Section 6
Grass Finishing Beef:
Nutrition, Growth, Carcass Characteristics, Grading, and Palatability

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Introduction

The demand for locally grown food is increasing. Likewise, grass-fed beef is being touted by many groups due to the high cost of cereal grains and concerns about the fat content of grain fed beef. When considering the production of grass-fed beef for the high-end or health-conscious consumer market, several factors become important: cost of production, the consumer segment being targeted, meat characteristics desired, and the fat characteristics of the product. In the meat industry, consumer acceptance and desires are driving forces, and palatability is the meat industry's term which refers to a consumer's overall perception of taste, tenderness, juiciness, flavor, and mouth feel. Tenderness has been identified as the most important palatability attribute of meat, and the primary determinant of meat quality (Miller et al., 1995). One of the major issues facing grass-fed beef in the marketplace, which must be addressed, is that carcasses from grass-fed cattle are recognized in the meat industry as having more yellow fat than grain-fed cattle, and this has been verified in numerous research studies. Fat color is highly associated with the carotenoid content of the fat, with high levels of ß-carotene, the precursor of vitamin A, which comes from green forages, resulting in more yellow fat. When this occurs, it is extremely important to educate consumers about this being a natural condition when cattle are grown on lush forages that are high in ß-carotene.

Grading Beef Carcasses

Grading Summary

In the United States, beef carcass value is determined by four primary factors: carcass weight; physiological maturity of the carcass as determined by bone ossification and lean color; intramuscular fat (marbling) content determined by USDA Quality Grade; and the percentage of boneless, trimmed retail product from the rib, loin, chuck, and round (cutability) determined by the USDA Yield Grade. Of these factors, carcass weight plays the largest role in determining overall value, within a maturity range. There are five physiological maturity stages: A, B, C, D, and E. These maturity classifications estimate the following chronological ages: A = 9 - 30 months, B = 30 - 42 months, C = 42 - 72 months, D = 72 - 96 months, and E is greater than 96 months. Marbling is used by the USDA Quality Grading system to be the primary predictor of palatability. Marbling is determined by a USDA meat grader with a visual appraisal of the amount of intramuscular fat on the cut surface of the ribeye between the 12th and 13th ribs. USDA Yield Grade (YG) is on a 1 to 5 scale, and the corresponding cutabilities are: YG1 > 52.3% cutability;

YG2 50 – 52.3%, YG3 47.7 – 50%, YG4 45.4 –47.7%, YG5 < 45.4%. USDA Yield Grading uses a formula that incorporates the hot carcass weight; external fat thickness measured ¾ of the way down from the chine bone on the cut surface of the rib at the 12^{th} rib; the percentage of kidney, pelvic and heart fat; and the number of square inches in area of the ribeye at the 12^{th} rib.

Depending on the marketing grid used, discounts in value occur when carcasses are lighter than 550 to 600 pounds, over 900 to 950 pounds, or have any of a number of other problems associated with lower consumer acceptance, such as having yellow fat, having dark colored meat, or being from bulls. In the U.S., meat is marketed in similarly-sized and graded boxes, and the muscle cuts from light-weight carcasses are smaller than those from larger animals, which makes marketing a consistently sized box very difficult. According to the USDA Yield Grade estimate, a 600 pound carcass should have an 11 sq. inch ribeye, a 700 pound carcass should have a 12.2 sq. inch ribeye, and an 800 pound carcass should have a 13.4 sq. inch ribeye. In the meat packing industry, the term dressing percentage refers to the hot weight of the carcass, before chilling, divided by the live weight at harvest. Factors that increase dressing percentage are carcasses that are heavily muscled, have more backfat and seam fat (the fat between muscles), or are heavier boned. Animals with more visceral fat, or animals with a greater weight of gut contents such as forage-fed animals compared with grain-fed animals, yield carcasses with a lower dressing percentage. As a point of reference, a dressing percentage of 62% to 63% would be a realistic average for Angus-based genetics marketed with an average of .5 inches of backfat over a range of final weights of 1,000 to 1250 pounds, if they were fed a grain-based diet.

The grading of beef carcasses is done voluntarily by the packer and is paid for by the packer. The Federal Meat grading service was established in 1927. The beef grading system has gone through many changes since then all the way up to the last change made in 1997 when the Select grade was no longer available for B maturity carcasses and the minimum for Choice B carcasses was raised to a minimum marbling degree of Modest. The beef carcasses are graded for both quality and yield. Where quality grades predict palatability of the meat and yield grades predict the cutability.

Quality Grading

Beef Quality grading involves two characteristics of the carcass - maturity and marbling. Maturity is the overall physiological maturity of the carcass and marbling is the intramuscular fat within ribeye.

Maturity

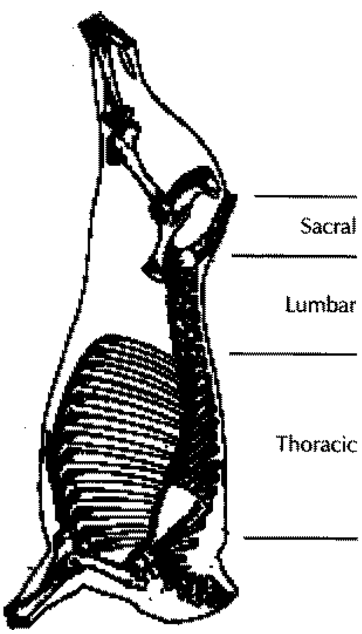
In bovine, physiological maturity has a significant effect on meat palatability, especially with regard to tenderness. As cattle mature, their muscles become progressively tougher. The primary cause of age-associated toughening of beef is a reduction in the solubility of connective tissue protein **collagen**. In beef from very young cattle, collagen is highly soluble and, upon cooking, is converted into gelatin. However, in beef from old animals, collagen maintains its structural integrity during cooking and, thus, contributes significantly to toughness. To account for the effects of age on beef tenderness, evaluations of carcass maturity are used to determine USDA quality grade.

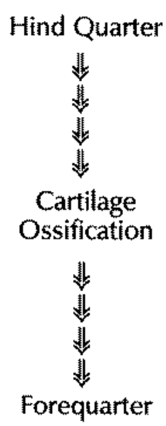
Skeletal Maturity

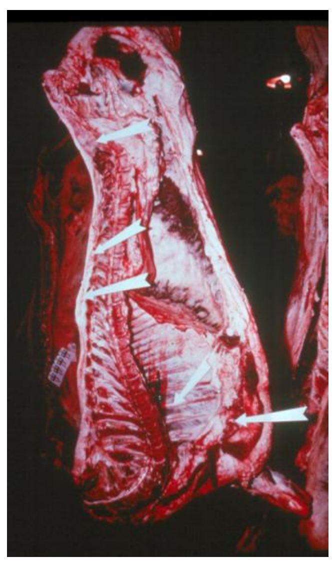
Maturity is the physiological age of the carcass rather than the chronological age. The size shape, and ossification of the bones and cartilage, especially the split chine bones help determine the maturity. The bones and cartilage evaluated to determine maturity is that of the sacral, lumbar, and most importantly the thoracic vertebrae of the backbone (the cartilage between and on the dorsal edges of the individual sacral and lumbar vertebrae and the cartilage on the top of each dorsal spinous process, “buttons”).

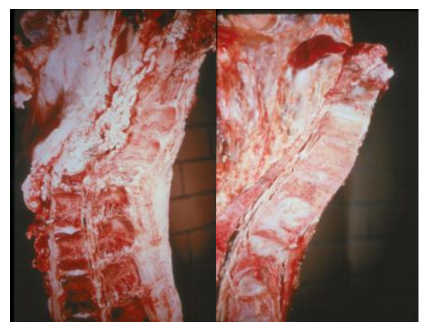
Youthful carcasses have a button of cartilage on the top of each dorsal spinous process of the vertebral column. They are most prominent, softest, and least ossified in younger carcasses. As the animal gets older these buttons begin to ossify or turn to bone. <u>Maturity is mainly determined by paying close attention to the thoracic button and by checking the ossification of the sacral and lumbar vertebrae</u>. Animals’ vertebral column ossifies from the back or rear end to the head so the most ossified bones should be the sacral and then lumbar and then the least ossified should be the thoracic. The thoracic buttons are the main indicators of maturity with the sacral and lumbar backing up your decision on maturity.

The shape and appearance of the rib bones is also an indicator of maturity. Youthful animals have rounded, narrow, red rib bones. As the animal gets older their rib bones flatten, become wider, and whiter in color. The loss of the red color is due to the lose of the rib’s ability to produce red blood cells in more mature animals.



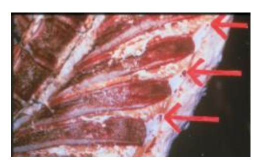






Distinct

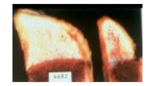
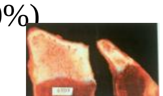
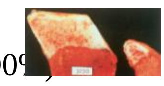
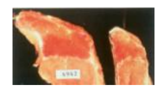
Fused



Thoracic Buttons on the 12th, 11th & 10th rib dorsal spinous process

USDA recognizes five classifications of maturity - A, B, C, D and E. Where A is the youngest and E is the oldest. A and B carcasses are considered young carcasses and C, D and E carcasses are considered old. Also, within each maturity class there is 100 degrees of variance. A carcass can be an old C or a young C. Where the oldest C would be a C 100 and the youngest C would be a C 0. When determining maturity it should be determined to the nearest 10 degrees. The key to becoming a good grader is knowing and never forgetting the difference between the oldest young carcass (B 90) and the youngest old carcass (C 0).

Bone Ossification Descriptions

USDA Maturity	Sacral	Lumbar	Thoracic	
A	Distinct separation	No ossification	No ossification (0 to 10%)	
B	Completely fused	Nearly complete ossification	Show some ossification (10 to 35%)	
C	Completely Fused	Complete ossification	Moderately ossified (35 to 70%)	
D	Completely Fused	Complete ossification	Show considerable ossification (70 to 90%)	
E	Completely Fused	Complete ossification	Are ossified (> 90%)	

*The descriptions above correspond to the youngest carcasses within each maturity group.

