TOPIC 1. GASTROINTESTINAL SYSTEM FUNCTIONS

The gastrointestinal system functions both mechanically and chemically as foods are ingested and broken down. The process of digestion involves the conversion of ingested food into forms that can be absorbed by the body and assimilated into body tissue. The preparation of ingested food for digestion begins with mechanical processes, and ends with biochemical processes.

Foods eaten "are merely the carriers of the nutrients and the potential energy . . . . in a satisfactory diet." (Crampton and Harris 1969:5). Nutritive analyses must include not only investigations of food habits but also the digestion and assimilation of nutrients at different times of the year and under different range conditions. Microorganisms are absoslutely essential in ruminant digestion as there are no glands in the lining of the rumen and reticulum to secrete digestive enzymes.

The four functional parts of the mature ruminant's stomach are, in order of food passage: rumen, reticulum, omasum, and abomasum. At birth, the abomasum, or "true stomach," is the most well-developed, and the neonates are essentially monogastric animals. Ingested milk goes directly into the omasum via the oral groove, a passage that opens to allow milk to go to the omasum but closes when forage is swallowed, diverting that to the rumen. As the amount of forage ingested increases, the rumen develops thick muscular walls that contract rhythmically, promoting the breakdown and sorting of the ingesta for additional mastication of the coarser particles and passage of the finer particles to the reticulum, omasum, and abomasum.

Saliva functions as a lubricant and has a part in maintaining the fluid volume in the rumen. It assists in digestion to a very limited extent as the microorganisms in the rumen are almost totally responsible for the chemical breakdown of food in the rumen and reticulum. Nitrogen in the saliva is a substrate for protein synthesis by the rumen microorganisms, and their protein is subsequently useful to the ruminant host (Annison and Lewis 1959).

The rumen is lined with very rudimentary papillae at birth, and their development is dependent on the presence of volatile fatty acids (VFA's), the end products of rumen fermentation (Flatt et al. 1958), which are an energy source for the host animal. The papillae lining the interior surface of the rumen elongate as the amount of rumen fermentation increases, greatly increasing the surface area inside the rumen and permiting more rapid absorption of the VFA'S.

The reticulum, the second stomach compartment, is not as muscular as the rumen, and the internal surface has only a few papillae and no glands. It is separated from the rumen by the rumenoreticular fold, which acts like a dam to retain the larger particles of ingesta in the rumen. The smaller particles of ingesta are washed into the reticulum, and then they move on to the third stomach compartment, the omasum.

The absorption of water from the ingesta seems to be the principal function of the omasum. The internal surface has many granular papillae that greatly increase the surface area for absorption. Since the omasum is relatively small, the processed ingesta must move on to the fourth compartment, the abomasum, rather quickly.

The abomasum has a muscular layer composed of thin fibers in small bundles, an outer serous layer, and an interepithelial lining that includes secretory glands (Short 1964). It is the only part of the stomach which secretes digestive juices (Phillipson 1970:454). He points out that the movement of ingesta into the abomasum from the omasum and from the omasum to the duodenum is influenced by the quantities of material in the recipient organ. It appears that both the amounts and chemical characteristics of ingested materials have become fairly uniform by the time the processed ingesta reaches the abomasum.

Ruminants have a small and nonsacrulated large intestine (Dukes 1955: 416). A diverticulum at the proximal end, called the cecum, does have some fermentation of food materials going on (Dukes 1955:428), but this is of little overall importance.

A series of mechanical actions keeps the ingesta moving through the gastrointestinal tract. Pressure or strain gauges are used to measure movement, especially in the rumen and reticulum. Both *in vivo* and *in vitro* techniques are used to study fermentation and digestion. Rumen fistulas, openings to the rumen through lateral incisions in the body walls, have been used extensively in studies on cattle and sheep, making it possible to suspend nylon mesh sacks of forage in the rumen for *in vivo* fermentation analyses, and to collect rumen fluid with a minimum of disturbance to the animal for *in vitro* measurements of fermentation. Several researchers have used fistulas on wild ruminants held in captivity as well.

The use of *in vitro* fermentation techniques, with flasks of forage samples and rumen fluid maintained at rumen temperatures in a water bath, is an inexpensive way to study fermentation rates and processes. The products of fermentation can be conveniently analysed, but with caution since artificial rumens are not identical to natural (*in vivo*) ones. Additional information and photos of a fistulated deer and an *in vitro* fermentation bath are in Moen (1973:149-159).

