, London.

45. Foster, J. F., J. T. Yang, and N. H. Yui. 1950. Extraction and electophoretic analysis of the proteins of corn. Cereal Chemistry. 27:477.

46. Gardner, R. W. 1968. Digestible protein requirements of calves fed high energy rations ad libitum. J. Dairy Sci. 51:888.

47. Gardner, R. W., J. D. Schuh, and L. G. Vargus. 1977. Accelerated growth and early breeding of Holstein heifers. J. Dairy Sci. 60:1941.

48. Gill, G. S., and F. R. Allaire. 1976. Relationship of age at first calving, days open, days dry, and herdlife to a profit function for dairy cattle. J. Dairy Sci. 59:1131.

49. Goering, H. K., and P. J. Van Soest. 1970. Forage fiber analysis (apparatus, reagents, procedures, and some applications). USDA Agric. Handbook 379. USDA Washington D.C.

50. Gordon, C. H., J. C. Derbyshire, H. G. Wiseman, E. A. Kane, and C. G. Melin. 1961. Preservation and feeding value of alfalfa stored as hay, haylage, and direct-cut silage. J. Dairy Sci. 44:1299.

51. Heinrichs, A. J., and G. L. Hargrove. 1987. Standards of weight and height for Holstein heifers. J. Dairy Sci. 70:653.

52. Hillman, D., C. A. Lassiter, C. F. Huffman, and C. W. Duncan. 1958. Effects of all-hay vs. all-silage rations on dry matter intake of lactating dairy cows; moisture and pH as factors affecting appetite. J. Dairy Sci. 41:720.

53. Huber, J. T., and L. Kung Jr. 1981. Protein and nonpro tein nitrogen utilization in dairy cattle. J. Dairy Sci. 64:1170.

54. Jahn, E., and P. T. Chandler. 1976. Performance and nutrient requirements of calves fed varying percentages of protein and fiber. J. Anim. Sci. 42:724.

55. James, R. E. 1984. Feeding heifers from birth to calving. Proc. Feed and nutritional cow college. V.P.I & S.U., Blacksburg.

56. Johnson, D. 1986. Proper growth, management important in raising of heifers. Feedstuffs. 58 (6):14.

57. Johnson, W. L., G. W. Trimberger, M. J. Wright, L. D. Van Vleck, and C. R. Henderson. 1966. Voluntary intake of forage by Holstein cows as influenced by lactation, gestation, body weight, and feeding frequency. J. Dairy Sci. 49:856.

58. Jones, D. I. H., and G. Griffith. 1962. Normal-acid fiber method for evaluating roughages. Nature. 193:882.

59. Jones, G. M., N. S. Wade, J. P. Baker, and E. M. Ranck. 1987. Use of near infrared reflectance spectroscopy in forage testing. J. Dairy Sci. 70:1086.

60. Jones, G. M. 1972. Chemical factors and their relation to feed intake regulation in ruminants: A Review. Can. J. Anim. Sci. 52:207.

61. Kertz, A. F., L. R. Prewitt, and J. M. Ballam. 1987. Increased weight gain and effects on growth parameters of Holstein heifer calves from 3 to 12 months of age. J. Dairy Sci. 70:1612.

62. Lahr, D. A., D. E. Otterby, D. G. Johnson, J. G. Linn, and R. G. Lundquist. 1983. Effects of moisture content of complete diets on feed intake and milk production by cows. J. Dairy Sci. 66:1891.

63. Leatherwood, J. M. 1973. Cellulose degradation by Ruminococcus. Fed. Proc. 32:1814.

64. Lentner, M., and T. A. Bishop. 1986. Experimental design and analysis. Valley Book Co., Blacksburg, Va.

65. Lush, J. L. 1972. Genetic statistics in animal breeding. Report by A. E. Freeman in: Proc. of the Anim. Breeding and Genetics Symp. Blacksburg, Va.

66. Martin, H. F., and C. A. Baile. 1972. Feed intake of goats and sheep following acetate or propionate injections into rumen, ruminal pouches, and abomasum as affected by local anesthetics. J. Dairy Sci. 55:606.

67. Mertens, D. R. 1980. Fiber content and nutrient density in dairy rations. Dist. Feed Res. Conf. 35:35.

68. Mertens, D. R. 1983. Using neutral detergent fiver to formulate dairy rations and estimate the net energy content of forages. Page 62 in Proc. Cornell Nutr. Conf.

69. Mertens, D. R. 1985. Factors influencing feed intake in lactating cows: from theory to application using neutral detergent fiber. Proc. Georgia Nutr. Conf., Athens.

70. Mertens, D. R., and L. O. Ely., 1979. A dynamic model of fiber digestion and passage in the ruminant for evaluat ing forage quality. J. Anim. Sci. 49:1085.

