INFLUENCE OF FEED INTAKE ON SITE AND EXTENT OF DIGESTION

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Performance of ruminant animals is dependent on intake of nutrients above maintenance. Efficiency of energy use increases progressively with energy intake. Though higher levels of low cost roughages can be used to grow cattle prior to finishing, less than maximum gains of feedlot cattle are financially hazardous due to interest rates and yardage costs. Factors regulating feed intake have been examined in a number of studies as reviewed by Baumgardt (1970), Baile (1975) and Campling (1970). This paper includes discussion of (1) feed intake prediction equations plus (2) influence of level of intake on site and extent of digestion.

Feed Intake of Feedlot Cattle

When digestibility of a typical diet falls below 60 percent for growing cattle or 65 percent for lactating cows, energy intake is reduced. This reduction is proportional to the bulk density of the diet. This limitation appears related to capacity for and clearance of fibrous material from the rumen. Certain roughages, such as cottonseed hulls and pelleted forages, require little chewing or digestion to exit from the rumen. These roughages are consumed in greater amounts than coarser, less dense roughages. That the bulk limitation is not at a site past the rumen has been demonstrated in a clever study by Grovum (1979). Besides density or fill limitations, lack of palatability, nutritional deficiencies for ruminal microbes or the animal and metabolic disorders have been shown to reduce feed intake.

Factors Influencing Feed Intake

Energy density, weight at the start of a feeding trial, current weight, frame size, feed additives and implants may influence feed intake of feedlot cattle. These factors are considered to different degrees in the equations developed by different workers and from the present summary. Equations are compiled in Table 1. Graphic comparison is provided in Figure 1. Influence of these factors will be discussed individually.

Table 1. Daily feed intake equations
(Intakes and animal weights are in pounds)

ARC (1980) $DMI = (.1423 - .0129 \times ME_{mcal/kg})Wt^{.75}$

Fox (1977) $DMI = 1.22 \times KM\ Wt^{.75}$

Where K = .10 for cattle <800 lb
= .095 for cattle 800-1060 lb
= .090 for cattle >1060 lb
and M = 1.0 for calves
= 1.1 for yearlings
= 1.17 for Holstein
= 1.09 for Holstein cross
= 1.00 for other breeds
= .91 with monensin
and Wt = equivalent weight

Garrett (1973) $DMI = 4.67 + .0144\ Wt + .077 \times \%\ roughage;$

Gill (1979) $DMI = K\left(\frac{Wt}{2.2}\right)^{.75} - \left(\frac{Wt-500}{200}\right)^{2} \quad \times \quad .90;$

Where $K = .18 + .007$ feeder grade $+ .0001$ initial weight.

Goodrich (1982) $DMI = 3.39 + .1249\ Wt^{.75} - 1.571 \times ME_{mcal/kg}.$

This summary $DMI = .0636\ Wt - .0000325\ Wt^{2} - 11.21 + .0039\ (In.\ Wt - 610);$