This topic contains three units describing the mechanical and chemical processes of digestion. Since gastrointestinal functions are an important and well-studied aspect of domestic animal science, several books which deal primarily with this topic are listed as references after the LITERATURE CITED. Serials describing gastrointestinal functions are listed after each of the units.

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Dukes, H. H. 1955. The physiology of domestic animals. 7th ed. Comstock, Ithaca, New York 1020 pp.

Flatt, W. P., R. G. Warner, and J. K. Loosli. 1958. Influence of purified materials on the development of the ruminant stomach. J. Dairy Sci. 41(11):1593-1600.

Moen, A. N. 1973. Wildlife ecology. W. H. Freeman and Co., San Francisco. 458 pp.

Phillipson, A. T. 1970. Physiology of digestion and metabolism in the ruminant. Proc. 3rd Intern. Symp., Cambridge, England. Oriel Press, Newcastle upon Tyne, England. 636 pp.

Short, H. L. 1964. Postnatal stomach development of white-tailed deer. J. Wildl. Manage. 28(3):445-458.

REFERENCES, TOPIC 1

GASTROINTESTINAL SYSTEM FUNCTIONS

BOOKS

TYPE	PUBL	CITY	PGES	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	edar	loen	252	rumi	reactions in the rumen	barnett,ajg; reid	1961
edbo	butt	loen	297	rumi	digestiv physiology of rum	lewis,d,ed	1961
edbo	butt	wadc	480	rumi	physiology of digesti, rum	dougherty,rw,ed	1965
edbo	libr	boma	261	many	recent advanc in anim nutr	abrams,jt,ed	1966
aubo	acpr	nyny	533	rumi	the rumen and its microbes	hungate,re	1966
edbo	acpr	nyny	427	many	comparativ nutrition, wild	crawford,ma,ed	1968
aubo	amph	wash		rumi	handbook of physiol: alime	code,cf,ed; heide	1968
aubo	moco	salo	262	many	physiol of gastroint tract	texter,ce,jr; ch/	1968
aubo	dcdh	coor	316	rumi	digest physiology, nutriti	church,dc	1969
aubo	whfr	sfca	753	many	applied animal nutrition	crampton,ew; harr	1969
edbo	orpr	nute	636	rumi	physiolog digest, metaboli	phillipson,at,ed	1970
aubo	orst	coor	801	rumi	dig physiol,nut of ruminan	church,dc	1971
edbo	dcch	coor	350	rumi	dig phys, nut of ruminants	church,dc,ed	1972
aubo	whfr	sfca	458	rumi	wildlife ecology: an analy	moen,an	1973
edbo	iepu	nyny	576	many	physiolog adapta to enviro	vernberg fj,ed	1974
edbo	unep	arau	602	rumi	digesti, metaboli, ruminan	mcdonald,iw; warn	1975
edbo	coup	itny	1020	rumi	physiolog domestic animals	dukes,hh	1955

UNIT 1.1: MECHANICAL FUNCTIONS

Mechanical functions keep the food materials moving through the alimentary canal. These begin with the prehension and ingestion of food, followed by mastication, swallowing, rumination (including regurgitation, mastication again, swallowing, and rumen contractions), passage to the omasum and abomasum, intestinal contractions, and the opening and closing of valves between the parts of the gastrointestinal tract. As the food passes through the alimentary canal, saliva and digestive juices are mixed with the food, and the enzymes in these secretions compliment the fermentations by rumen microorgaisms in the overall process of digestion in the ruminant. Food in the rumen and reticulum is actively moved and churned as it is metabolized by rumen microorganisms. The movement results in the separation of the ingesta into layers, with the finer particles moving from the rumen and reticulum onto the omasum and abomasum. Finally, defecation of undigested food materials occurs.

Prehension. Prehension is accomplished in different ways among wild ruminants. Browse is removed by grinding it off with the molars, and low herbaceous vegetation is ingested by seizing the plant material between the lower incisors and upper gum. Plant parts, such as flowers, can be carefully and selectively removed. Moose sometimes feed underwater, submerging their heads, blocking off the nasal passages, and grasping the vegetation in their mouths. The different abilities of wild ruminants in selective foraging contribute to differences in their food habits; Cervids are generally more selective feeders than Bovids.

