SDSU Extension

BEEF

Chapter 14

Nutrient Requirements of Beef Cows

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Introduction

All cattle have basic nutrient requirements that are determined based on the age, weight, stage of production and environmental conditions. Multiple factors change these requirements, but a general understanding of how nutrients are used in the body and what influences the changes are key to basic ruminant nutrition.

Beef cows are given access to feeds that contain nutrients. Cattle have a requirement for nutrients, not specific feeds, therefore it is key to understand how nutrients are absorbed and utilized by the cattle in order to meet their nutrient requirements.

The five nutrients that are key to sustaining life are water, protein, energy, minerals, and vitamins. Within the body, these nutrients are used for various metabolic processes. The animal's requirements must be managed to ensure health, reproduction and optimal performance.

Rumen Physiology

Cattle are ruminant animals. That means they have a four-compartment stomach where fermentation takes place, allowing them to utilize fibrous feeds that cannot be digested by monogastric animals. The four compartments of the ruminant stomach are the reticulum, rumen, omasum and abomasum.

The digestion process begins with the tongue and teeth. The tongue is used by wrapping it around the forage and pulling to tear it. Cattle will chew the forage between the teeth on the bottom jaw and dental pad on top. The particle size of the feed is decreased between the lower molars and the dental pad. From this point, feed is swallowed and enters the reticulo-rumen (the reticulum and rumen combined) from the esophagus, where it is mixed with previously ingested feeds, saliva, and rumen fluid containing billions of microbes. The reticulo-rumen acts as a large fermentation vat which can hold approximately 55 gallons of feed and liquid rich in rumen microbes in a mature beef cow. These microbes consist of bacteria,

Key Points

- To reach optimal performance, nutrient requirements based on body weight, stage of production, and milk production must be met.
- Nutrient requirements are lowest during mid-gestation, increase in late gestation, are highest in early lactation and begin decreasing in late lactation.
- When feeding cows, the goal is to feed the rumen microbes first and cow second. A diet crude protein level of 7% or greater must be maintained to feed the microbes or forage digestion will decrease.

protozoa and fungi that work to break down complex dietary ingredients to produce end products that can be used by the host animal (cow) to meet its nutrient needs. End products of fermentation include volatile fatty acids (a source of energy), carbon dioxide, methane, ammonia, B-vitamins, and other compounds. In addition to fermentation end products, the host animal obtains most of its dietary protein from the digestion of the microbes growing in the rumen. Ruminants can utilize forage or fibrous feeds (unlike non-ruminants) because the microbes can break down cellulose and hemicellulose (components of the forage fiber) into volatile fatty acids. These volatile fatty acids are absorbed across the rumen wall and utilized by the cow. Microbial fermentation in the reticulo-rumen results in the production of large amounts of gases (primarily carbon dioxide and methane) which must be eliminated or bloat results.

The reticulo-rumen wall consists of a group of large muscles that contract and relax rhythmically to mix the rumen contents to assist microbial digestion of feedstuffs. The movements of the reticulo-rumen not only mix the feed, they also allow for the eructation of gases and regurgitation, commonly referred to as "chewing their cud" or rumination. Rumination is the process of ingesting feed rapidly and chewing it at a later time. This process decreases particle size to allow the rumen microbes to more efficiently break down the fibrous components in the diet. The process also adds additional saliva to the rumen (up to about 50 gallons per day) while expelling gasses. The saliva acts to buffer the rumen environment and maintain rumen pH, as saliva contains large quantities of bicarbonate (Hofmann, 1988). However, not all digestion and absorption occurs in the rumen. As the particle size decreases due to cud-chewing, ruminal fermentation and rumination, the smaller particles pass into the omasum which regulates the passage of particles from the rumen into the abomasum or true stomach. Small feed particles and bacteria pass through the omasum into the abomasum, but large feed particles are trapped in the omasum and flushed back into the rumen (via contraction) so they can be fermented and ruminated into smaller particles. The abomasum functions similar to the monogastric stomach (beginning of enzymatic digestion). Digesta from the abomasum passes into the small intestine where digestion is completed for the lipids (fat and oil), proteins, vitamins, many minerals and non-structural carbohydrates (starch and sugar) present in the diet. Nutrients are absorbed across the wall of the small intestine into the bloodstream and utilized by the animal for normal body function.