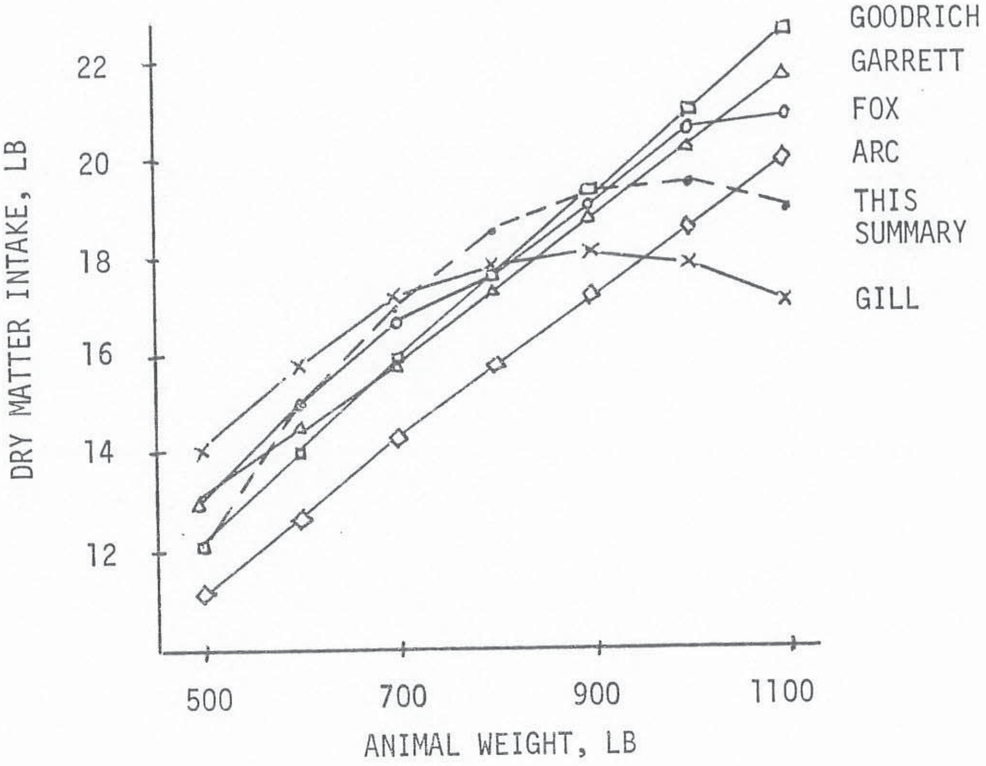

Figure 1. Feedlot intake equations.

The influence of concentration of energy on feed intake of feedlot diets has received limited research attention. Diets containing from 3.0 to 3.6 kcal metabolizable energy (ME) per kg of dry matter were fed to finishing steers for 121 days in a trial at Oklahoma State (Gill et al., 1981). The relationship of intake of feed to ME concentration in the diet from that study is presented in Figure 2. For each 10 percent increase in ME, feed intake declined by 8.8 percent leaving ME intake relatively constant across these energy levels. This compares with equations of the ARC (1980) and Goodrich (1981) which estimate decreases of 4.4 and 3 percent for each 10 percent increase in ME. Baumgardt (1970) has indicated that ME intake is relatively constant for diets containing more than 2.5 kcal ME per kg.

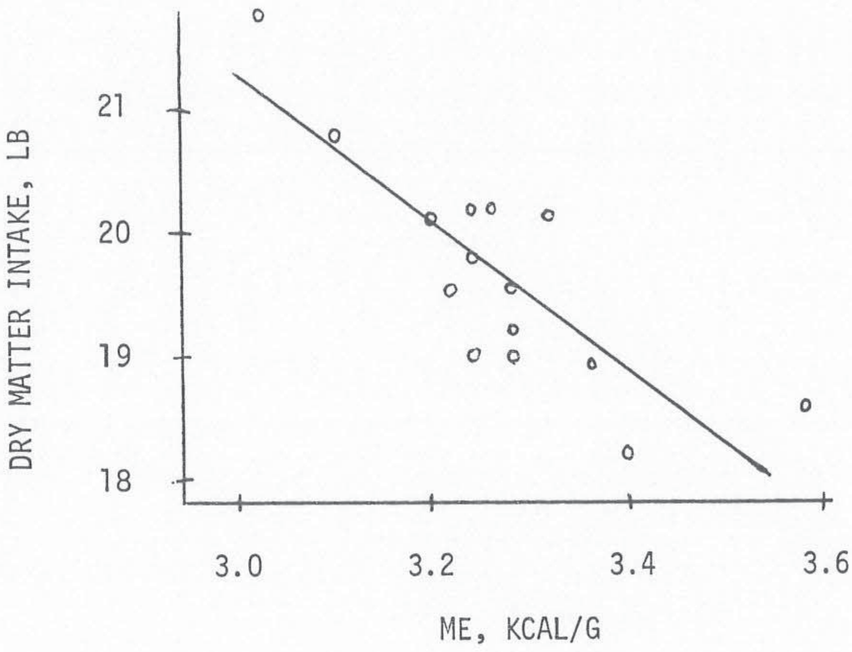

Figure 2. Energy concentration and feed intake of feedlot steers.