Mastication. Ruminants chew the forage some when it is ingested and again after it has been regurgitated. Most of the mechanical reductions in particle size occurs when the animal chews the regurgitated bolus, usually while bedded between feedings. The vertical and lateral movements of the jaws result in a rotary motion centered on one side at a time. The teeth wear roughly, increasing their grinding efficiency as particle sizes are reduced and surface areas increased, resulting in greater efficiencies in fermentation.

Swallowing. Swallowing is a complex reflex act in the ruminant. Milk ingested by nursing young goes into the omasum via the closed esophageal groove. After weaning, the esophageal groove no longer functions and water goes directly to the rumen with the rest of the ingesta. The water content of the forage is important for ruminants as foods that are not sufficiently moist do not start the muscular contractions involved in swallowing. Salivation also occurs, and the saliva is mixed with the food during mastication until the bolus is swallowed. When swallowing occurs, respiration is inhibited and the glottis and posterior end of the nares are closed, preventing the possibility of food entering the respiratory tract via the trachea. The food swallowed enters the rumen where rumination adds to the mechanical treatment of the food, followed by chemical fermentation in the rumen and reticulum.

Rumination. Rumination includes regurgitation, mastication and salivation again, followed by swallowing. The frequencies and durations of these events are dependent on the characteristics of the diet. Rumination begins a few days after birth, and adult-type rumination rhythms occur within a few weeks. Regurgitation involves contraction of the skeletal muscles. Dzuik et al. (1963:782) observed that white-tailed deer sometimes regurgitated ingesta, swallowed without mastication and regurgitated again in less than ten seconds. The rapid reswallowing may have been associated with characteristics of the bolus. The contraction patterns of the rumen and reticulum of a showed that contractions of the musculature of the rumen and reticulum were very closely associated (Dziuk et al. 1963). The first or primary rumen contraction, involving all parts of the rumen, followed two successive contractions of the reticulum, or "reticular doublet." A secondary rumen contraction, involving the dorsal sac, posterior dorsal blind sac, and the ventral sac of the rumen, sometimes occurred. The duration of the ruminoreticulum cycle in the white-tailed deer was 20-30 seconds. The frequency of reticular and primary rumen contractions varied with the activity of the deer, with 1.8 contractions per minute when standing and 2.2 contractions per minute when bedded. Secondary rumen contractions varied from 0.6 to 0.8 contractions per minute while standing and 0.2 to 0.5 contractions per minute when bedded. Dzuik et al. concluded that similarity of the pressure events in deer, cattle, and sheep were marked.

Stomach and intestinal movements. In the omasum, contractions of the muscular walls compress and pulverize the food and much of the water is absorbed. The food materials are then passed on to the abomasum where gastric juice is secreted and the fluid content is restored to the approximate level in the omasum. The hydrochloric acid content of the gastric juice causes the pH to fall to 1.5 - 3.0. The protozoa disintegrate there and some of the bacteria are killed. The food materials pass through the abomasum quite rapidly and move on into the small and then the large intestine (Annison and Lewis 1959:18).

Defecation. When the food reaches the rectum it consists largely of undigestible materials and water. The fecal mass also includes tissue that has been removed from the lining of the alimentary canal, as well as the remains of rumen microorganisms that have escaped digestion in the small intestine. The water content is variable, depending on species, diets, and time of year. Defecation occurs several times a day, often but not necessarily shortly after the animal leaves its bed. The number of defecations per day have been used in estimating populations from pellet group counts.

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REFERENCES, UNIT 1.1

MECHANICAL FUNCTIONS

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	20--1	70	74	odvi	eval pell gr count, census	eberhardt,l; van	1956
JWMAA	26--1	50	55	odvi	rain, count of pellet grou	wallmo,oc; jacks/	1962
JWMAA	26--3	341	342	odvi	use of rumen fistula in wh	short,hl	1962
JWMAA	28--3	4451	458	odvi	postnatal stomach developm	short,hl	1964
JWMAA	29--4	723	729	odvi	sourc of error, pell group	van etten,rc; ben	1965
JWMAA	39--3	596	600	odvi	rumen overld, rumenitis in	wobeser,g; runge	1975
JWIDA	13--3	281	285	odvi	rumenitis in suppl fed her	woolf,a; kradel,	1977
NAWTA	32---	420	429	odvi	use, chrom 51, digest stud	mautz,ww; petride	1967
NFGJA	7--1	80	82	odvi	perist, wint pelle grp, ny	patric,ef; bernha	1960

