THE BIOLOGY AND MANAGEMENT OF WILD RUMINANTS

CHAPTER ELEVEN

FORAGE CHARACTERISTICS AND THE DIGESTIBILITY OF PLANT TISSUE

by

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CHAPTER 11. FORAGE CHARACTERISTICS AND THE DIGESTIBILITY OF PLANT TISSUE

Life on earth depends on the process of photoshynthesis. Plants are called primary producers, using light energy to synthesize carbon dioxide, water, and minerals into new plant material. Animals that eat plant materials are called primary consumers, and animals that eat the primary consumers are called secondary consumers. They are also dependent on plants even though they do not eat plant material directly.

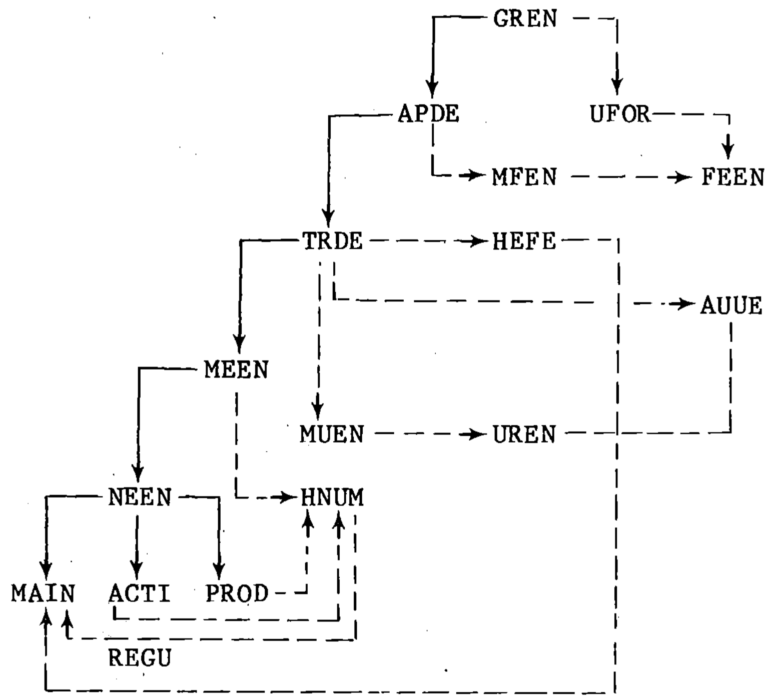
The nutrients in forage are the substrate for metabolic processes. The annual pattern of ecological metabolism reflects the timing and costs of metabolic processes that result in maintenance, growth, and reproduction in relation to the changing nutrient characteristics of the range forage over the annual cycle.

Metabolic patterns were discussed in CHAPTER 7. An understanding of these patterns is essential for an understanding of animal-range interactions. How can nutritive relations between animal and range be understood if the metabolic characteristics of the animals and nutritive characteristics of the range are not both known?

The nutrients in ingested food are partitioned into several pathways as food traverses the gastro-intestinal tract and nutrients are extracted and metabolized. This is so because mechanical, chemical, and metabolic processes are not 100% efficient. The idea of a process being less than 100% efficient implies a "waste," but that is not a good term for describing pathways in biological systems. Heat energy, for example, is part of the "waste" by microflora involved in rumen fermentation, but the heat dissipated by the microflora is useful to the host in the regulation of body temperature.

The efficiencies of nutrient pathways are related to specific nutrients and their specialized roles in physiological functions. There is a general pattern, however, beginning with the gross amount ingested, to the amount present in the urine and feces. Some of the forage is digested and metabolized, converted to body tissue, and then broken down and incorporated into urine and feces. Some of the fecal material is undigested forage residue, left intact from ingestion to defecation. Thus some ingested nutrients go through the gastrointestinal tract without being broken down and assimilated, and others are assimilated into new tissue that is broken down later and its constituents eliminated.

The major nutrient pathways of energy and protein are illustrated in the diagrams pages 2 and 4. Note that the basic format is very similar for the pathways of energy and protein breakdown from gross to net.



Definitions of the four-letter symbols are given below, and the categories on the upper left side of the flow diagram are discussed in the paragraphs that follow.