Monensin addition to various diets at 30 g per ton of feed decreased feed intake by 10.7 percent according to the summary of trials reported by Elanco (1975). A summary of 6 trials with feedlot rations from Oklahoma (Witt et al., 1980) indicate that intake was reduced throughout the feeding period (Figure 3) by a mean of 5.2 percent. This compares with a reduction of 9 percent proposed in the feed intake equation of Fox and Black (1977). Other ionophores may depress feed intake less than monensin (Owens and Gill, 1982) though more comparisons are needed.

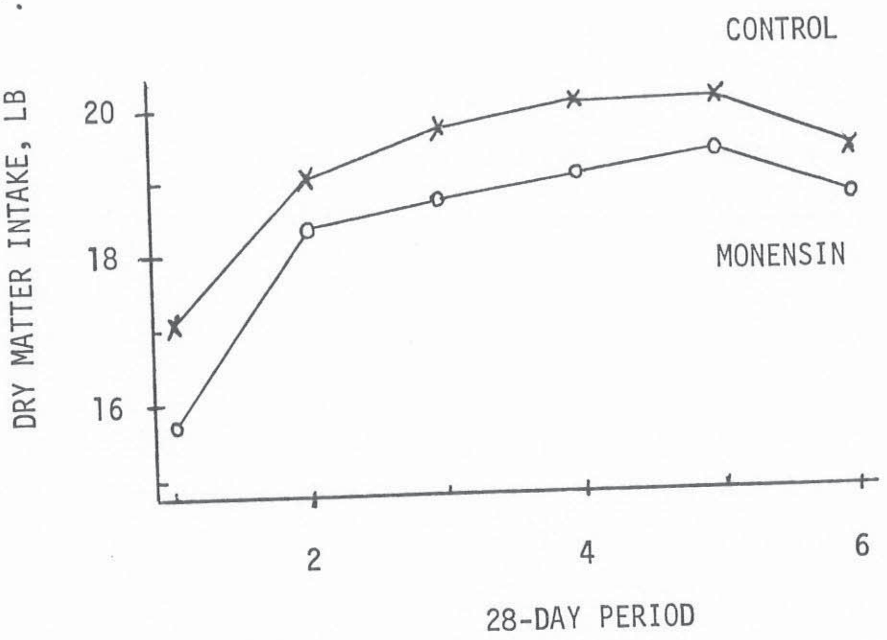

Figure 3. Influence of monensin on feed intake.

Growth stimulating implants usually increase feed intake by feedlot cattle by 3 to 10 percent. Feed intake response is transitory and is most apparent during the first two months after implants are administered (Owens and Gill, 1981; Wagner et al., 1976). Fox and Black (1977) included no adjustment for growth stimulants in their intake equation.

Bulls consume about 2 percent more feed than steers of similar weight in most trials. The influence of frame size and breed of cattle on feed intake is debated. The British summary (ARC, 1980) suggests little if any effect of breed type on feed intake. The equation of Fox and Black (1977) indicates that Holstein cattle eat 17 percent more feed than cattle of typical beef breeding and Garrett (1971) indicated 2 to 10 percent greater intake per unit of body weight for Holstein than Hereford steers. Increased intake at some sacrifice in efficiency may be the result of generations of selection. Genetic selection for intake may yield similar results with beef breeds. Steers of exotic breeding consume feed in amounts equal to steers of common beef breeds. The "equivalent weight" adjustment of Fox and Black (1977) projects intake to be 6 to 13 percent greater for large than medium frame size cattle. The adjustment for frame size by Gill (1979) has a similar effect. Initial weight and frame size of steers are usually correlated. Initial weight also is considered in the equation of Gill (1979). Backgrounding and previous diet appear to influence feed intake patterns as well. Habits established and conditioning during early parts of a feeding trial set the intake profile for an entire feeding period. Some compensatory growth will occur following a period of deprivation, but responses are more in gain and feed efficiency than in feed intake.

Since metabolizable energy intake is reasonably constant for growing feedlot cattle fed high concentrate rations, chemostatic systems appear to be active. Which chemicals, nutrients and intestinal or central nervous system hormones may be involved is being examined by several research groups. Though meal size and meal frequency can be easily monitored following administration of drugs or compounds, application of findings to practical conditions must consider intake regulation over a longer term than just a few days.