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JOMAA	36--3	474	476	odhe	values, alimen canal ph	browman,lg; sears	1955
JOMAA	46--2	196	199	odhe	reminoreticular characteri	short,hl; medin,/	1965
JWMAA	28--3	435	444	odhe	defecation rates of mule d	smith,ad	1964
JWMAA	34--1	29	36	odhe	ceel, freq dist pellet grp	mcconnell,br;smit	1970
UASPA	32---	59	64	odhe	indices of carc fat, color	anderson,ae; med/	1972

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ATRLA	15---	253	268	ceel	relatio, age, size, poland	dzieciolowski,r	1970
JWMAA	24--4	429	429	ceel	dyes to mark ruminan feces	kindel,f	1960
JWMAA	29--2	406	407	ceel	determ defeca rate for elk	neff,dj; wallmo,/	1965
JWMAA	35--4	673	680	ceel	rumen characteristi, red d	prins,ra; geelen,	1971

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	40--2	374	375	alal	dail wint pell gr, bed, al	franzmann,aw; ar/	1976
NCANA	95--5	1153	1157	alal	[numb pellet-gro each day]	desmeules,p	1968

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AVSPA	57---	1	18	rata	topograph, internal organs	engebretsen,rh	1975
NJZOA	24--4	407	417	rata	morph,fat stor,org wt,wint	krog,j; wika,m; /	1976

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				anam			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				bibi			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				ovca			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				ovda			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				obmo			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				oram			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ATRLA	13---	499	509	bibo	capac, weigh, walls, diges	gill,j	1968
ATRLA	14---	349	402	bibo	morphology digestive tract	pytel,sm	1969

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
FEPRA	27--6	1361	1366	rumi	regulation of feed intake	baile,ca	1968

UNIT 1.2: FERMENTATION AND DIGESTION

Food materials are complex structures that must be broken down by rumen fermentation and digestion before the nutrients can be assimilated into new body tissue. Foods can be divided into two physical groups, water and dry matter, and the latter can be divided into chemical groups with similar characteristics as outlined below.

- I. Water
- II. Dry Matter
  - A. Organic substances
    - 1. Nigrogenous compounds (crude protein)
      - a. True protein
      - b. Non-protein nitrogenous materials
    - 2. Non-nitrogenus substances
      - a. Carbohydrates
        - 1. Soluble carbohydrates (nitrogen free extract)
        - 2. Insoluble carbohydrates (crude fiber)
  - B. Inorganic substances (ash)
    - 1. Salts
    - 2. Mineral matter

Rumen microorganisms break the food materials down into substrates that can be used for their own metabolism, and the metabolic by-products of the microorganisms and the microbes themselves are then chemically processed by the ruminant host for use in their own energy, protein, mineral, vitamin, and water metabolism. The ruminant host and the rumen microorganism represent a highly developed symbiotic relationship. Nearly 900 strains of bacteria and more than 100 species of protozoa have been identified in the anaerobic rumen environment of different ruminants (Moen 1973:151). No individual has this many kinds, of course; variations in the number present of each strain are primarily due to differences in diets.

The actual number of microorganisms in the rumen is very large. The mean number of protozoa may be 10^6 or one million in each milliliter of rumen contents (Pantelouris 1967:193), and of bacteria about 10^9 to 10^{10} in each milliliter (Annison and Lewis 1959:33). Expressed in longhand, the number is 10,000,000,000 (ten billion) bacteria in each milliliter of rumen contents.

The rumen is an open system that depends on the flow of food materials into it and the flow of microorganism metabolites and food residues out. When the supply of food in the rumen is maintained by frequent intake, conditions in the rumen remain quite constant as the microorganisms have a stable substrate for the maintenance of their own metabolic activities. If food remains undigested in the rumen, appetite and rumen movement stop. If the rumen is then filled with actively fermenting rumen fluid from other animals, both appetite and rumen movement begin again (Nagy et al. 1967:447).