Appearance of Skeletal Bones

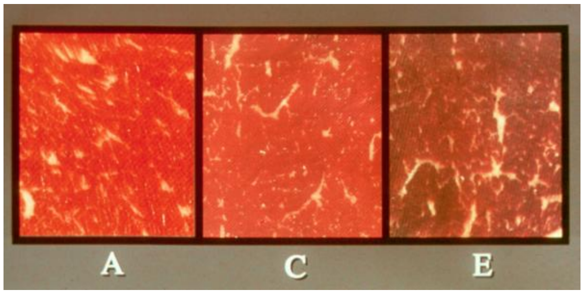
USAD Maturity	Split Chine Bones	Ribs
A	Red, porous and soft	Narrow and oval
B	Slightly red and slightly soft	Slightly wide and slightly flat
C	Tinged with red and slightly hard	Slightly wide and moderately flat
D	Rather white and moderately hard	Moderately wide and flat
E	White, nonporous and extremely hard	Wide and flat

Lean Maturity

Color and texture of the lean tissue in the ribeye is also used to determine maturity. In younger animals, the lean is very finely textured and a light pinkish-red color. As the animal gets older the muscles become darker and coarser. The color and texture of the lean also goes through changes during maturation. Young animals have very fine textured, light pinkish red color lean. As the animal matures this lean becomes darker and coarser in texture. Very mature cattle produce meat that is dark purplish red and very coarse in texture.

Lean color and Texture Descriptions

USDA Maturity	**Lean Color**	**Lean Texture**
A^{00}	Light Grayish Red	Very Fine
A^{100}	Light Red to Slightly Dark Red	Fine
B^{100}	Moderately Light Red to Moderately Dark Red	Tends to be Fine to Moderately Fine
C^{100}	Moderately Light Red to Dark Red	Slightly Coarse
E^{00}	Dark Red to Very Dark Red	Coarse



Balancing Lean and Skeletal Maturity

To balance the lean and skeletal Maturity simply take the average of the two values and round to the nearest 10 degrees in the direction of the skeletal maturity.

	Skeletal	Lean	Final
Example	A 60	B 20	A 90
	B 10	A 70	A 90
	A 50	B 60	A 55 = A50

If a carcass has skeletal maturity that is old (C, D or E) then the overall maturity must be old. Young lean can not bring a carcass from old to young. Same as old lean can not make a young carcass old. Skeletal maturity is the only thing that can make a carcass cross the B/C line. Also, the final maturity can not be adjusted more than 100 degrees no matter how far apart the lean and skeletal maturities are. For example a carcass with D 70 skeletal and B 10 lean would average to be a C 40 but has to be a C 70.

Although carcass maturity is based on visual evidence of physiological age, the following approximate relationships to chronological age are provided to assist in determining maturity in live slaughter cattle.

Maturity Classification	**Approximate Age**
A	9 to 30 months
B	30 to 42 months
C	42 to 72 months
D	72 to 96 months
E	more than 96 months

Lean Quality

Evaluations in lean quality in carcass beef are based on visual observations of the amount and distribution of marbling (intramuscular fat) and firmness of lean in the is cut surface of the lean between the 12th and 13th rib of the beef carcass. Unlike pork, and lamb carcasses, beef carcasses are usually ribbed. Beef carcasses vary much more in quality than the other species and the carcass's value is much more dependent on its quality. Marbling is a predictor of eating quality. The more marbling in the ribeye the higher eating enjoyment one should have. Marbling is divided into ten degrees, which are from lowest to highest:

Devoid (D)	Modest (MT)
Practically devoid (PD)	Moderate (MD)
Traces (TR)	Slightly abundant (SA)
Slight (SL)	Moderately abundant (MA)
Small (SM)	Abundant (AB)

Each marbling degree is then further broken down into percentages of that degree from 0 to 100. Thus, small marbling can be anything from Small 0 to Small 100. Small 100 has more marbling than the Small 0 but almost the same amount as a Modest 0. The percentages allow determining more precise marbling scores. Determining marbling scores is a procedure that takes a lot of practice and time to get consistent. You might have to see hundreds of cattle before you feel comfortable.

Final Quality Grade

After the marbling and maturity are determined they are then combined to give the final quality grade. There are eight beef quality grades, which are **USDA Prime**, **Choice**, **Select**, **Standard**, **Commercial**, **Utility**, **Cutter**, and **Canner**. Where Prime, Choice, Select and Standard are designated for the young (A&B) cattle only with the exception that B carcasses cannot be graded Select. Then the old carcasses can only be graded Commercial, Utility, Cutter, and Canner.

Each grade is broken down into high, average, or low, or into just high and low, based on what degree of marbling is represented. The following shows the corresponding grades for A maturity carcasses:

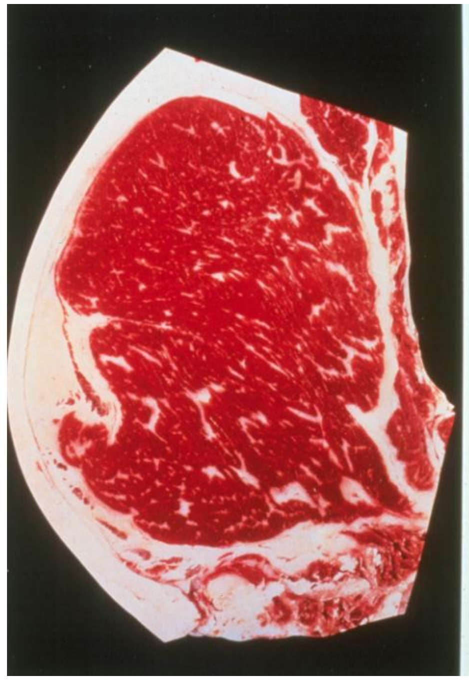
Prime

Pr + Abundant

Pr o Moderately Abundant

Pr - Slightly Abundant

Moderately Abundant



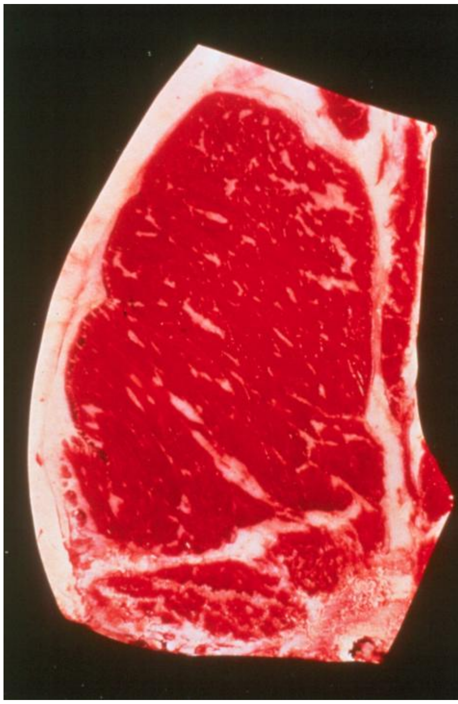
Slightly Abundant

Choice

Ch + Moderate

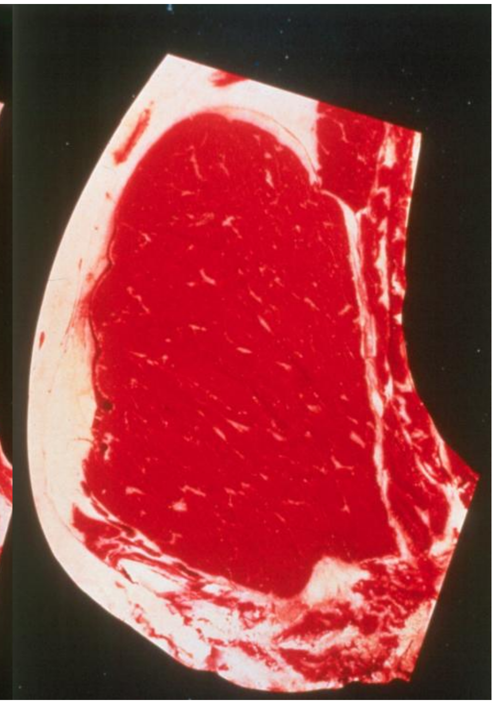
Ch o Modest

Ch - Small



Moderate

Modest



Small

Select

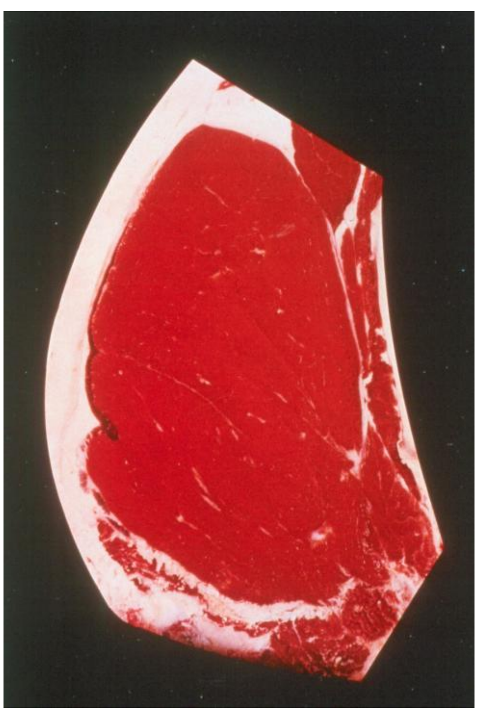
Se + Slight 50-100

Se - Slight 00-49

Standard

St + Traces

St - Practically Devoid



Slight

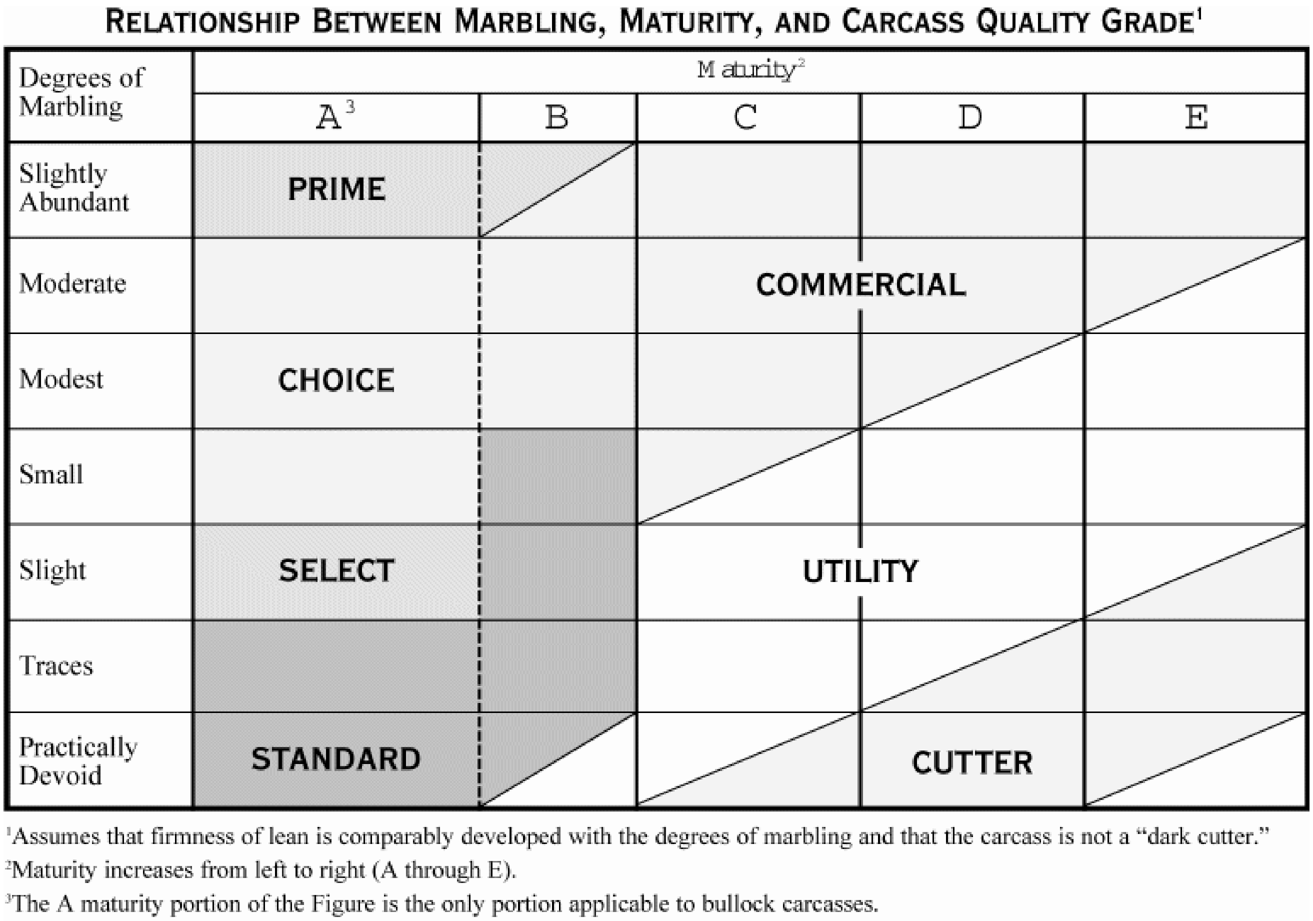


Figure 2: USDA Beef Grading Chart

compared to the rest of the carcass. Carcasses often have varied amounts of fat at the ribeye as compared to other parts of the carcass and the measurement must be adjusted either up or down for such a difference. Fat over the loin edge, round, and chuck are good regions to observe when adjusting for fat thickness. After adjusting the fat thickness you are left with a preliminary yield grade. An increase in fat thickness increases the yield grade and decreases the overall cutability.

Ribeye Area and Hot Carcass Weight

Ribeye area is measured in square inches by using a grid. The longissimus dorsi muscle exposed when the carcass is ribbed is where you measure this area. The ribeye area is the most accurate predictor of overall muscling in the carcass. A larger ribeye area decreases the yield grade and increases the cutability. As the hot carcass weight increases, the cutability decreases. The expected carcass yields of boneless retail cuts for each grade are represented below. The size of the ribeye should increases proportionately as a hot carcass weight increases to yield the same cutability.

%KPH

Kidney, pelvic, and heart fat is that fat deposited around the kidney and heart and in the pelvis area. The amount of this fat is determined subjectively and expressed as a percentage of the carcass weight. As the amount of KPH increases, the percentage of retail cuts decreases.

Procedures for Determining USDA Yield Grades (4-step method)

1. Preliminary Yield Grade (PYG) is determined on the adjusted back fat thickness (BF).

BF	PYG	BF	PYG	BF	PYG	BF	PYG
.00	2.0	.28	2.7	.56	3.4	.84	4.1
.04	2.1	.32	2.8	.60	3.5	.88	4.2
.08	2.2	.36	2.9	.64	3.6	.92	4.3
.12	2.3	.40	3.0	.68	3.7	.96	4.4
.16	2.4	.44	3.1	.72	3.8	1.00	4.5
.20	2.5	.48	3.2	.76	3.9	1.20	5.0
.24	2.6	.52	3.3	.80	4.0	1.40	5.5

2. Adjust for Hot Carcass Weight.

HCW	Adj.	HCW	Adj.	HCW	Adj.	HCW	Adj.
500	-.4	625	+.1	750	+.6	875	+1.1
525	-.3	650	+.2	775	+.7	900	+1.2
550	-.2	675	+.3	800	+.8	950	+1.4
575	-.1	700	+.4	825	+.9	1000	+1.6
600	0	725	+.5	850	+1.0	1050	+1.8

3. Adjust for Ribeye Area (REA).

REA	Adj.	REA	Adj.	REA	Adj.	REA	Adj.
8.9	+.7	11.0	0	13.1	-.7	15.2	-1.4
9.2	+.6	11.3	-.1	13.4	-.8	15.5	-1.5
9.5	+.5	11.6	-.2	13.7	-.9	15.8	-1.6
9.8	+.4	11.9	-.3	14.0	-1.0	16.1	-1.7
10.1	+.3	12.2	-.4	14.3	-1.1	16.4	-1.8
10.4	+.2	12.5	-.5	14.6	-1.2	16.7	-1.9
10.7	+.1	12.8	-.6	14.9	-1.3	17.0	-2.0

4. Adjust for percentage kidney, pelvic and heart fat (KPH).

KPH	Adj.	KPH	Adj.	KPH	Adj.	KPH	Adj.
0.5	-.6	1.5	-.4	2.5	-.2	3.5	0
1.0	-.5	2.0	-.3	3.0	-.1	4.0	+.1

The cutability of a carcass can be estimated by using the following equation:

$$\% \text{ Cutability} = 51.34 - (5.78 \times FT) - (.46 \times KPH) + (.74 \times REA) - (.0038 \times HCW)$$

The formula for calculating Yield Grade is:

$$YG = 2.5 + (2.5 \times FT) + (.2 \times KPH) - (.32 \times REA) + (.0038 \times HCW)$$

Importance of Consumer Acceptability, Palatability and Meat Tenderness

Summary:

Palatability is the meat industry's term which refers to a consumer's overall perception of taste, tenderness, juiciness, flavor, and mouth feel. The term umami was developed by Dr. Kikunae Ikeda of the University of Tokyo, and has been recognized as one of the taste sensations (in addition to sweet, salty, sour, and bitter). Umami refers to the savory or delicious sensation and comes from glutamic acid, glutamates, and nucleotides in foods, and it is very important to the Japanese palate, for instance. Furthermore, meat tenderness has been recognized as the most important quality attribute of meat (Hertzman et al., 1993, Miller et al., 1995), and it has been suggested that establishing a tenderness acceptability level for consumer markets would lead to new value added marketing schemes for which a tenderness value could be placed on a beef carcass, box of beef, or retail package for sale to restaurants or the retail case (Huffman et al., 1996). The two primary determinants of meat tenderness are maturity of the connective tissue, and myofibrillar toughness. Nutritional strategies that lead to slaughtering cattle at a young age have the greatest potential impact on maturity of the connective tissue.

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Meat tenderness has been recognized as the most important quality attribute of whole meat (Hertzman et al., 1993). It has been suggested that establishing a tenderness acceptability level for consumer markets would lead to new value added marketing schemes for which a tenderness value could be placed on a beef carcass, box of beef, or retail package for sale to restaurants or the retail case (Huffman et al., 1996). Although some research has reported that loin steaks from carcasses with a modest degree of marbling (average choice) or greater had lower Warner-Bratzler shear force values and higher tenderness values from a trained sensory panel compared with loin steaks having less marbling (Jennings et al., 1978), the 1998 National Beef Tenderness Survey reported that Quality Grade had little or no effect on Warner-Bratzler shear force values or consumer sensory evaluations of retail and foodservice steaks (Brooks et al., 2000). However, it must be pointed out that the steaks in the 1998 National Beef Tenderness Survey had an average post-fabrication aging time of 19 days for retail cuts and 32 days for foodservice cuts (Brooks et al., 2000). This is important, because the length of the aging time necessary to achieve no further decrease in shear force values has been reported to be 7 days for steaks with modest marbling or greater (upper 2/3 of the USDA Choice Quality Grade) , but steaks with slight marbling (USDA Select) required at least 14 days to achieve no further decrease in shear force (Bratcher et al., 2005).