Feed Intake and Feed Formulation

Most diets formulated for livestock are calculated using nutrient requirements expressed on a percentage basis. Although requirements for most nutrients have been determined on a gram per day basis, they are usually converted to a percentage of ration basis for use. Feed intake must be estimated for this conversion. Nutrient requirement tables often are criticized for inaccuracy due to errors in percentage values. Discrepancies in the percentage figure, not on a gram per day basis, are primary concerns. Some of these problems are precipitated by differences between expected and observed feed intakes. As intake increases, dietary concentrations of most nutrients can decrease and the diet will still meet daily needs for nutrients.

Feed intake level also can alter requirements for some nutrients. For example, replacement of the inevitable loss of nitrogen in feces is the primary force driving protein requirements for ruminant animals under most conditions. As feed intake increases, metabolic loss of nitrogen increases and the requirement for protein, when expressed on a gram per day basis, increases. Expressed on a diet concentration basis, however, the requirement decreases as feed intake increases.

Though rate of growth and energy intake are closely related, cause and effect are not established. Depending on which is assumed to be the cause, equations for estimating feed intake for feedlot cattle have developed differently. Most workers monitor intake of cattle at various weights and determine which equation fits the data best. Alternatively, one can assume that rate of deposition of energy or other nutrients follow mathematical equations as have been developed by Brody (1945). Feed intake is then driven by animal performance. This concept is supported by the fact that factors which increase energy availability, such as monensin feeding and grain processing, maintain animal rate of gain and energy intake but reduce intake. But differences in energy intake with certain diets do not match that concept completely. Levels of intake inhibitors, such as acid or soluble N as well as levels of specific metabolites like propionate or intestinal protein may be responsible. If the signals for metabolic control of intake can be isolated and altered, animal performance should be increased tremendously.

Summary of OSU Trials.

For testing the intake equations presented in Table 1, we measured dry matter intake with pens of 7 to 25 cattle at intervals of one to two months during 15 feeding trials lasting 96 to 196 days with about 1500 cattle. Weights and intakes of the cattle were recorded at intervals of 28 to 56 days. Cattle were of medium or large frame size and were fed diets containing less than 16 percent roughage with corn or milo grain in the dry or high moisture form. In five of these trials, steers were subdivided by initial weight into replicate groups of at least 32 head. Other means are from 140 to 336 steers. Intakes for sets of cattle are plotted against shrunk weights in Figure 4 with lines connecting cattle within a single trial.

Feed intake equations from the literature (Table 1) all have considered intake to be proportional to animal weight or animal weight taken to the three-fourths power (metabolic size). Adjustment factors in the Fox and Black (1977) and Gill (1979) equations suggest that intake will decline to some degree at higher weights. Regression of feed intake on shrunk weight for the 120 data points from our feeding studies revealed that intake was related to weight to the $.47 \pm .048$ power. This value is far from both the .75 and the 1.0 power. Data points for feed intake within a trial all increase as weight increases for lighter cattle, but during the final stages of finishing and heavier cattle weights, intake plateaus or declines. In 13 of the 27 comparisons, feed intake declined. Continued increase is expected if intake is an exponential function of body weight. Dry matter intake peaked at weights of 900 to 1000 lb and declined above this point. This decline is probably a function of degree of finish and deposition of fat. Therefore it is less apparent when