Factors That Affect Nutrient Requirements

Multiple factors can and do affect nutrient requirements. The factors that most commonly come to mind are body weight and stage of production of the female. Cow body weight is one of the most important factors, being the driver of dry matter intake. Nutrient requirements change with changes in body weight, and if the correct body weight is not used in determining nutrient requirements, cows can be under- or over-nourished, depending on whether body weight is over- or under-estimated (NRC, 2000). For example, a 1200 lb cow has lower nutrient requirements than a 1400 lb cow, merely due to size. Dry matter intake is also impacted by forage type and maturity. Table 1 shows the forage dry matter intake capacity of dry versus lactating cows consuming various qualities of forages. This table assumes that protein requirements are met in order for these forage intakes to be attained.

Other factors such as stage of production and milk production further contribute to changes in requirements. As a cow approaches calving and lactation, nutrient requirements increase to meet the increased demand for growth and production. To understand nutrient requirements, it is important to understand how nutrients are partitioned among different uses. All animals have a maintenance requirement, which is simply what is needed to maintain life without weight loss or gain. After maintenance, nutrients will then be used for reproduction and lactation. If nutrient requirements are not met, reproduction will suffer and lactation will decrease. In order to reach optimal performance, nutrient requirements need to be met based on the stage of production and pounds of milk production (see Tables 2-6). Abbreviations used in the tables are as follows: DM = Dry matter, TDN = Total digestible nutrients, NEm = Net energy for maintenance, CP = Crude protein, Ca = Calcium,

P = Phosphorus. Where the cow is in the annual production cycle will determine what her nutrient requirements are and how they will be changing in the future. Stage of production and peak milk production affect nutrient requirements in the cow due to increased nutrient demands with increased fetal development or lactation. The production cycle of the cow is broken down into four time frames with varying requirements. Nutrient requirements are lowest during mid gestation, increase in late gestation, reach their highest point in early lactation and begin decreasing in late lactation.

Mid-gestation is characterized as the time period from weaning until the beginning of the last trimester of gestation. During this time period nutrient requirements will be lowest since there is no longer a demand for nutrients for lactation and the fetus is very small, not having a large demand for nutrients yet. If cow body condition is a concern (see Chapter 4, Influence of Body Condition on Reproductive Performance of Beef Cows), this is typically the easiest and most economical time in the production cycle to put weight back on the cow because nutrient demands are low.

Late gestation encompasses the last 90 days of gestation. About 70% of fetal growth occurs during this period. This is the stage of second-lowest nutrient requirements. If cow body condition is still of concern after mid-gestation, this period is the second best opportunity to improve BCS before calving. Early lactation is from calving until the calf is 90 days old. This period of time requires the highest plane of nutrition due to the demand for nutrients going toward lactation. Peak lactation

Table 1: Forage capacity of beef cows. *Hibberd and Thrift, 1992*

Forage Type and Maturity	Stage of Production	Forage Dry Matter Intake Capacity, % of Body Weight
Low quality forage (<52% TDN), (e.g., dry winter forage, mature legume and/or grass hay, straw)	Dry	1.8
	Lactating	2.2
Average quality forage (52 - 59% TDN), (e.g., dry summer pasture, dry pasture during fall, late-bloom legume hay, boot stage and early bloom grass hay)	Dry	2.2
	Lactating	2.5
High quality forage (>59% TDN), (e.g., mid-bloom, early-bloom and pre-bloom legume hay, pre-boot stage grass hay)	Dry	2.5
	Lactating	2.7
Lush, growing pasture	Dry	2.5
	Lactating	2.7
Silages	Dry	2.5
	Lactating	2.7
Intake estimates assume that protein requirements are met. When protein requirements are not met, forage intake will be lower than the values shown in the table.		