Tenderness has been identified as the most important palatability attribute of meat, and the primary determinant of meat quality (Miller et al., 1995) and consumer acceptability (Brewer and Novakofski, 2008). The two primary determinants of meat tenderness are maturity of the connective tissue, and myofibrillar toughness. Nutritional strategies that lead to slaughtering cattle at a young age have the greatest potential impact on maturity of the connective tissue. Myofibrillar toughness is controlled by the calcium dependent proteolytic system (calpain) involved in postmortem meat tenderness (Koohmaraie,1992). Calpastatin, an endogenous enzymatic inhibitor of calpain is both highly heritable and directly related to Warner-Bratzler muscle shear force values that quantitatively measure muscle tenderness (Shackelford et al., 1994). One of the dogmas that exist is that grass-finishing systems always result in carcasses that have less tender steaks compared with grain-finishing systems. However, this is not always the case. In two studies where a forage finishing system was compared with a grain-finishing system, the carcasses from grain-finished cattle had a higher marbling score, and whiter fat, compared with carcasses from forage-finished cattle, but there were no differences in Warner-Bratzler shear force or muscle tenderness as rated by trained sensory panel scoring (Bidner et al., 1985; Bidner et al., 1986). This same finding was reported by Cox et al. (2006), in comparing forage versus grain finishing, however, in that study, there were no differences in marbling score, with carcasses in both groups being USDA Select. Interestingly, in one study comparing 18 month old Wagyu-sired steers that were fed a 92% barley finishing diet for either 90 or 170 days, feeding the high-concentrate diet for 170 days actually increased Warner-Bratzler shear force values and tended to decrease sensory evaluations for tenderness (Xie et al., 1996). While this would not normally be expected, it shows the complexity surrounding tenderness. Several factors contribute to the lack of consistency in beef cattle carcass composition and meat tenderness. These factors include, but are not limited to: animal genetics, environmental stress, diet, growth rate, age at harvest, chill cooler temperature, length of aging, cooking method, cooking temperature, and degree of doneness. In fact, product handling and aging of meat cuts have a tremendous impact on tenderness. In one study, bone-in vacuum packaged meat cuts had lower shear force values than conventionally aged controls and controlled atmosphere, boneless, display-ready cuts. Additionally, boneless, vacuum packaged cuts were also more tender than controlled atmosphere, boneless, display-ready cuts (Jeremiah and Gibson, 2003).

Production systems and nutritional programs vary widely in the beef industry. Developing feeding strategies to produce economically viable and consumer acceptable beef, are critical to the advancement of a high-value beef industry. One of the key concerns regarding grass finishing systems in Ohio deal with keeping cattle growing during the winter. If cattle are not gaining weight, then the connective tissue in the muscle becomes mature, and the meat becomes tougher. The reason this occurs is that the main component of a muscle's connective tissue is collagen, a protein. Proteins are constantly broken down (catabolism), and re-built (anabolism), and the maturity of the connective tissue is the result of these two processes. If an animal's growth slows, then the protein turnover slows, and the age of the collagen in the muscle is older. This is one of the reasons why meat from grass-fed cattle is sometimes found to have a higher Warner-Bratzler shear force than meat from grain-fed cattle. Usually, grain-fed cattle are growing at a faster rate resulting in more soluble collagen, as well as their being harvested at a younger chronological age which results in less collagen cross-linking, a component of toughness. However, even the use of growth promotants, that are used to reduce the cost of production by increasing the average daily gain of an animal can impact consumer acceptability, as they have been found to increase shear force and tended to increase the toughness of the longissimus muscle due to a limited post-mortem proteolytic activity (Faucitano et al., 2008).

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Ruminant Anatomy, Function, and Efficiency

Summary:

Ruminants are herbivorous animals that have developed the ability to "chew their cud". The act of rumination is regurgitating a bolus of feed from the rumen-reticulum region of the digestive tract into the mouth for resalivation, remastication and reswallowing. The most common ruminants in this country are cattle, sheep, goats and deer. They have adopted a highly specific population of bacteria, protozoa, and fungi capable of obtaining energy from plant polysaccharides (cellulose, hemicellulose, starch, simple sugars). The ruminant stomach has four compartments, the rumen, reticulum, omasum and abomasum. An extensive microbial fermentation occurs in the rumen-reticulum portion of the stomach, after which food passes to the omasum. The functions of the omasum are screening of large food particles, and absorption of water and acids. The ingesta then passes to the abomasum or "true stomach" where gastric secretions resembling those in non-ruminant stomachs take place. Rumen fermentation is the result of physical and microbiological activities which convert feed components into chemical or microbial products. There are approximately 1-10 billion bacteria, 1-10 million protozoa, and 1-10 thousand fungi in each milliliter (1/1000 of a liter) of rumen contents. The major gases in the rumen are carbon dioxide (65%) and methane (27%), both of which are end products of microbial fermentation and are excreted through eructation since they are useless to the animal. The major useful end-products of microbial fermentation are the volatile fatty acids (VFA), microbial protein and B-vitamins.

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Ruminants possess three nutritional advantages due to the presence of the microorganisms responsible for pre-gastric fermentation of feedstuffs. First, cellulose, hemicellulose and pectin, structural carbohydrates of plants not normally hydrolyzed by the enzymes present in non-ruminant digestive systems, are degraded by the bacterial, protozoal and fungal enzymes in the rumen and reticulum. Second, the ruminal microbial population can utilize non-protein nitrogen (ie: urea) for growth, converting it into microbial protein which is in turn available to the animal's dietary amino acid pool when it passes into the abomasum. Third, vitamin synthesis by the rumen microbial population makes the ruminant virtually independent of dietary sources of all vitamins except A ,D, and E.

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Feed Efficiency

In the U. S. feedlot industry, feed efficiency has a major economic impact on profitability. Other than the cost of the animal, feed is the major cost associated with feeding cattle. With high-grain diets, feedlots try to put a pound of gain on an animal with no more than 5.5 to 6.5 pounds of feed. With high-forage diets, feedlots try to put a pound of gain on an animal with no more than 7.0 to 8.0 pounds of feed. A majority of the feed that an animal consumes in a day goes toward maintenance requirements, and having the ability to gain more weight in a day may reduce the number of days that an animal is in the feedlot, which lowers the total amount of feed required for maintenance.

How does diet affect tissue growth, carcass quality, and meat characteristics? How does diet affect feed efficiency? To answer these questions, you probably need to understand some basics of ruminant nutrient use and animal growth as well as where management can improve carcass characteristics so that your cattle achieve their genetic potential.

First, all nutrients (energy, protein, vitamins, minerals, and water) are used in a hierarchy that goes from maintenance → development → lean and bone growth → lactation → reproduction → fattening. This means that an animal must have sufficient nutrients to maintain its body before bone or muscle growth can occur, and these must occur before fattening can occur. The second thing that you need to understand about ruminant nutrition is that feed is digested in the rumen by ruminal bacteria that attach to the surface of a feed particle to digest it. In ruminants, maintaining the digestive organs (rumen, reticulum, omasum, abomasum, small intestine, and large intestine) plus the liver and kidneys can take as much as 40-50% of the energy and 30-40% of the protein consumed in a day. Forage diets that are very bulky and only 40-60% digestible increase the weight of the digestive tract, because more undigested feed remains in each segment of the digestive tract. In contrast, grain-based diets result in decreased organ weights compared with forages, because grains are 80-100% digestible, and have a much smaller particle size, which allows them to have a faster rate of digestion and passage through the digestive tract. The result is that grain is more digestible than forage, plus it decreases an animal's maintenance requirement by resulting in less digestive organ mass, leaving more nutrients for muscle growth and fattening.

Why does visceral organ size impact an animal’s maintenance requirements? A large proportion of an animal's maintenance energy requirements can be attributed to the visceral organs, especially the liver and gastrointestinal tract, and appear to be associated with the high rates of protein synthesis in these tissues (Ferrell and Jenkins, 1985). The maintenance energy requirements of organs change with the relative weights of the organs and are affected by the level of nutrition, or feed intake (Ferrell et al., 1986). Burrin et al. (1989) fed lambs a high-concentrate diet either at a maintenance level of intake, or were offered as much feed as they could consume (ad libitum). They reported that the O_2 consumption, a measure of energy expenditure, in the portal-drained viscera and liver of the lambs fed at maintenance intake was 37 and 63% lower, respectively, than in the lambs offered feed ad libitum. This means that more feed intake results in larger organ weights, which increases energy use by the organs. Later, Burrin et al. (1992) reported that changes in visceral organ mass due to changes in the level of feed intake result from changes in cellular hypertrophy (cell size) rather than changes in cell number. Differences in visceral mass, and differences in energy source, could have rather large implications in feed efficiency and growth. The increase in feed efficiency that occurs with limit-feeding, or restricted feeding systems, where animals are fed a specific amount of feed rather than being offered all that they can consume, is due primarily to reductions in visceral organ weight (Fluharty and McClure, 1997).

Volatile Fatty Acid (VFA) Production in the Rumen

The major volatile fatty acids (VFA) produced by rumen microorganisms are acetate (2 carbons), propionate (3 carbons), and butyrate (4 carbons). These VFA are the main products of the digestion of feed by bacteria in the rumen, and serve as the main precursors for both glucose and fat in ruminants. Propionic acid is transported to the liver and is the only one of these VFA converted to glucose. Acetic acid is used primarily as the starting point of milkfat and animal fat production. On a forage based diet, the proportion of VFA would be approximately 65-70% acetate, 15-25% propionate, and 5-10% butyrate. Feeding diets high in readily fermentable carbohydrate (starch) increases the proportion of propionate, and results in VFA proportions of approximately 50-60% acetate, 35-45% propionate, and 5-10% butyrate. This shift toward more propionate is extremely important to carcass characteristics. Research by Johnson et al. (1982) and Bines and Hart (1984) found that increased peak insulin concentrations with increased propionate production will also lead to increased insulin secretion. Insulin increases fat and protein syntheses while inhibiting the breakdown of fat and protein at the tissue level. The increase in fat and protein synthesis due to insulin secretion is due to enhanced rates of nutrient uptake by tissues. The point that increasing propionate production enhances nutrient uptake by tissues cannot be overlooked. It is the primary reason that cattle in feedlots are fed high-grain diets. Increased propionate production results in a more efficient gain, a greater average daily gain, and increased marbling, as there is less energy loss from the feed in the form of CO_2 and CH_4, and grain-based diets result in reduced visceral organ weights compared with forages, leaving more energy for tissue gain. To dairy producers who have been trained that forages are needed in the diet, it is often difficult to imagine feeding diets with only 10% forage on a dry matter basis. However, the important thing to remember is that milk fat production requires acetate, and more acetate is produced on a forage-based diet. As the production system changes from milk production to meat and intramuscular fat production, the diet must change, also.