71. Miller, W. J., and H. E. Amos. 1986. Feeding dairy heifers in the current economic climate. Feedstuffs. Vol. 58 No.43:28.

72. Montgomery, M. J., and B. R. Baumgardt. 1965. Regulation of food intake in ruminants. 2. Rations varying in energy concentration and physical form. J. Dairy Sci. 48:1623.

73. Murley, W. R. 1980. Feeding guidelines for dairy replacements. Dairy guidelines. Series 102. VPI & SU Coop. Ext. Serv., Blacksburg.

74. National Research Council. 1978. Nutrient Requirements of Dairy Cattle. 5th ed. National Academy of Sciences, Washington D.C.

75. National Research Council. 1981. Effect of Environment on Nutrient Requirements of Domestic Animals. National Academy of Sciences, Washington, D.C.

76. National Research Council. 1985. Ruminant Nitrogen Usage. National Academy of Sciences, Washington, D.C.

77. National Research Council. 1988. Nutrient Requirements of Dairy Cattle. 6th ed. Unpublished.

78. Norman, H. D., P. D. Miller, B. T. McDaniel, F. N. Dickinson, and C. R. Henderson. 1974. USDA-DHIA factors for standardizing 305-day lactation records for age and month of calving. USDA-ARS-NE-40.

79. Norris, K. H., R. F. Barnes, J. E. Moore, and J. S. Shenk. 1976. Predicting forage quality by infrared reflectance spectroscopy. J. Anim. Sci. 43:889.

80. Norris, K. H., 1985. Near infrared reflectance spectro scopy (NIRS: Analysis of forage quality). USDA Agric. Handbook 643. USDA Washington D.C.

81. Okamoto, M., D. R. Waldo, R. W. Miller, and L. A. Moore. 1964. Histamine levels in forages and dry matter intake of heifers. J. Dairy Sci. 47:1231.

82. Park, C. S., G. M. Erickson, Y. J. Choi, and G. D. Marx. 1987. Effect of compensatory growth on regulation of growth and lactation: response of dairy heifers to a stair-step growth pattern. J. Anim. Sci. 64:1751.

83. Quigley, J. D. 1985. Development of equations to predict dry matter intake of dairy heifers. Ph.D. Dissert. VPI & SU, Blacksburg.

84. Quigley, J. D., R. E. James, and M. L. McGilliard. 1986. Dry matter intake in dairy heifers. 1. Factors affecting intake of heifers under intensive management. J. Dairy Sci. 69:2855.

85. Quigley, J. D., R. E. James, and M. L. McGilliard. 1986. Dry matter intake in dairy heifers. 2. Equations to predict intake of heifers under intensive management. J. Dairy Sci. 69:2863.

86. Rakes, A. H. 1978. Heifer feeding system. Page 483. In: Large Dairy Herd Management. H. H. Van Horn, and C. J. Wilcox, ed. University press of Florida, Gainsville.

87. Raymond, W. F., E. C. Jones, and E. C. Hains. 1955. Use of alkaline solutions in analysis of feedstuffs. Agr. Progress. 30:120.

88. Robertson, J. B. and P. J. Van Soest. Fiber content of forages. 1981. In: The Analysis of Dietary Fiber. W. P. T. James and O. Theander, eds. Marcell Dekker, New York.

89. Roffler, R. E., R. P. Niedermeier, and B. R. Baumgardt. 1967. Evaluation of alfalfa-brome forage stored as wilted silage, low-moisture silage, and hay. J. Dairy Sci. 50:1805.

90. SAS Institute, Inc. 1985. SAS User's Guide. Statistical Analysis System Institute, Inc. Cary, N.C.

91. Schultz, L. H. 1969. Relationship of rearing rate of dairy heifers to mature performance. J. Dairy Sci. 52:1321.

92. Sejrsen, K., J. T. Huber, H. A. Tucker, and R. M. Akers. 1982. Influence of nutrition on mammary development in pre- and postpubertal heifers. J. Dairy Sci. 65:793.

93. Shaver, R. D., R. A. Erdman, A. M. O'Conner, and J. H. Vandersall. 1985. Effects of silage pH on voluntary intake of corn silage and alfalfa haylage. J. Dairy Sci. 68:338.

94. Shenk, J. S., M. O. Westerhaus, and M. R. Hoover. 1979. Analysis of forages by infrared reflectance. J. Dairy Sci. 62:807.

95. Simpkins, K. L., Jr., J. W. Suttie, and B. R. Baumgardt. 1965. Regulation of food intake in ruminants. 4. Effect of acetate, propionate, butyrate, and glucose on voluntary food intake in dairy cattle. J. Dairy Sci. 48:1629.