GREN = Gross energy
APDE = Apparent digestible energy
UFOR = Undigested forage residue
MFEN = Metabolic fecal energy
FEEN = Fecal energy
TRDE = True digestible energy
HEFE = Heat of fermentation
AUUE = Absorbed but unused urinary energy
MEEN = Metabolizable energy
MUEN = Metabolic urinary energy
UREN = Urinary energy
NEEN = Net energy
HNUM = Heat of nutrient metabolism
MAIN = Maintenance
ACTI = Activity
PROD = Production
REGU = Regulation

ENERGY

Energy is a very basic nutrient that is necessary for all of the life functions. The pathways of energy partitioning from gross to net are discussed in the paragraphs that follow.

Gross energy. The gross energy in any combustible material can be expressed in kcal per unit weight or kcal per unit volume. Firewood is sold on the basis of volume, where one cord = 128 cubic feet, equal to a stack 8 by 4 by 4 feet. Ther energy in this cord varies. A cord of white oak, a very dense wood, gives off 7,700,000 kcal when burned, and of white pine, a light porous wood, 4,100,000 kcal when burned.

The gross energy in a forage is the amount of energy released when that forage is completely oxidized in a bomb calorimeter (See Moen 1973: 172). It is an initial nutritive measurement of the energy in the product of primary production. The energy content per unit dry weight, or kcal per kg, is not widely different for different forages: 4500 KCAL PER KG is a good approximation of gross energy in many forages. Complete oxidation and the yield of gross energy is not necessarily related to the nutritive energy as a result of the biochemical functions in the gastrointestinal tract. The amount of energy available as a result of digestion is dependent on the effectiveness of the rumen microflora in breaking down the forage ingested and releasing the nutrients.

Apparent digestible energy. The apparent digestible energy is the gross energy in ingested food minus the energy in the feces. It is easily determined by measuring fecal energy and subtracting it from the gross energy, but it is of limited value since feces also contain tissues of metabolic origin. These tissues have been assimilated and broken down, and are not the same as undigested food residue. These two sources of fecal energy--undigested forage residue and metabolic fecal energy--must be separated before nutritive pathways can be quantified properly.

Apparent digestibility, expressed as a percent, may be calculated with the formula:

$$\text{Apparent digestibility} = [(\text{Intake energy} - \text{Fecal energy})/\text{Intake energy}]\ 100$$

True digestible energy. True digestible energy is determined by subtracting metabolic fecal energy from fecal energy, and subtracting that from gross energy. Metabolic products in the feces include such things as mucous, digestive juices, intestinal cell walls, bacteria, and protozoa. True digestibiligy, expressed as a percent, may be calculated with the formula:

$$\text{True digestibility} = \{[\text{Intake energy} - (\text{Fecal energy} - \text{Metabolic fecal energy})]/\text{Intake energy}\}\ 100$$

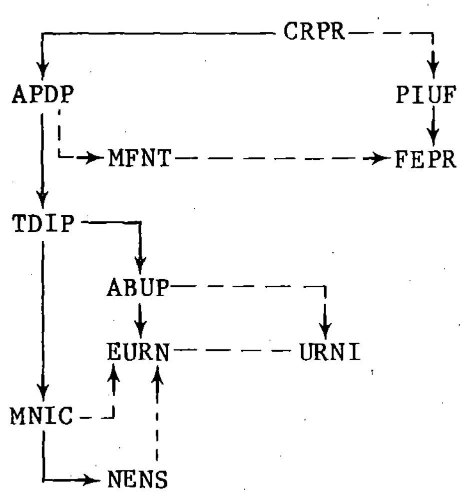
Numerically, true digestibility is greater than apparent digestibility.

Metabolizable energy. Metabolizable energy is that which is available for the nutrient metabolism that supports maintenance, activity, and production. It is the energy left after true digestible energy, heat energy of fermentation, energy in the methane, and urinary energy have been partitioned out of the gross energy. Methane, plus a few other gases in trace amounts, are produced in the digestive tract as a result of rumen fermentation. They are elimnated by eructation. The heat energy of fermentation is due to the exothermic metabolic reactions of rumen microflora. This heat energy contributes to the regulation of body temperature, and indirectly, at least, affects levels of activity and production.