Feedlots take advantage of the energy content and digestive characteristics of grains to finish cattle. However, if you have a grass-based system growing system for your animals you probably aren't going to switch to grain. Therefore, maximizing gain on forages is necessary in order to have cattle harvested under 30 months of age. One way to increase an animal's performance with forages is grinding the forage to increase its' digestibility by making more surface area available to ruminal bacteria and increasing the rate of passage of the forage through the digestive tract, decrease the bulk fill inherent with the forage, and decrease the animal's maintenance requirement by decreasing the digestive tract weight.

In contrast to cattle being fed grain-based diets, the size of the rumen limits the amount of energy that can be consumed with forage-based diets, and digestible energy intake decreases with increasing forage maturity. Ruminal fiber digestion is a function of the rate of digestion of the forage and the rate of passage of the forage particles from the rumen. From a practical standpoint with unprocessed forages, the large particle size of mature forage reduces the energy available to the animal. Remember that for digestion to occur, the microorganisms in the rumen must first be associated with the forage, and then attach to the forage. Digestion normally occurs from the inside of the forage to the outer layers. Limitations to the speed at which this occurs include the physical and chemical properties of the forage, the moisture level of the forage, time for penetration of the waxes and cuticle layer, and the extent of lignification (Varga and Kolver, 1997). Undigested feed is broken down through the process of rumination and re-chewing until it is either digested, or small enough to pass from the reticulo-omasal orifice. Most particles leaving the rumen are smaller than 1mm, although particles as large as 5 cm may leave the rumen (Welch, 1986). It is, therefore, not hard to understand how reducing the large particle size of many mature forages to 1mm to 5 cm can increase maintenance energy expenditures due to an increase in visceral organ mass and the energy expenditure of rumination and re-chewing. Furthermore, the conversion of fibrous forages to meat and milk is not efficient, with only 10 to 35% of the energy intake being captured as net energy to the animal, because 20 to 70% of the cellulose may not be digested (Varga and Kolver, 1997).

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Growth and Adipocyte (Fat Cell) Formation

Summary:

Typically, cattle are finished on high-concentrate diets for a period of time ranging from 80-350 days prior to slaughter. This finishing period allows for more rapid, efficient growth, and increased intramuscular fat (marbling) deposition so that the cattle carcasses grade choice compared with cattle grown on forage-based feeding systems. In general, tissues are deposited in the order of: 1. brain, 2. bone, 3. muscle, and 4. fat.

> A young, rapidly growing animal that is in a linear phase of growth will naturally put on more bone and muscle. As an animal ages, and its' genetic potential for muscle growth begins to plateau, it will put on fat. These two sites of adipocyte (fat cell) development may vary in synthesis rate with changes in age and nutrition. Adipose tissue mass increases by hyperplasia (cell proliferation), hypertrophy (cell enlargement), or a combination of both. The end products of ruminal fermentation, the VFA, as well as net energy intake are interrelated in terms of adipocyte formation. Finally, genetics are involved from the standpoint that a breed with exceptional marbling ability, like the Jersey or Wagyu breeds, should be better able to marble with diets that are lower in energy than a breed with a lesser genetic predisposition for marbling.

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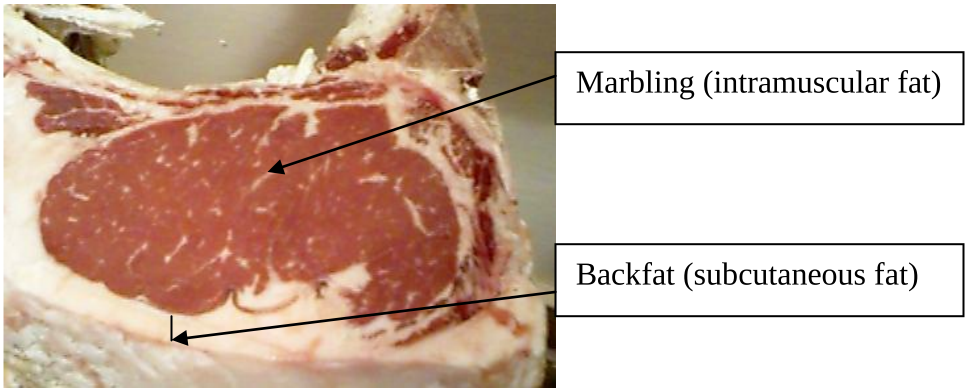
In order to understand how different management strategies can affect the ability of an animal to produce a choice carcass, and the yield grade of that carcass, some basic understanding of fat cell (adipocyte) growth is necessary. First, keep in mind that the marbling score is determined by the amount of intramuscular fat, and the preliminary yield grade is determined largely by the subcutaneous fat (backfat) measured at the 12 th rib.



These two sites of adipocyte (fat cell) development may vary in synthesis rate with changes in age and nutrition. Adipose tissue mass increases by hyperplasia (cell proliferation), hypertrophy (cell enlargement), or a combination of both. Adipose tissue synthesis requires a source of fatty acid and glycerol 3-phosphate, almost all of which comes from glucose (which comes from propionate). Remember that in ruminant animals that are grazing forages, acetate is the major fatty acid precursor for adipocyte synthesis, but when animals are fed a high-concentrate diet, the amount of propionate produced increases relative to acetate. The importance of this is that propionate is the major glycogenic fatty acid. The reason that ionophores, such as Bovatec® or Rumensin® improve ADG on forage-based diets is that more propionate is produced, and more glucose is produced in the liver, resulting in more net energy available to the animal.

The age at which cattle are thought to develop sufficient intramuscular fat to achieve the choice grade is diet dependent, because of the ability of ruminants to use different feedstuffs for growth and the fact that we have management systems for nearly every possible feedstuff. Smith (1995) stated that the age of an animal dictated the timing of the onset of lipogenesis (the formation of fat), but the diet modulated the amplitude of the rate of lipogenesis. Additionally, Smith et al. (1984) reported that backfat thickness and the activities of several enzymes involved in lipogenesis were greater in steers fed a high-concentrate, corn based diet versus steers fed a forage based, alfalfa pellet diet, even though the metabolizable energy intake was higher with the pelleted forage diet. Therefore, the end products of ruminal fermentation as well as net energy intake are interrelated in terms of adipocyte formation. This was shown by Smith and Crouse (1984) in a study where they fed either a corn silage (low energy) or ground corn (high energy) diet to Angus steers from weaning, at 8 months of age, to a terminal age of 16 or 18 months of age. They reported that acetate provided 70 to 80% of the acetyl units for lipogenesis in subcutaneous adipose tissue, but only 10 to 25% of the acetyl units for lipogenesis in intramuscular adipose tissue. Conversely, glucose (from propionate) provided 1 to 10% of the acetyl units for lipogenesis in subcutaneous adipose tissue, but 50 to 75% of the acetyl units for lipogenesis in intramuscular adipose tissue. The authors concluded that different regulatory processes control fatty acid synthesis in intramuscular and subcutaneous adipose tissue.

Therefore, the enzymes responsible for fatty acid synthesis, and therefore lipogenesis and adipocyte hypertrophy, are regulated by the end products of ruminal fermentation, which are determined by diet. In very practical terms, what this shows is that high-forage diets result in more backfat and seam fat production due to the high acetate levels, and that high-grain diets result in more intramuscular fat production due to more propionate production in the rumen leading to more glucose production in the liver.

The age at which actual initiation of adipocyte growth begins is probably very early in life as Vernon (1980) reported that hypertrophy of adipocytes begins after 100 to 200 days of age. Additionally, the age at which lipogenesis and adipocyte growth occurs is highly related to the age at which cattle are started on a high-concentrate diet, due to days on a high-concentrate diet, and a propionate fermentation being the major determining factor. Fluharty et al. (2000) reported that 85% of Angus-cross steer calves weaned at 103 days of age, immediately started on a high-concentrate diet, and harvested at 385 days of age (282 days on feed) graded choice, with 60% of the calves being in the upper 2/3 of the choice grade. Similarly, Myers et al. (1999) weaned crossbred steers at 117 days of age and either started them directly on a high-concentrate or put them on pasture until 208 days of age at which time they were moved to the feedlot and fed the high-concentrate diet. The calves started directly on a high-concentrate diet were 394 days at slaughter (268 days on high-concentrate diet), and the pasture calves were 431 days of age at slaughter (222 days on high-concentrate diet). At harvest, 89% of the concentrate fed calves graded low choice or higher, with 56% average choice or higher, and 89% of the pasture fed calves also graded low choice or higher, with 38% average choice or higher. These kinds of results would not have been possible if the steers had been brought into the feedlot at a year of age. It would not have been genetics, but management that prevented the cattle from grading choice at a year of age.

Genetics are involved from the standpoint that a breed with exceptional marbling ability, like the Jersey or Wagyu breeds, should be better able to marble with diets that are lower in energy than a breed with a lesser genetic predisposition for marbling. The recent study by Lehmkuhler and Ramos (2008) indicates that this is possible, because Jersey steers had similar marbling whether they were fed a diet containing 20% corn silage, on a dry matter basis, throughout a 317 day feeding period, or were phase fed diets that started with 60% corn silage for 84 days, 40% corn silage for 84 days, and 20% corn silage for 174 the remainder of a 327 day total feeding period. When grain prices are high, it’s advantageous to feed as much roughage as possible to reduce feed costs. Additionally, well-eared corn silage is commonly estimated to be 50% roughage (stalk, leaf, and cob) and 50% corn grain on a dry matter basis. This study indicates that it may be possible to use corn silage-based growing programs to allow steers with a high marbling potential to achieve an acceptable final weight without significantly reducing marbling. This has positive implications from both a feed cost standpoint and a carcass value standpoint.