Table 2: Estimating peak milk production in beef cows. *Adapted from NRC, 2000*

Mature Weight (lb)	Peak Milk Production (lb/day)				
	10	15	20	25	30
Expected weight of 7 month old male calf (lb)					
900	440	465	495	---	---
1000	460	485	515	545	570
1100	480	510	540	565	590
1200	500	530	560	585	615
1300	520	550	580	605	635
1400	540	570	600	625	655

Table 3: Nutrient requirements of beef cows. *Adapted from NRC, 2000*

Weight (lb)	Expected Calf Birth Weight (lb)	DM Intake		Diet Nutrient Density					Daily Nutrients per Animals				
		(lb/day)	% of BW	TDN (% DM)	NE_m (Mcal/lb)	CP (% DM)	Ca (% DM)	P (% DM)	TDN (lb)	NE_m (Mcal)	CP (lb)	Ca (lb)	P (lb)
Gestating cow, middle 1/3 of pregnancy													
1000	69	18	1.8	50	0.44	7.1	0.17	0.14	9	7.9	1.3	0.031	0.025
1200	80	21	1.7	50	0.44	7.1	0.18	0.15	10.3	9.1	1.5	0.037	0.03
1400	91	23	1.7	50	0.44	7.1	0.19	0.15	11.6	10.2	1.6	0.043	0.035
Gestating cow, last 1/3 of pregnancy													
1000	69	21	2.1	54	0.5	7.9	0.25	0.16	11.2	10.4	1.6	0.052	0.034
1200	80	24	2	54	0.5	7.9	0.25	0.17	12.9	12	1.9	0.061	0.04
1400	91	27	1.9	54	0.5	7.9	0.26	0.17	14.5	13.5	2.1	0.071	0.046
Lactating cow, first 90 days after calving													
1000	10	22.2	2.2	55.6	0.54	8.7	0.24	0.17	12.34	11.99	1.93	0.05	0.04
	20	24.8	2.5	59.7	0.6	10.7	0.31	0.2	14.81	14.88	2.65	0.08	0.05
	30	27.3	2.7	63.1	0.66	12.3	0.36	0.23	17.23	18.02	3.36	0.10	0.06
1200	10	25.1	2.1	55	0.53	8.5	0.24	0.17	13.81	13.30	2.13	0.06	0.04
	20	27.7	2.3	58.7	0.59	10.2	0.3	0.2	16.26	16.34	2.83	0.08	0.06
	30	30.2	2.5	61.9	0.64	11.7	0.35	0.22	18.69	19.33	3.53	0.11	0.07
1400	10	27.9	2	54.6	0.53	8.2	0.24	0.17	15.23	14.79	2.29	0.07	0.05
	20	30.4	2.2	58	0.58	9.9	0.29	0.19	17.63	17.63	3.01	0.09	0.06
	30	33	2.4	60.9	0.62	11.3	0.33	0.22	20.10	20.46	3.73	0.11	0.07

will be reached at 60 to 80 days post calving, with a slow decline in milk production following that time frame. It is key to remember that breeding will also need to take place, therefore a drop in body condition score and nutritional status is not advisable, as pregnancy rates could be negatively impacted during this stage of production.

Late lactation is the period from when the calf is 90 days old until weaning. The cow still has a significant demand for nutrients going toward lactation and a very small demand going toward the developing fetus.

The age of the cow also plays a significant role in determining nutrient requirements. In particular, nutrient requirements are greater in young cows than mature cows because they have not reached mature weight, and therefore they have nutrient requirements for growth that are in addition to the other requirements for mature cows. Remember that nutrient use is prioritized to maintenance first, growth second, lactation third, and finally reproduction. Thus, if all of these requirements are not fulfilled, reproduction will be the first to suffer. This is why first-calf heifers have difficulty rebreeding; their nutrient supply is often exhausted by maintenance, growth and lactation, and nothing is left to ensure that she can start cycling again and be fertile by the beginning of her second breeding season.

Cows do not reach maturity until about four years of age, but the additional nutrient requirements are largest for heifers that are pregnant and then lactating for the first time. After that, remaining growth to maturity is small enough that the nutrient requirements for growth can be considered virtually inconsequential. Nutrient requirements for gestation in coming two-year-old heifers (Tables 4 and 5), and for lactation in two-year-olds (Table 6) take into consideration the body weight of the heifer during the production stage of interest, the expected mature body weight, and the rate of growth (ADG) needed to attain performance targets. It is recommended that heifers achieve 85% of mature body weight by the time their first calf is born. Attaining this size decreases the probability of dystocia, ensures that they have achieved a point in their growth curve that will probably allow nutrient requirements to be met, and increases the likelihood that they have the sexual maturity to return to cyclicity and get pregnant in the subsequent breeding season. Thus, when using Tables 4 and 5, ADG should be chosen to target growth to achieve 85% of mature body weight by calving.