Net energy. Net energy for maintenance, activity and heat production is the metabolizable energy less the heat of nutrient metabolism. It is a high-level distinction in the series of energy pathways, surpassed only by the further division into net energy for specific body functions, such as contraction of heart muscle, net energy for the muscular contraction necessary for walking, net energy for the growth of fetal tissue, and many other specific functions. These distinctions are beyond the considerations for wild ruminants in this book· metabolizable energy is the finest division division that will be applied directly to ecological situations.

PROTEIN

Ingested protein is partitioned into different sequences of metabolic processes just as energy is. Some is left intact as it traverses the gastrointestinal tract. Digested protein is broken down into amino acids and synthesized into new protein tissue. Some of this new tissue is in the form of rumen microflora, and some is new host tissue. The pathways are illustrated below.



Definitions of the four-letter symbols are given on the next page, and the categories on the upper left of the flow diagram are discussed in the paragraphs that follow.

CRPR = Crude protein
APDP = Apparent digestible protein
PIUF = Protein in undigested forage
MFNT = Metabolic fecal nitrogen
FEPR = Fecal protein
TDIP = True digestible protein
ABUP = Absorbed but unused protein
EURN = Endogenous urinary nitrogen
URNI = Urinary nitrogen
MNIC = Metabolizable nitrogenous compounds
NENS = Net nitrogen synthesized

Crude protein. Crude protein is the gross protein content of forage. It is an expression of the total protein in the forage, whether or not it may become metabolically available to a primary consumer.

Apparent digestible protein. The apparent digestible protein is the crude protein minus the protein in the feces. The feces, however, contain some protein of metabolic origin. Epithelial linings of the gastrointestinal tract, for example, are found in the feces. Thus the apparent digestible protein fraction of the crude protein is higher than the true digestible protein fraction.

True digestible protein. The true digestible protein fraction includes not only the undigested protein in the forage but also the fecal nitrogen of metabolic origin (MFEN). The true digestible protein fraction of the crude protein is higher than the apparent digestible protein, indicating that more protein was digested than at the apparent digestible protein level.

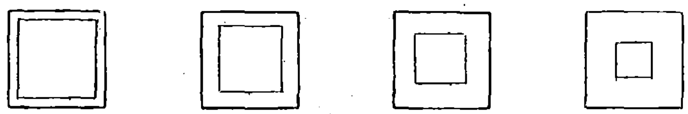
Metabolizable nitrogenous compounds. The nitrogenous compounds that actually end up being metabolized are available for synthesis, with some of the nitrogen ending up as endogenous urinary nitrogen (EURN) and some as net nitrogen synthesized (NENS) as new tissue. Endogenous urinary nitrogen is eliminated, though some is subject to resorption and recycling.

Net nitrogen synthesized. The nitrogen in the metabolizable nitrogenous compounds that actually ends up in new tissue represents the net nitrogen synthesized, becoming part of the protein tissue in the body.

FORAGE ANALYSES

An understanding of the nutrient pathways begins with an understanding of digestion. Food ingested must first be broken down into chemical forms that can be absorbed, metabolized, and synthesized. Since forage characteristics are very important in determining digestion, forage analyses are of definite interest.

What factors determine the digestibility of a forage for a ruminant animal? How does forage quality change as the range goes from the dormant winter condition, through various stages in phenology during the growing season, and back to the dormant winter condition? The nutritive use of the range by consumers ultimately occurs at the cellular and molecular level. Digestibilities are affected by the molecular structure of plant cell walls. Their complex molecular structure is hard to break down; the cell walls are often quite indigestible. Materials within the cell have fairly simple molecular structures, however, and are usually very digestible. Visualize the structure and volume of the cell wall in relation to the volume of intracellular space as the growing season passes. Cell walls of emerging plant tissues are thin, and as the tissues mature, the cell walls become thicker. The cell walls of mature tissues, especially structural tissues, are thick.



Tissue maturation - - →

As the cell walls increase in thickness, the amount of intracellular material decreases. Since highly lignified thick cells walls provide structural support to the plants, they also are an effective barrier to structural and chemical breakdown by rumen microflora. Since thicker cell walls are more resistant to chemical breakdown than thinner ones, the digestibility pattern over the annual cycle follows lplant maturation patterns; the general pattern of plant development at the cellular level is the basis for variations in digestibility.