In summary, a balance must be achieved between feed costs, having a harvest age that is as young as possible as increasing age increases muscle toughness, achieving an appropriate carcass weight, and achieving an acceptable level of marbling. A balance must then be struck between a growing and finishing diet that has sufficient protein for growth, and enough energy for marbling, but which does not lead to a carcass weight less than 550 to 600 pounds.

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Energy and Protein Interactions

Summary:

Feed grain costs are rising worldwide. Therefore, forage-based operations must utilize cost effective management tools that maximize forage digestibility. Ruminant animals in grazing situations need to maximize forage digestion in order to increase performance parameters such as average daily gain or milk production. Factors that limit the animal's ability to reach production goals may include the forage's energy

> and protein content, or availability. These factors are impacted by the forage species, maturity, lignin concentration, and ruminal ammonia requirements of cellulose digesting bacterial species. With forage-based diets, digestible energy intake decreases with increasing forage maturity. Ruminal fiber digestion is a function of the rate of digestion of the forage and the rate of passage of the forage particles from the rumen. From a practical standpoint with unprocessed forages, the large particle size of mature forage reduces the energy available to the animal.

With forage-based diets, digestible energy intake decreases with increasing forage maturity. Ruminal fiber digestion is a function of the rate of digestion of the forage and the rate of passage of the forage particles from the rumen. From a practical standpoint with unprocessed forages, the large particle size of mature forage reduces the energy available to the animal. Remember that for digestion to occur, the microorganisms in the rumen must first be associated with the forage, and then attach to the forage. Digestion normally occurs from the inside of the forage to the outer layers. Limitations to the speed at which this occurs include the physical and chemical properties of the forage, the moisture level of the forage, time for penetration of the waxes and cuticle layer, and the extent of lignification (Varga and Kolver, 1997). Undigested feed is broken down through the process of rumination and re-chewing until it is either digested, or small enough to pass from the reticulo-omasal orifice. Most particles leaving the rumen are smaller than 1mm, although particles as large as 5 cm may leave the rumen (Welch, 1986). It is, therefore, not hard to understand how reducing the large particle size of many mature forages to 1mm to 5 cm can increase maintenance energy expenditures due to an increase in visceral organ mass and the energy expenditure of rumination and re-chewing. Furthermore, the conversion of fibrous forages to meat and milk is not efficient, with only 10 to 35% of the energy intake being captured as net energy to the animal, because 20 to 70% of the cellulose may not be digested (Varga and Kolver, 1997).

The rate, and extent, of fiber digestion in the rumen is controlled by the amount of surface area that is available for the fiber digesting bacteria to attach. Additionally, the digestible carbohydrate portions of fiber, cellulose and hemicellulose, must be freed from the indigestible structural strengthening component, lignin, in a timely manner to allow for an adequate amount of digestible energy to be achieved. In a grass-based system, the important economic outcome is that animal performance such as body weight gain, or milk production with cows and heifers, is limited by the amount of digestible carbohydrate and protein that can be acquired from the forage. When animals consume mature forages, they are often chewed more than one time, as they need to be physically broken down by re-chewing. The undigested forage forms a mat layer in the rumen, on the top of the rumen fluid, and this mat layer is regurgitated and re-chewed until it is either digested or reduced in particle size to a point where it can pass through the reticulum to the omasum. In many cases, the space that the mat layer takes up actually reduces an animal's feed (and energy) intake, because it takes up space that a more digestible feed could occupy. Since all forages are not consumed when they are in a very early growth stage, and since it is impossible to grind forages for grazing cattle, or cattle being fed hay in many situations, it is advantageous to look for those feed additives that have been proven to increase forage digestibility, and which comply with the requirements of all-natural markets.

Based on extensive research, the mode of action of Amaferm®, an all-natural fermentation extract of *Aspergillus* oryzae, (Biozyme Incorporated, St. Joseph, MO) is very well documented. Chang et al. (1999) reported that Amaferm, accelerated both the rate and extent of fiber digestion through increased growth of the rumen fungus *Neocallimastix frontalis* EB188, thus functioning like a prebiotic in stimulating the activity of fungi that break lingo-cellulose bonds leading to enhanced bacterial digestion. Furthermore, in vitro studies have shown the addition of Amaferm to increase NDF and ADF degradation of several feedstuffs (Beharka and Nagaraja, 1993). The increase in digestion of feedstuffs by Amaferm supplementation is the result of increased numbers of ruminal bacteria and the activity of the normally occurring intestinal microflora, as calves supplemented with Amaferm have been found to have higher total ruminal bacteria counts than controls (Beharka et al., 1991), increased cellulolytic bacteria counts in beef cattle supplemented with Amaferm (Kreikemeier and Varel, 1997; Beharka et al., 1991), and higher hemicellulolytic and pectinolytic bacteria counts than controls (Beharka et al., 1991).

The rumen fungi are the only rumen microorganisms capable of breaking the lingo-cellulose bonds of forages in the rumen, and Amaferm has been shown to accelerate the growth of motile zoospores of the rumen fungus *Neocallimastix frontalis* EB188, with a resulting increase of cellulase enzyme production peaking at 150% greater than controls, resulting in a 37% increase in carboxymethyl cellulase, a 261% increase in β-glucosidase, and a 407% increase in amylase, showing that the effects of Amaferm are not limited to enzymes responsible for fiber digestion, but also starch digestion (Schmidt et al., 2004). The increase in growth rate is not limited to fungi, as Amaferm® has been shown to increase the growth rate of the fiber digesting bacteria in the rumen, *Fibrobacter succinogenes* S85 and *Ruminococcus albus* 7 as well as several strains of the lactate utilizing bacteria *Megasphaera elsdenii*, *Selenemonas ruminantium*, and *Selenomonas lactilytica* (Beharka and Nagaraja, 1998). Additionally, Amaferm has been shown to increase fungal mass in three rumen fungi species, which can lead to more surface area being made available to bacterial attachment, as well as increasing total VFA production. (Harper et al., 1996). When a greater rate of digestion occurs, more microbial protein is produced, which leads to a greater flow of microbial protein to the small intestine. Finally, Caton et al., (1993) reported that steers grazing cool-season pastures had increased dry matter intake and fiber digestibility during July and August when pastures were dormant, when supplemented with Amaferm.

Feed grain costs are rising worldwide. Therefore, forage-based operations must utilize cost effective management tools that maximize forage digestibility. Ruminant animals in grazing situations need to maximize forage digestion in order to increase performance parameters such as average daily gain or milk production. Factors that limit the animal’s ability to reach production goals may include the forage’s energy and protein content, or availability. These factors are impacted by the forage species, maturity, lignin concentration, and ruminal ammonia requirements of cellulose digesting bacterial species. In recent years, degradable intake protein (DIP) has been reported to be the first-limiting nutrient for beef cattle grazing low-quality forages (Köster et al., 1996; Olson et al., 1999; Bandyk et al., 2001). However, unlike grain-based diets, there is a time period, referred to as the lag phase, required for cellulose digesting bacteria to attach to forage particles. This creates a situation where protein availability in the rumen must match the timing of energy availability in order to achieve optimum microbial digestion.

Several factors have been shown to alter bacterial degradation of protein, and, in turn, the amount of microbial protein reaching the ruminant small intestine. In production situations where energy is limiting, either because of relatively low-quality forage such as native tall grass prairie, mature fescue, or corn stover, etc., or in production situations where there is reduced dry matter intake, microbial protein reaching the small intestine may be insufficient to maximize animal growth, and ruminally undegradable intake proteins (UIP, or bypass protein) may be warranted, (Firkins and Fluharty, 2000). The daily microbial yield to the ruminant animal is a product of the efficiency with which microbes are synthesized and presented post-ruminally to the small intestine where they are absorbed as amino acids. This is usually defined as microbial nitrogen synthesized per kilogram of organic matter fermented in the rumen, and the total kilograms of organic matter fermented in the rumen per day (Hoover and Stokes, 1991). The efficiency of microbial protein synthesis is a major factor affecting the overall amino acid requirement of ruminants, and is influenced by a number of factors including; 1) energy source, 2) supply of nutrients such as nitrogen, sulfur, branched chain fatty acids, and 3) ruminal environmental characteristics such as dilution rate, pH and microbial species present in the rumen (Hespell and Bryant, 1979). An average efficiency of microbial synthesis of 17 grams of microbial protein per 100 grams of digestible organic matter was determined for many diets, although values were generally higher for sheep compared with cattle, and forage-based diets compared with grain-based diets (Bergen et al., 1982). The key factor to consider is 'digestible organic matter', therefore, a mature forage with less potential digestibility will result in less microbial production compared with a more immature forage with less lignin and more potentially digestible organic matter. In this situation, two interrelated opportunities to increase the digestibility of the forage as a result of more microbial growth and a faster rate of digestion are: first, increasing the surface area of forage available for bacterial attachment and degradation and second, increasing the amount of protein (or nitrogen, N) that rumen bacteria need in order to replicate.