96. Stallings, C. C., G. Kroll, J. C. Kelley, and M. L. McGilliard. 1985. A computer ration evaluation program for heifers, dry cows, and lactating cows. J. Dairy Sci. 68:1015.

97. Stone, J. B., G. W. Trimberger, C. R. Henderson, J. T. Reid, K. L. Turk, and J. K. Loosli. 1960. Forage inake and efficiency of feed utilization in dairy cattle. J. Dairy Sci. 43:1275.

98. Sullivan, J. T. 1966. Studies of the hemicelluloses of forage plants. J. Anim. Sci. 25:83.

99. Swanson, E. W. 1960. Effect of rapid growth with fattening of dairy heifers on their lactational ability. J. Dairy Sci. 43:377.

100. Swanson, E. W. 1967. Optimum growth patterns for dairy cattle. J. Dairy Sci. 50:244.

101. Swanson, E. W. 1978. Heifer performance standards: relation of rearing systems to lactation. Page 494. In: Large Dairy Herd Management. H. H. Van Horn, and C. J. Wilcox, ed. University press of Florida, Clearwater.

102. Swanson, E. W., and S. A. Hinton. 1964. Effect of seriously restricted growth upon lactation. J. Dairy Sci. 47:267.

103. Thomas, J. W., L. A. Moore, M. Okamoto, and J. F. Sykes. 1961. A study of factors affecting rate of intake of heifers fed silage. J. Dairy Sci. 44:1471.

104. Thomas, P. C., N. C. Kelly, and D. G. Chamberlain. 1980. Silage. Proc. Nutr. Soc. 39:257.

105. Tucker, H. A. 1987. Quantitative estimates of mammary growth during various physiological states: A review. J. Dairy Sci. 70:1958.

106. Van Soest, P. J., 1963. Use of detergents in the analysis of fibrous feeds. I. Preparation of fiber residues of low nitrogen content. J.A.O.A.C. 46:825.

107. Van Soest, P. J., 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. J.A.O.A.C., 46:829.

108. Van Soest, P. J. 1965. Symposium on factors influencing the voluntary intake of herbage by ruminants: voluntary intake in relation to chemical composition and digestibility. J. Anim. Sci. 24:834.

109. Van Soest, P. J. 1966. Nonnutritive residues: A system of analysis for the replacement of crude fiber. J.A.O.A.C. 49:546.

110. Van Soest, P. J. 1973. The uniformity and nutritive availability of cellulose. Fed. Proc. 32:1804.

111. Van Soest, P. J. 1977. Plant fiber and its role in herbivore nutrition. Cornell Vet. 67:307.

112. Van Soest, P. J., 1982. Nutritional Ecology of the Ruminant. O & B Books, Inc. Corvallis, OR.

113. Van Soest, P. J., 1987. Fiber components and the nutritive value of feedstuffs. Proc. of 38th European Assoc. Anim. Prod. Lisbon, Portugal. Sept. 27.

114. Varga, G. A.,and W. H. Hoover. 1983. Rate and extent of neutral detergent fiber degradation of feedstuffs in situ. J. Dairy Sci. 66:2109.

115. Varga, G. A., E. M. Meisterling, R. A. Daily, and W. H. Hoover. 1984. Effect of low and high fill diets on dry matter intake, milk production, and reproductive performance during early lactation. J. Dairy Sci. 67:1240.

116. Waldo, D. R., R. W. Miller, M. Okamoto, and L. A. Moore. 1965. Ruminant utilization of silage in relation to hay, pellets, and hay plus grain. II. Rumen content, dry matter passage, and water intake. J. Dairy Sci., 48:1473.

117. Wedig, C. L., E. H. Jaster, and K. J. Moore. 1986. Composition and digestibility of alfalfa and orchardgrass hemicellulose monosaccharides by Holstein steers. J. Dairy Sci. 69:1309.

118. Wilkinson, J. M., J. T. Huber, and H. E. Henderson. 1976. Acidity and proteolysis as factors affecting the nutritive value of corn silage. J. Dairy Sci. 42:208.

119. Williams, K. T., and A. Bevenue. 1956. Problems and techniques in the analysis of plant material for hemicellulose. J.A.O.A.C. 39:901.

120. Woodford, J. A., N. A. Jorgensen, and G. P. Barrington. 1986. Impact of dietary fiber and physical form on performance of lactating dairy cows. J. Dairy Sci. 69:1035.

121. Woods, W., and R. W. Rhodes. 1962. Effect of varying roughage to concentrate ratios on the utilization by lambs of rations differing in physical form. J. Anim. Sci. 21:479.

122. Yungblut, D. H., J. B. Stone, B. K. Macleod, D. G. Grieve, and E. B. Burnside. 1979. Development of feed intake prediction equations for Holsteins. J. Dairy Sci. 62:162. (Abstr.)

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