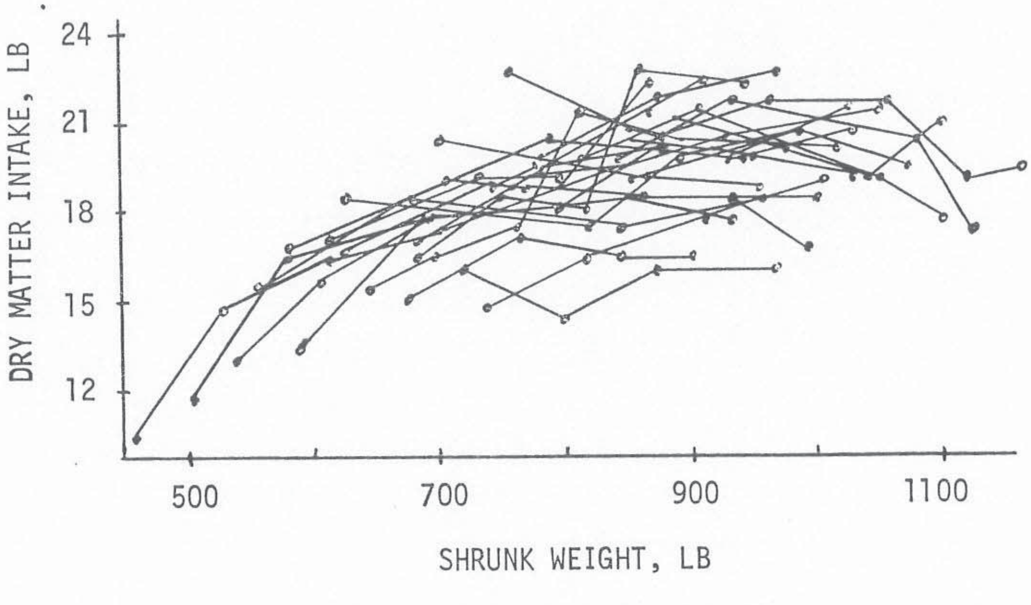

Figure 4. Interval feed intakes vs body weight of finishing cattle.

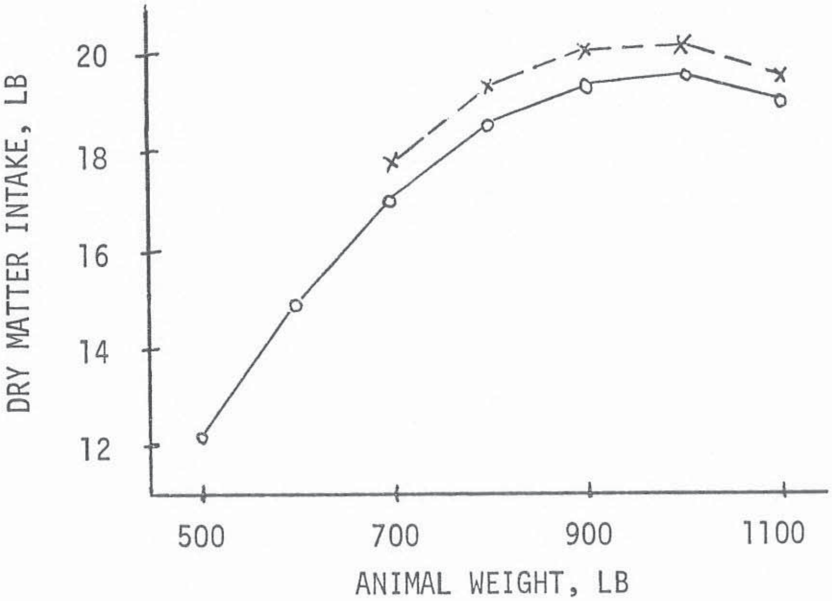

Figure 5. Initial weight vs feed intake.

cattle are slaughtered at lighter weights or when intake is averaged across entire feeding trials rather than calculated within periods in a feeding trial. Curves for higher roughage diets may peak at heavier weights. Other physiological explanations for the curve include 1) crowding of the intestinal tract by internal fat deposits and 2) the indication that gastrointestinal capacity peaks when animals are only 80 percent of mature weight. If these explanations were valid, energy density of rations for cattle of heavy weights would be important.

Other equations were explored to find one which would fit the data points more closely. We conducted multiple regression of intake on weight, weight squared and weight cubed. Data points were reasonably well represented by: Intake = .0636 Wt - .0000325 Wt_{kg}^2 - 11.21 (r^2 = .53). Two-thirds of the observed intakes fell within 8 percent of this regression line. Additional adjustments should be helpful.