As Hoover and Stokes (1991) pointed out, the ruminal microbial population achieves the highest growth rate when peptides, amino acids and ammonia are all present, even though all three may individually serve as sources of N for various microbes. Ruminal bacteria can supply a large part of the amino acids reaching the small intestine when high-energy diets are fed in conjunction with ruminally degradable protein. However, the energy and protein content of many crop residues or mature forages alters supplemental protein requirements. When energy and protein are limiting, there is a reduction in both the number of bacteria and the growth rate of bacteria, which results in a reduction in the amount of ruminal NH_3N that can be used for protein synthesis (Satter and Roffler, 1975). Several researchers have reported lower ruminal NH_3N concentrations when ruminal bypass proteins were fed compared with SBM in forage-based diets (Titgemeyer et al., 1989; Cecava et. al., 1990; Hussein et al., 1991a; Sultan et al., 1992a). The lower ruminal NH_3N concentrations with ruminal bypass proteins would be expected in diets that are inherently low in CP, and that have a large proportion of their supplemental protein bypassing ruminal degradation. Additionally, total amino acid flow to the duodenum has been greater when ruminal bypass proteins have been fed compared with SBM (Cecava et al., 1988, 1990; Titgemeyer et al., 1989; Sultan et al., 1992b).

In diets based on crop residues, and low-quality or mature forages, sufficient evidence is available to justify feeding combinations of ruminally available (DIP) protein sources such as urea or soybean meal (SBM) in combination with UIP sources that mostly bypass rumen degradation but are available for enzymatic degradation in the small intestine if not over-heated during drying. Common sources of UIP include corn gluten meal (CGM), distillers grains (DG), feather meal (Fth), or fish meal (FM), or blood meal (BM). This is due to the fact that diets low in readily available carbohydrates and protein result in reduced microbial growth, so a greater percentage of the animal's protein presented to the small intestine must come from non-microbial sources, or a deficiency in amino acids reaching the small intestine may limit animal production. One way to make more of the cellulose and hemicellulose, the primary carbohydrates in forage, available would be to grind the forage and thereby increase the amount of carbohydrates available for immediate attachment by bacteria. However, in many production situations, it is not possible or feasible to grind forage. In these situations, it is simply more economical and easier to provide N for the ruminal bacteria and use bypass protein sources, in combination, to maximize performance.

Ruminants have the ability to recycle N in the rumen, which reduces the amount of DIP that needs to be fed to meet the bacteria's requirement for N for growth. However, N recycling differs greatly between diets. Nitrogen recycling in the rumen provided 38 and 49% of N intake for SBM and BM supplemented wheat straw diets that contained 10.2% CP, and its' subsequent flow to the duodenum was equivalent to providing additional N to the animal (Sultan et al., 1992a). The regulatory factors for increased N recycling in the rumen are lower ruminal NH_3N concentrations and greater organic matter digestion. Therefore, ruminants fed slowly degraded protein sources in crop residue-based diets benefit form both an increased supply of protein to the small intestine and increased conservation of N through N recycling (Sultan et al., 1992a). However, total microbial N flow to the duodenum increased when SBM was added to the diet compared with CGM/BM combinations (Cecava et al., 1990, 1991) FM (Hussein et al., 1991b), or BM (Sultan et al., 1992b) demonstrating the benefit of using combinations of DIP and UIP.

When DIP sources of protein are fed, the profile of amino acids entering the small intestine closely resembles microbial protein, and amino acids that are limiting in bacterial protein will probably be limiting to the ruminant's production capability (Willms et al., 1991). Additionally, Titgemeyer et al. (1989) reported that SBM, CGM, BM, and FM varied greatly in their ruminal degradability and the quantities of individual amino acids, and all were a poor source of at least one of the essential amino acids. Therefore, supplying combinations of DIP and UIP could best meet the animal's amino acid requirement.

Protein supplementation costs can be reduced if a portion of the DIP comes from non-protein nitrogen (NPN) sources such as urea [(NH2)2CO] or biuret (NH2CONHCONH2) . In fact, cellulolytic bacteria prefer ammonia (NH_3) as their N source (Russell et al., 1992), so substituting NPN for a portion of the degradable true protein in supplements for range cows should be a viable option (Köster et al., 2002). Urea has a protein equivalent of 287% protein equivalents on a dry matter basis (NRC, 1996). However, urea hydrolyzes rapidly to ammonia and carbon dioxide (CO_2) (Helmer and Bartley, 1971), and can result in ammonia toxicity if consumed in large quantities in a short time period (Bartley et al., 1976). At high levels, .44 gm/kg of body weight, urea is almost always fatal, unless acetic acid is administered at levels of one mole of acetic acid / 1 mole of urea within 3 hours, because the acetic acid lowers the pH of the rumen, slowing the rate of absorption of urea into the blood (Word et al., 1969). Additionally, Williams et al. (1969) and Rush et al. (1976) reported reduced performance in cattle receiving NPN-based supplements compared with cattle receiving true-protein supplements. However, in those studies, NPN was a high proportion of the total supplemental N, and in the case of Rush et al. (1976), was used in conjunction with molasses-based supplements. The basal rations that Williams et al. (1969) used contained 4% or 12.1% urea and was not consumed every day, and Rush et al. (1976) fed 30% protein supplements with half of the CP coming from NPN. Rush et al. (1976) reported that rumen biuretolytic activity was apparent within 6 days, reached a high level of activity within 20 days, and continued through the 74 day feeding period. Furthermore, Rush et al. (1976) reported that cows fed biuret refused less feed than cows consuming urea and suggested that the slower hydrolysis of biuret resulted in an ammonia release rate more comparable to the rate of energy release from the mature forage being consumed. In another series of studies, urea or biuret provided 50% of the nitrogen in 30% CP dry supplements, or urea provided 94% of the nitrogen in 30% CP liquid supplements with molasses. In these studies, cow winter weight loss, cow summer weight gain, and calf performance were not different ($P > .50$) for cows fed natural protein or liquid supplements (Rush and Totusek, 1976).

Hersom (2007) suggested that the improvement in performance which occurs with the addition of protein to diets of ruminants being fed low-quality forage occurs due to a correcting of a protein/N deficiency in the diet, resulting in a better synchronization of the supply of energy and protein in the rumen, and in many cases occurs regardless of the source of protein, although increasing the proportion of natural protein often improves animal performance. Currier et al. (2004a) used cows in the last third of gestation to compare the difference between urea (5.2% of supplement dry matter) or biuret (6.1% of supplement dry matter) in diets where NPN treatments were formulated to provide 90% of the estimated DIP requirement, with the supplements being fed at .04% of the cows' body weight per day, or roughly .5 lb/d for a 1250 pound cow. Both NPN sources resulted in greater positive weight and body condition score (BCS) changes compared with the control group, and calf birth weight was not affected by NPN supplementation or NPN source, and the authors concluded that ruminants consuming low-quality forage can effectively use supplemental NPN to maintain nitrogen status and performance in both hand-fed and self-fed situations. In a concurrent study with steers consuming low-quality forage, these same diets were used in daily or alternate-day supplementation, and did not adversely affect forage intake, nutrient digestibility, site of digestion, or microbial efficiency compared with unsupplemented animals (Currier et al., 2004b), and ruminal pH never fell below 6.3, suggesting that it would not negatively affect fiber digestion (Currier et al., 2004c). These findings would support the conclusion of Köster et al. (2002) that urea could replace between 20 and 40% of the DIP in high-protein supplements, containing 30% protein, without significantly altering supplement palatability or cow and calf performance. In summary, supplying combinations of DIP and UIP could best meet the animal's amino acid requirement through maximizing microbial growth and cellulose digestion, as well as providing amino acids from both microbial and feed origin to the small intestine.

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GLOSSARY:

Absorption: The process of taking up nutrients from the digestive tract to be incorporated into the body.

Acid: A compound that releases hydrogen (H+) ions when dissolved in water.

Active Transport: A process occurring at the cell membrane in which a cell expends energy to move materials through the membrane, often against a concentration gradient.

Adenosine Triphosphate (ATP): The macromolecule that functions as an energy carrier in cells. The energy is stored in a high-energy bond between the second and third phosphates.

Ad Libitum Feeding: Where animals are allowed to eat as much daily as they desire.

Adsorption: Adhesion in an extremely thin layer of molecules (as of gases, solutes, or liquids) to the surfaces of solid bodies or liquids with which they are in contact.

Aerobe: A microorganism whose growth requires the presence of air or free oxygen.

Aerobic Respiration: The process by which a cell releases the energy in glucose, producing adenosine triphosphate (ATP). Aerobic respiration includes glycolysis, the citric acid cycle (Krebs cycle), and electron and hydrogen transport.

Aflatoxin: One type of mycotoxin produced by some strains of the fungus Aspergillus flavus.

Alkaline: A condition in which hydroxyl (OH-) ions are in abundance. Solutions with a pH of 7.1 or higher are alkaline or basic.

Amino Acid: A nitrogen containing organic compound that serves as a primary unit of a protein molecule.

Amylopectin: The branched form of starch in which branching of the glucose units occurs through the alpha 1-6 units from an amylose backbone. They are more easily digested than amylose.

Amylose: The straight chain form of starch in which glucose linkages are exclusively in the alpha 1-4 form.

Anaerobe: A microorganism that grows only or best in the absence of free oxygen. Organisms utilize bound oxygen.

Anhydrous: Without water.

Backgrounding: Growing of cattle, usually on high forage diets. It may take place anytime after weaning until the animal goes into the feedlot or the breeding herd.

Bacteria: Typically one-celled organisms that have no chlorophyll multiply by simple division and can be seen only with a microscope. Bacteria are procaryotes.

Base: A substance that removes hydrogen ions from an acid and combines with them in a chemical reaction.

Bloat: Excessive accumulation of gases in the rumen.

Carbohydrate: A class of organic compounds made of carbon, hydrogen and oxygen, with the latter two elements in a ratio of 2 to 1, such as sugars, starches and cellulose.

Carboxyl Group: The univalent radical COOH, occurring in the fatty acids, amino acids and most other organic acids.

Carrying Capacity: The number of individuals an environment can support without significant negative impacts to the given animal population and its environment, also known as grazing capacity. It can also refer to the stocking rate which achieves a targeted level of production in a defined time period, without negative effects on a pasture or range land.

Catalyst: A substance that can speed up a reaction or cause a reaction to occur without itself being altered permanently.

Caudal Vertebrae: Vertebrae in the tail, posterior to the sacral vertebrae.