Environmental factors also need to be considered when determining nutrient requirements, particularly energy. As ambient temperatures decrease, energy requirements increase to help the animal maintain internal body temperature. If rain or snow is part of the temperature decrease, the energy requirements will increase more substantially. Wind chill can also play a role in increased energy requirements. Being aware of increased energy requirements because of cold, windy, or wet weather conditions will allow for proper allocation of additional energy during key points in time (See Chapter 8, Cold Stress Impacts on Cattle).

Digestion

Rumen fermentation and digestion requires protein to feed the rumen microbes. As a minimum, dietary crude protein levels must be maintained at greater than 7%, otherwise forage digestion will decrease (Paterson et al., 1996, Leng, 1990). For further discussion see Chapter 18, Supplementation of Beef Cows. With decreased digestion comes decreased passage rate, which can reduce feed intake resulting in decreased performance due to less feed being digested and fewer nutrients absorbed for use by the cow (Owen and Goetsch, 1988). The first thing to remember when feeding cows is that the goal is to feed the rumen microbes first and the cow second. Realize that 7% crude protein is the minimum needed to support the rumen microbes; the requirements for the cow may be higher (NRC, 2000, see Tables 3-6).

Nutrients

Water is the most important nutrient and often not thought of as a nutrient, however a lack of water will result in adverse affects or death quicker than a deficiency of any other nutrient. It is critical to provide fresh clean water at all times for optimum production and performance. Water is needed for many processes in the body including regulation of

Table 4: Nutrient requirements of pregnant, yearling replacement heifers, middle third of pregnancy. *Adapted from NRC, 2000.*

Current Weight (lb)	ADG lb	Dry Matter Intake		Diet Nutrient Density				
		lb/day	% BW	TDN % DM	NE_m Mcal/lb	CP % DM	Ca % DM	P % DM
1000 lb mature weight at BCS = 5								
600	1.0	13	2.2	54	0.49	9.1	0.42	0.17
	1.5	14	2.3	56	0.53	10.2	0.48	0.20
	2.0	15	2.4	59	0.58	11.4	0.53	0.23
700	1.0	15	2.2	54	0.50	8.5	0.38	0.16
	1.5	16	2.3	57	0.55	9.5	0.43	0.19
	2.0	17	2.4	60	0.59	10.4	0.47	0.21
800	1.0	17	2.0	56	0.53	8.4	0.37	0.16
	1.5	18	2.1	59	0.58	9.1	0.41	0.18
	2.0	19	2.1	62	0.62	9.8	0.44	0.20
1200 lb mature weight at BCS = 5								
650	1.0	16	2.1	53	0.48	8.7	0.40	0.17
	1.5	16	2.2	55	0.52	9.8	0.45	0.19
	2.0	17	2.3	58	0.56	10.7	0.49	0.22
750	1.0	17	2.0	54	0.49	8.2	0.37	0.16
	1.5	18	2.1	56	0.53	9.1	0.41	0.18
	2.0	19	2.2	59	0.57	9.9	0.45	0.20
850	1.0	19	1.9	56	0.52	8.2	0.36	0.16
	1.5	19	2.0	58	0.56	8.9	0.39	0.18
	2.0	20	2.1	61	0.60	9.4	0.42	0.19
1400 lb mature weight at BCS = 5								
900	1.0	18	2.0	53	0.48	8.5	0.38	0.17
	1.5	18	2.0	55	0.51	9.3	0.42	0.19
	2.0	19	1.9	57	0.55	10.1	0.46	0.21
1000	1.0	20	1.9	53	0.49	8.0	0.36	0.16
	1.5	20	2.0	56	0.52	8.9	0.40	0.18
	2.0	21	2.1	58	0.56	9.5	0.43	0.20
1100	1.0	21	1.9	55	0.52	8.0	0.35	0.17
	1.5	21	1.9	58	0.55	8.7	0.39	0.18
	2.0	22	2.0	60	0.59	9.3	0.41	0.20

Table 5: Nutrient requirements of pregnant, yearling replacement heifers, last third of pregnancy. *Adapted from NRC, 2000.*