Initial weight of feedlot cattle is considered in one intake equation. Regression of deviations from predicted intake on initial weight revealed a significant effect ($P<.01$) of starting weight on feed intake: Change = .0039 (initial weight - 610). An example of this effect is shown in Figure 5. Weather changes abruptly alter daily intake of feedlot cattle. Seasons also influence feed intake. Cold temperatures can increase intake of roughage rations by increasing rate of passage. Increased passage appears associated with decreased digestibility and increased heat production. Effects of climatic factors on intake are less defined for concentrate rations though increases with cold stress and decreases with mud have been reported.

Influence of Intake Level on Digestibility

As feed intake of finely ground forages and mixed rations by a ruminant animal increases, digestibility of energy declines as reviewed by Reid et al. (1980) and the ARC (1980). Metabolizable energy declines from 0.3 to 5 percent per multiple of maintenance increase in feed intake with hemicellulose and cellulose digestibility declining over 8 percent per multiple of maintenance. Wheeler (1975) found starch digestibility dropped from over 96 percent at maintenance level of intake to 85 percent with intake over 2.5 times maintenance. The committee for dairy cattle (NRC, 1978) applied a standard reduction of 4 percent for each multiple of maintenance increase in intake. The ARC (1980) concluded that the depression in metabolizable energy increases at an increasing rate with feed intake. They suggested the equation: Change in digestibility = .107 -.113 (digestibility at maintenance). A feed with 75 percent digestibility would decline to 72.8 percent or about 3 percent when fed at twice maintenance according to this equation. Tyrell and Moe (1975) indicated that the effect of intake on digestibility is greater with high concentrate than high forage rations.

We examined the influence of level of feed intake on digestibility of various nutrients by finishing steers fed rations containing 10 or 50 percent roughage (Rust and Owens, 1982). Whole shelled corn and a soybean meal supplement were fed with six different sources of roughage. Effect of level of intake at the two roughage levels, averaged across roughage sources, on digestibility of various nutrients is presented in Table 2.

Table 2. Influence of intake and roughage level on digestibility by feedlot steers.

		Digestibility, %			
Intake (times maint.)	Roughage level, %	Organic matter[ab]	Starch[a]	ADF[b]	Nitrogen[a]
1.2	10	78.4	90.3	37.3	68.6
1.9	10	73.6	83.2	35.9	61.3
1.2	50	71.3	92.3	49.8	66.0
1.9	50	68.1	85.7	48.2	60.5

[a] Depression by higher intake level (P<.01).

[b] Effect of roughage level on digestibility (P<.01).

For each multiple of maintenance, organic matter digestibility was reduced 8.7 and 6.2 percent for the 10 and 50 percent roughage levels, respectively. No interaction of intake level and roughage level when averaged across roughage sources was significant, however. Depression in organic matter digestion with increased feed intake was attributable primarily to starch and hemicellulose with little effect on ADF digestibility. This contrasts with the suggestion that reduced digestibility of fiber is largely responsible for the digestibility depression. In the depressions reported in several studies (Moe et al., 1973; Moe & Tyrrell 1977; 1979), cell contents were responsible for 28 to 95 percent of the depression in organic matter digestibility with intake. Certain roughage sources (alfalfa, sorghum silage) depressed starch digestion much more than others (cottonseed hulls, prairie hay) indicating that forage source as well as forage level influenced the degree of depression in our study. This confirms earlier suggestions by Teeter et al. (1981).

Although digestibility usually declines as feed intake increases, it appears that grain processing, forage source and forage level can all influence the degree of depression. Consequently, a standard reduction of 4 percent for each multiple of maintenance increase in intake as employed by the NRC for Dairy Cattle (1978) appears questionable. Digestibility depressions are automatically considered in net energy trials since high feed intakes are attained. When net energy values are calculated from digestible energy values, their validity seems less certain since depressions in digestibility with intake level may differ among feedstuffs.

Causes of reduced digestibility at higher intakes include (1) increased passage rate and reduced time for digestion (2) enzymatic insufficiencies and (3) an altered ruminal environment. Cell wall digestibility explains only a portion of the reduction in digestibility with increased feed intake. Yet cell wall composition and concentration may alter passage rate. Thereby cell walls may be related to the extent of digestibility depression. Adjustment factors based on cell wall composition have been proposed by Van Soest (1973).