Cellulase: The enzyme that attacks cellulose. Certain bacteria possess this enzyme, but mammals do not.

Cellulose: A major skeletal (structural) plant polysaccharide found in the cell wall of plants. Chemically, it is an anhydride of beta-D linked glucose units

Cell Wall: The cell structure exterior to the cell membrane of typical plants, algae, bacteria and fungi. It provides form and shape to cells.

Chine Bone: Vertebra or back bone.

Collagen: The most abundant protein in an animal's body. The primary cause of age-associated toughening of beef is a reduction in the solubility of the connective tissue protein, collagen.

Culture: Any growth or cultivation of microorganisms.

Deamination: The removal of an amino (NH_2) group from a compound.

Diaminopimelic Acid (DAPA): A compound found in nature only in procaryotic organisms, particularly in the cell wall of bacteria.

Diet: That which an animal or human consumes.

Endogenous: Produced or synthesized within the organism or system. For example, endogenous fecal nitrogen comes from mucosal cells from the animal's digestive tract.

Ensile: To store a freshly chopped, harvested forage in such a way that it undergoes a partial fermentation, such as silage or haylage. Over several days, or weeks, lactic acid bacteria (LAB) ferment the water-soluble carbohydrates in the crop to lactic acid, and to a lesser extent to acetic acid. The production of these acids, the pH of the ensiled material decreases to a pH below 5.0, and spoilage micro-organisms are inhibited in an anaerobic environment.

Enzyme: An organic (protein) catalyst that causes changes in other substances without undergoing any alteration itself.

Eucaryote: An organism characterized by a cellular organization that includes a nuclear membrane and other internal membrane organelles such as mitochondria and mitotic apparatus.

Exoenzyme: An enzyme secreted by the cell to the environment.

Fatty Acid: A straight chain of carbon atoms with a COOH at one end in which most of the carbons are attached to hydrogen atoms.

Fermentation: The enzymatic breakdown of complex organic compounds under anaerobic conditions in which the final hydrogen acceptor is an organic compound.

Fungus: Eucaryotic unicellular and sometimes multicellular organism with rigid cell walls and an absorptive type of nutrition. e.g. molds, mushrooms, puffballs and yeasts.

Grass: Any member of the plant family Gramineae. Common examples are orchardgrass, timothy, bromegrass, and fescue. The term does not refer to the cereal grain heads, but does include the forage portion of the plant, if grazed or harvested before seed head development and maturation. Examples of this include oats, barley, and wheat. Grasses lack the ability to fix atmospheric nitrogen, and are commonly grown with legumes in a pasture situation.

Haylage: Ensiled forage that can be from grasses or legumes.

Hemicellulose: Heterogeneous polysaccharide fraction existing largely in the secondary cell wall of the plant.

Hormone: A substance produced in minute amounts in one part of the body and transported to another region where it produces its effects. Insulin and glucagon are examples.

Hydrolysis: A chemical process of splitting a bond with the addition of the elements of water.

Implant: To put a substance in the body. In livestock production, this is usually refers to a growth promoting substance inserted under the skin.

Inoculum: The microorganism-containing specimen used to start microbial cultures.

Intramuscular fat: The fat found within a muscle, commonly referred to as marbling.

In Vitro: In glass, especially experiments performed under artificial conditions.

In Vivo: In the living body or organism.

KPH Fat: The acronym for kidney, pelvic, and heart fat. It is used in the calculation of USDA Yield Grades.

Legume: A member of the plant family Leguminosae, with the characteristic of forming nitrogen-fixing nodules on its roots, making use of atmospheric nitrogen for its needs. Common legumes are alfalfa, clover, birdsfoot trefoil, peas, and beans.

Lignin: Complex non-carbohydrate strengthening material in the thickened cell walls of plants. They are practically indigestible by both bacterial and mammalian enzymes.

Lipids: A group of organic compounds composed of carbon and hydrogen, such as fats, oils, waxes and steroids.

Listeriosis: An infectious disease caused by *Listeria monocytogenes*, and affecting all species, which can grow in silage above pH 5.0-5.5. Listeriosis in ruminants is commonly associated with feeding poorly prepared silage, moldy feeds, or in situations where spoiled feed is allowed to accumulate in feed bunks. Listeria organisms thrive in cool or cold environments, and are common from December through May. Listeriosis is characterized by unilateral brain stem and cranial nerve dysfunction, resulting in circling, facial paralysis, head pressing, and death following a short clinical course. Due to affected animals walking in circles, the common name for listeriosis is circling sickness or circling disease.

Lumbar Vertebrae: Vertebrae of the loin, which are between the last rib and the hip bone. Pork and lamb carcasses have seven lumbar vertebrae, but beef carcasses have six.

Lysis: A process of disintegration or dissolution (as of cells).

Maillard Product: Lignin artifact that is an artificial indigestible polymer between proteins and amino acids and degradation products of sugar and other carbohydrates. They form in the presence of water and heat when the carboxyl group of a sugar is bound to the free amino end of lysine. This causes heat damage and renders the feed indigestible.

Marbling: The fat found within a muscle, commonly referred to as marbling

Metabolism: The sum total of cellular chemical reactions by which energy is provided for vital processes and new cell substances are assimilated.

Mycelium (pl. mycelia): An interwoven mat of fungal filaments.

Nutrient: Any food that promotes growth and development.

Organic Compound: A substance primarily composed of carbon, hydrogen and nitrogen and that in nature is produced only by various forms of life. Any compound containing carbon.

Ossification: The process of bone formation in which connective tissues, such as cartilage, are turned to bone or bone-like tissue. Blood vessels bring minerals, like calcium, and deposit them in the ossifying bone tissue. Bone formation is a dynamic process which continues throughout life, with cells called osteoblasts deposition minerals, and cells called osteoclasts removing bone tissue through removing minerals, like calcium, when they are required as in lactation in a process known as bone resorption.

Palatability: The quality of a food that makes it acceptable or agreeable to one's personal taste. The three primary determinants of palatability in meat are tenderness, juiciness, and flavor.

Pasture: Land with grasses and legumes used for grazing of livestock as part of a farm or ranch.

Peptide: Two or more amino acids joined by a peptide bond.

Peptide Bond: The covalent bond that joins an amino group of one amino acid to the carboxyl group of another amino acid, with the formation of water.

pH: A symbol for the degree of acidity or alkalinity of a solution. Values below 7 indicate acidity, 7 is neutrality, and values above 7 indicates alkalinity. The scale goes from 0 to 14. It is a logarithmic scale, therefore a solution with a pH of 4 is 100 times more acid as one with a pH of 6 and 10 times as acid as one with a pH of 5. It is determined by the negative logarithm of the hydrogen ion concentration of the solution.

Plasma: The liquid portion of blood and lymph.

Polypeptide: A molecular chain of amino acids.

Procaryote: An organism exhibiting a cellular organization characterized by an absence of a true nucleus and other internally membrane-bound organelles.

Protease: An enzyme that hydrolyzes proteins esp. to peptides.

Protein: A macromolecule containing carbon, hydrogen, oxygen, nitrogen and at times sulfur and phosphorus. Proteins are composed of chains of amino acids joined by peptide bonds.

Proteolysis: Protein degradation or breakdown.

Protozoa: Unicellular, eucaryotic microorganisms. Many are motile and require organic food and obtain it from their environment. Because of these traits they have traditionally been considered animals.

Quality Grade: A subjective evaluation of factors that affect palatability of meat, performed by a trained USDA Grader. These factors include carcass maturity, and the amount and distribution of marbling within the lean.

Ration: A 24 hour allowance of a feed or a mixture of feeds making up the animal's diet.

Sacral: Located near the sacral vertebrae; sirloin steaks come from this region.

Sacral Vertebrae: Vertebrae of the sacrum. They are posterior to the lumbar vertebrae and anterior to the caudal vertebrae.

Seam Fat: Fat between individual muscles. The greatest depot site for fat in ruminants is seam fat.

Serum: The light yellow fluid left after the clotting of blood had occurred, or after centrifugation.

Silage: A fermented, high-moisture feed for ruminants. It is fermented and stored in a process called ensiling, and usually made from corn or sorghum, using the entire plant, not just the grain. For proper fermentation, the pH should drop below Silage differs from stover in that the cereal grain has not been harvested prior to ensiling.

Starch: The main storage carbohydrate in many plants, particularly seeds, roots and tubers.

Steroid: A complex macromolecule containing carbon atoms arranged in four interlocking rings, three of which contain six carbon atoms each and the fourth of which contains five.

Stocker: A beef animal being backgrounded prior to entering the feedlot or breeding herd.

Stocking Rate: The number of animals that can be effectively grazed on any area of land, or alternatively, the number of animals stocked per acre of grazing land in a management unit for a defined period of time. Stocking rates are expressed in terms of number of stock per hectare or acre. The rate will vary greatly depending both on the class of livestock, the fertility of the land, and the climatic conditions.

Stover: Mature, cured stalks of such crops as corn or sorghum from which grain has been removed. It is often ensiled.

Substrate: A substance acted upon, as by a bacteria or an enzyme.

Thoracic Vertebrae: Vertebrae associated with the rib cage. Rib steaks come from this region.

Toxin: A poisonous substance.

USDA: United States Department of Agriculture

Yeast: A type of unicellular fungus that characteristically does not form typical mycelia.

Yield Grade: The percentage of boneless, trimmed retail product from the rib, loin, chuck, and round (cutability). USDA Yield Grade (YG) is on a 1 to 5 scale, and the corresponding cutabilities are: YG1 > 52.3% cutability; YG2 50 – 52.3%, YG3 47.7 – 50%, YG4 45.4 – 47.7%, YG5 < 45.4%. Yield Grade is calculated using a formula that incorporates the hot carcass weight; external fat thickness measured ¾ of the way down from the chine bone on the cut surface of the rib at the 12^{th} rib; the percentage of kidney, pelvic and heart fat; and the number of square inches in area of the ribeye at the 12^{th} rib.