Current Weight (lb)	ADG lb	Dry Matter Intake		Diet Nutrient Density				
		lb/day	% BW	TDN % DM	NE_m Mcal/lb	CP % DM	Ca % DM	P % DM
1000 lb mature weight at BCS = 5								
700	1.0	16	2.2	57	0.54	8.8	0.28	0.17
	1.5	17	2.4	60	0.59	9.9	0.34	0.20
	2.0	17	2.4	63	0.64	10.9	0.39	0.22
800	1.0	17	2.1	55	0.52	8.8	0.28	0.17
	1.5	18	2.3	60	0.59	9.4	0.32	0.19
	2.0	19	2.4	63	0.64	10.2	0.36	0.21
900	1.0	18	2.0	57	0.54	8.8	0.28	0.18
	1.5	19	2.1	62	0.62	9.3	0.31	0.19
	2.0	20	2.2	65	0.66	9.9	0.34	0.20
1200 lb mature weight at BCS = 5								
850	1.0	18	2.1	57	0.54	8.5	0.27	0.17
	1.5	19	2.2	59	0.57	9.4	0.32	0.19
	2.0	19	2.3	61	0.61	10.3	0.36	0.21
950	1.0	19	2.0	55	0.52	8.4	0.27	0.17
	1.5	20	2.2	59	0.58	9.1	0.31	0.19
	2.0	21	2.2	62	0.62	9.8	0.34	0.20
1050	1.0	20	1.9	57	0.54	8.5	0.27	0.18
	1.5	21	2.0	61	0.60	9.1	0.30	0.19
	2.0	22	2.1	63	0.64	9.6	0.33	0.20
1400 lb mature weight at BCS = 5								
1020	1.0	21	2.0	56	0.52	8.3	0.26	0.17
	1.5	21	2.1	58	0.55	9.2	0.31	0.19
	2.0	22	2.1	60	0.59	9.8	0.34	0.21
1120	1.0	22	2.0	55	0.52	8.2	0.26	0.17
	1.5	23	2.0	58	0.56	8.9	0.30	0.19
	2.0	23	2.1	60	0.59	9.4	0.33	0.20
1220	1.0	23	1.9	57	0.54	8.3	0.27	0.18
	1.5	24	1.9	60	0.59	8.8	0.30	0.19
	2.0	24	2.0	62	0.62	9.4	0.33	0.20

Table 6: Nutrient requirements of lactating, first-calf heifers, first 90 days after calving. *Adapted from NRC, 2000.*

Current Weight (lb)	ADG lb	Dry Matter Intake		Diet Nutrient Density				
		lb/day	% BW	TDN % DM	NE_m Mcal/lb	CP % DM	Ca % DM	P % DM
1000 lb mature weight at BCS = 5								
700	0	19	2.7	59	0.58	10.1	0.27	0.19
	0.5	20	2.9	64	0.65	12.0	0.36	0.23
	1.0	22	3.1	68	0.70	13.5	0.42	0.26
800	0	20	2.6	60	0.59	9.7	0.26	0.18
	0.5	22	2.8	64	0.65	11.3	0.34	0.22
	1.0	24	3.0	68	0.70	12.7	0.39	0.25
900	0	21	2.4	60	0.59	9.8	0.27	0.19
	0.5	23	2.6	66	0.67	11.2	0.33	0.22
	1.0	25	2.7	70	0.73	12.4	0.38	0.24
1200 lb mature weight at BCS = 5								
850	0	21	2.5	59	0.57	9.7	0.27	0.19
	0.5	23	2.7	62	0.62	11.3	0.34	0.22
	1.0	24	2.9	66	0.68	12.8	0.40	0.25
950	0	23	2.4	59	0.57	9.3	0.26	0.18
	0.5	25	2.6	63	0.63	10.9	0.32	0.21
	1.0	26	2.7	66	0.68	12.1	0.37	0.24
1050	0	24	2.2	61	0.60	9.4	0.26	0.18
	0.5	25	2.4	65	0.66	10.8	0.32	0.21
	1.0	27	2.6	68	0.71	11.9	0.37	0.24
1400 lb mature weight at BCS = 5								
1020	0	24	2.3	58	0.55	9.3	0.26	0.18
	0.5	25	2.5	61	0.61	10.8	0.32	0.21
	1.0	27	2.6	65	0.66	12.1	0.38	0.24
1120	0	25	2.3	58	0.56	9.0	0.25	0.18
	0.5	27	2.4	62	0.62	10.4	0.31	0.21
	1.0	29	2.6	65	0.66	11.6	0.36	0.23
1220	0	27	2.2	62	0.62	9.8	0.28	0.20
	0.5	29	2.4	65	0.67	11.1	0.34	0.22
	1.0	30	2.5	68	0.72	12.1	0.38	0.24