A method of nutrient analyses called "Proximate analysis" has been used for over 100 years. Unfortanately, the results of this chemical method are not always closely aligned with the biological processes going on in the ruminant animal. Short (1966:163) states: "The proximate analysis of important species of deer browse has many times been shown to have little value in predicting how a deer digests a particular forage item." Why is this statement true? Because proximate analysis is an analysis of the chemical characteristics of forages, and these chemical characteristics are not always related to the digestion process of living organisms. These considerations are discussed further in Moen (1973:136-139).

How, then, should forage analyses be conducted to be of greatest value in evaluating nutritive relationships of wild ruminants? What factors determine the digestibility of a forage for a ruminant animal? How does forage quality change as the range goes from the dormant winter condition, through various stages in phenology during the growing season, and back to the dormant winter condition? Cell characteristics and digestibilities are considered in TOPIC 1. Chemical characteristics, sorted according to nutrients, genus and species of plants, and different plant parts are given in TOPIC 2. Diet digestibilities, determined by _in vivo_, _in vitro_, and calculations are given in TOPIC 3.

LITERATURE CITED

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman and Company, San Francisco. 458 pp.

REFERENCES, CHAPTER 11

FORAGE CHARACTERISTICS AND THE DIGESTIBILITY OF PLANT TISSUE

BOOKS

TYPE	PUBL	CITY	PGES	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	dvnc	nyny	427		the essential oils	guenther,e	1949
aubo	mopc	itny	1165	doru	feeds and feeding	morrison,fb	1956
aubo	mhbc	nyny	533	doru	animal nutrition	maynard,la; loosl	1962
edbo	acpr	nyny	618		biochemi, phenolic compnds	harborne,jb	1964
edbo	butt	wadc	480	doru	physiol of dig, rumin	dougherty,rw,ed	1965
aubo	agrc	loen	264	doru	nutr requi, farm livestock	smith,jab; armst/	1965
aubo	prha	ecnj	306	doru	princi of microbial ecolog	brock,td	1966
aubo	olbo	edsc	407	doru	animal nutrition	mcdonald,p; edwa/	1966
aubo	acpr	nyny	383		compar biochem, flavonoids	harborne,jb	1967
edbo	acpr	nyny	427	wiru	comparat nutri, wild anima	crawford,ma,ed	1968
edbo	nhfg	conh	256	odvi	p 182-196 deer nutrit stud	siegler,hr,ed	1968
aubo	whfr	sfca	753	doru	applied animal nutrition	crampton,ew; harr	1969
aubo	mhbc	nyny	613	doru	animal nutrition	maynard,la; loosl	1969
aubo	stmp	nyny	347		the cuticles of plants	martin,jt; junipe	1970
edbo	esli	edgb	549		trace elemnt metab in anim	mills,cf	1970
edbo	spve	nyny	214		integrated experime ecolog	heinz,e,ed	1971
aubo	cdch	coor	316	doru	digest physiology, nutritn	church,dc	1972
edbo	acpr	nyny	272	rumi	phytochemical ecology	harborne,jb	1972
book	nasc	wadc	772	doru	atlas nutrition data feed	NRC*	1972
edbo	acpr	nyny	3vol		chemis, biochem of herbage	butler,gw; baile	1973
aubo	long	loen	479	doru	animal nutrition	mcdonald,p; edwa/	1973
aubo	acpr	nyny	179		chemi of vegetable tannins	haslam,e	1974
edbo	acpr	nyny	1204		the flavonoids	harborne,jb; mab/	1975
edbo	acpr	nyny	326		chem & biochem plnt protns	harborne,jb; van	1975
aubo	acpr	nyny	243		introduc, ecolog biochemis	harborne,jb	1977
edbo	isup	amia	755	doru	forages; scien grsslnd agr	hughes,hdm; heat/	1977
edbo	acpr	nyny	435		biochem, plnt anim coevolu	harborne,jb	1978
edbo	acpr	nyny	718	hrbv	interact, plnt metabolites	rosenthal,ga; jan	1979

*National Research Council. Committee on Animal Nutrition. Subcommittee on Feed Composition