Intake Level and Site of Digestion

Steers equipped with cannulas at the start and at the end of the small intestine have been used to examine limits to digestion in the rumen, small intestine and large intestine (Zinn and Owens, 1982). Feed intake of an 84 percent concentrate ration was varied from 1.2 to 2.1 percent of body weight in one experiment. Disappearance of nutrients from the rumen and small intestine at these levels of intake are presented in Table 3. As feed intake increased, digestion of organic matter in the rumen declined. However, percentage of starch digested in the rumen in this study actually increased with feed intake. Assuming that retention time for digestion in the rumen decreased as steers ate more feed, this means that time was not the factor limiting ruminal digestion of starch. This illustrates that an increase in feed intake does not increase bypass of all feed ingredients. Increased ruminal starch digestion may be due to increased mastication or rumination or to ruminal conditions more suitable for starch exposure and digestion.

Table 3. Ruminal and intestinal digestion at four intake levels.

	Feed intake, % of BW			
	1.2	1.5	1.8	2.1
Ruminal disappearance, %				
Organic matter[a]	59.0	53.5	49.9	48.8
Starch[a]	79.6	80.2	84.9	91.0
ADF[a]	32.5	26.4	11.7	0.0
Nitrogen fractions, intake g/d				
Total	61.8	83.6	100.4	117.4
Insoluble N	45.1	61.0	73.3	85.7
Abomasal flow				
Total, g/d[a]	57.8	82.1	119.0	141.5
Microbial N, g/d[a]	25.5	34.6	47.8	49.5
Bypass of feed N, %[a]	43.8	48.0	61.9	70.6
Intestinal digestion				
Nonammonia N, %[a]	65.9	64.1	71.4	76.6
Total tract N digestion, %	70.3	71.2	67.0	70.4

[a] Linear effect of feed intake ($P<.05$).

Ruminal fiber digestion dropped from 32 percent to 0 percent as intake increased. This is probably a result of reduced time for digestion plus a ruminal environment lower in pH and less favorable for fiber digestion. Such a change could precipitate bulk fill problems when cattle are being adapted to a high concentrate ration. Passage of nitrogen to the small intestine, both as microbial and bypassed feed nitrogen, increased dramatically with feed intake. Over 70 percent of the dietary protein (90 percent of the insoluble dietary N) escaped ruminal digestion at the high level of intake compared with only 44 percent at the low level of intake. How much of this difference is due to ruminal retention time or to reduced ruminal pH and fiber digestion is unknown. Intake level may have less effect on protein bypass with higher fiber diets since ruminal changes are probably less drastic. One might also expect nonlinear responses to feed intake since at lower intakes, fill of the tract may increase, but at higher intakes, no room remains for expansion.

Intestinal digestion of nonammonia nitrogen increased as bypass increased. This may be due to passage of a relatively constant amount of indigestible feed protein to the small intestine together with different amounts of the digestible fraction from the rumen. Previous studies with widely varying amounts of starch and protein entering the small intestine show no indication of decreased digestion of either starch or protein when higher amounts enter the small intestine. Indeed, net disappearance of both protein and starch in the small intestine have tended to increase as amount supplied to the small intestine has increased. The amount of fecal nitrogen and nitrogen digestibility at these levels of feed intake did not reflect the marked changes in nitrogen metabolism (bypass, recycling, microbial protein synthesis) occurring in this study. Total tract digestibility is a poor indicator of site of digestion since later segments of the tract may compensate for reduced digestion earlier in the tract.

Results indicate that feed intake level influences site of digestion markedly. This can explain why feed intake level can influence animal performance more than one would expect from measurement of digestibility. Further, digestibilities of nutrients in the rumen or the total tract determined at one level of intake or of forage cannot be extrapolated to other intake or forage levels until more information is available concerning factors influencing time for and rate of digestion at various sites.

Future Efforts

Chemical or hormonal factors which alter site and extent of digestion should have a major impact on efficiency of beef and milk production in the future. Various hormones from the gastro-intestinal tract and the brain may be used in the future to increase feed intake. Limits to and efficiencies of nutrient absorption at different sites in the tract need further study. Control and prediction of feed intake should prove economically relevant today and in the future.

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