Table 7: Approximate total daily water intake of beef cattle. *Adapted from NRC, 2000.*

Mature Weight (lb)	Temperature in °F					
	40	50	60	70	80	90
Wintering Pregnant Cows (gallons)						
900	6.7	7.2	8.3	9.7	---	---
1000	6.0	6.5	7.4	8.7	---	---
Lactating Cows (gallons)						
900+	11.4	12.6	14.5	16.9	17.9	16.2

body temperature, growth, reproduction, lactation, digestion, metabolism, and lubrication of joints, just to name a few. Recommended water intake based on the animal size, production stage, and ambient temperature is provided in Table 7.

Protein is necessary for muscle growth and development within the animal. It is also a key element of enzymes that are needed throughout the body to conduct all of the functions of life.

Energy is provided to the ruminant animal from multiple sources, including structural carbohydrates (cellulose, hemicellulose, and pectin), soluble or non-structural carbohydrates (sugars and starch), and fat. Cattle cannot directly utilize the energy from structural carbohydrates; however the rumen microbes break down these components and provide volatile fatty acids as an energy source for the cow. Fat contains 2.25 times more energy per unit of weight than carbohydrates, but needs to be limited to less than 5% of the diet dry matter (Byers and Schelling, 1988). Levels greater than this are harmful to fiber digesting bacteria in the rumen, causing forage digestion to be compromised.

Minerals play key roles in multiple metabolic functions in the animal. Minerals are divided into two classes based on the actual amount required in the diet: macro-minerals and micro-minerals (or trace minerals). Macro-mineral requirements are expressed as a percent of the diet, while micro-mineral requirements are expressed as parts per million (ppm). Macro-minerals include calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sulfur (S), sodium (Na), and chlorine (Cl). Key micro-minerals are all required but in a small quantity and can reach toxic levels if not closely monitored. For more details on the specifics of mineral nutrition and requirements for each mineral, see Chapter 20, Mineral Nutrition for Beef Cattle.

All nutrients are required and important. Under some specific production circumstances, a specific nutrient can be identified as first limiting. For example, see the discussion in Chapter 18 about protein being the first limiting nutrient in low-quality forages. However, it is important to understand that there is not one nutrient that is always the first limiting in all circumstances. Overall, rations need to be balanced to provide all nutrients required to meet performance goals.

Summary

Ensure that cow size, stage of production, cow age and milk production are taken into consideration when determining the cow's nutrient requirements. Appropriate measures need to be taken to meet the nutritional needs of the cows to maintain body condition score appropriate to her stage of production. The proper balance of protein, energy, minerals and vitamins is key to optimizing performance. An adequate amount of clean, fresh water needs to be available at all times.

References

Byers, F.M., and G.T. Schelling. 1988. Lipids in Ruminant Nutrition. In: D.C. Church, editor, The Ruminant Animal. Digestive Physiology and Nutrition. Waveland Press, Inc, Prospect Heights, IL p. 298-312.

Hibberd, C.A., and T.A. Thrift. 1992. Supplementation of forage-based diets: Are results predictable? J. Anim. Sci. 70(Suppl. 1):181. (Abstr.)

Hofmann, R.R. 1988. Anatomy of the Gastro-Intestinal Tract. In: D.C. Church, editor, The Ruminant Animal. Digestive Physiology and Nutrition. Waveland Press, Inc, Prospect Heights, IL p. 14-43.

Leng, R.A. 1990. Factors affecting the utilization of 'poorquality' forages by ruminants particularly under tropical conditions. Nutrition Research Reviews 3:277-303.

NRC. 2000. Nutrient requirements of beef cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Owens, F.N., and A.L. Goetsch. 1988. Ruminal Fermentation. In: D.C. Church, editor, The Ruminant Animal. Digestive Physiology and Nutrition. Waveland Press, Inc, Prospect Heights, IL p. 145-171.

Paterson, J., R. Cochran, and T. Klopfenstein. 1996. Degradable and undegradable protein responses of cattle consuming forage-based diets. In: M.B. Judkins and F.T. McCollum III (eds.) Proc. 3rd Grazing Livestock Nutrition Conference. Proc. West. Sec. Amer. Soc. Anim. Sci. 47(Suppl. 1):94-103.