The failure of deer to survive when fed artificially in the winter has been attributed to a lack of the types of rumen microorganisms necessary for breakdown of such things as alfalfa hay. Research by Nagy (1967:446) has shown that no major adjustments in the microbial spectrum were necessary when deer were fed alfalfa hay, and other factors appear to be more important when deer are found dead with their rumens full of nutritious hay and other artificial feeds. Nagy suggests that as the amount of forage ingested decreases under starvation conditions there is a concomitant loss in the number of properly functioning rumen microorganisms. When the rumen contains a relatively small number of active microorganisms, the food residues would, in normal passage through the intestinal tract, tend to remove these microorganisms at a faster rate than their population growth can sustain. A supply of new forage then becomes residual in the rumen as death occurs.

Digestion is also affected by oils in certain plant materials. Oils of big sage-brush, for example, had in inhibitory action on bacteria in the rumen of mule deer, with a subsequent decrease in the rate of cellulose digestion (Nagy et al. 1964:785). Appetite and rumen movement stopped completely when three 7-pound portions of sage brush were introduced into a steer through a rumen fistula. When range conditions deteriorate to the point where wild ruminants are forced to eat certain plants that might otherwise be avoided, reductions in the digestive efficiencies are inevitable.

It is clear that rumen fermentation continues only if the substrate is adequate for support of microorganism metabolism. Not only must there be an adequate quantity, but the balance between carbohydrates and nitrogen is also important. The use of starch is an important factor in maintaining a flourishing rumen flora, and the digestion of starch is influenced by the quantity and nature of the nitrogenous components of the diet. A minimal level of protein is essential for supplying the nitrogen requirements of the rumen nicroorganisms (Annison and Lewis 1959:79-83). Two main conclusions are usually drawn from experiments on carbohydrate and nitrogen effects. One, there is a more rapid attack by the rumen microorganisms upon the fibrous components of the ration as the protein intake is increased, and two, there is better use of protein in the presence of added carbohydrate (Annison and Lewis 1959:109).

The complex ecology of the rumen can be at least partially controlled when animals in captivity are fed known quantities of diets with selected nutritive characteristics. Wild ruminants are subject to natural changes in range conditions, resulting in a much more complex rumen ecology than that of penned domestic ruminants. This increase in complexity adds many problems to nutritive analyses of wild ruminants, but it also presents many new challenges to creative thinking. The opportunities for nutritive analyses beyond the food habits level are many in wild ruminant ecology.

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Nagy, J. G., G. Vidacs, and G. M. Ward. 1967. Previous diet of deer, cattle, and sheep and ability to digest alfalfa hay. J. Wildl. Manage. 31(3):443-447.

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FERMENTATION AND DIGESTION

BOOKS

TYPE	PUBL	CITY	PGES	ANIM	KEY WORDS------------------	AUTHORS/EDITORS--	YEAR
aubo	acpr	nyny	533	rumi	the rumen and its microbes	hungate,re	1966

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
CJZOA	48--6	1437	1442	cerv	varia, ruminal nitrog leve	klein,dr; schonhe	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
XAMPA	1147-	159	163	od	biol rel, rumen flor, faun	nagy,jg	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JPROA	8---1	33	41	odvi	ophryoscol fauna, ciliates	zielyk,mw	1961
JWMAA	26--3	341	342	odvi	use of rumen fistula in wh	short,hl	1962
JWMAA	27--2	184	195	odvi	rumen fermen, energy relat	short,hl	1963
JWMAA	28--4	791	797	odvi	digest cedar, aspen browse	ullrey,de; youat/	1964
JWMAA	29--3	493	496	odvi	rumen organis, south texas	pearson,ha	1965
JWMAA	33--1	187	191	odvi	vari, rumin-retic contents	short,hl; remmen/	1969
JWMAA	33--2	380	383	odvi	rumino-retic char, 2 foods	short,hl; segelq/	1969
JWMAA	35--4	732	743	odvi	limitat winte aspen browse	ullrey,de; youat/	1971
JWMAA	36--4	1052	1060	odvi	variation, digest capacity	mothershead,cl; /	1972
JWMAA	39--1	67	79	odvi	feed analyses, digestion	robbins,ct; vans/	1975
NAWTA	32---	420	429	odvi	use, chrom 51, digest stud	mautz,ww; petride	1967
VJSCA	23--3	116	116	odvi	dosh, chrm acid, feel otpt	sanders,ot;skeen/	1972

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
APMBA	17--6	819	824	odhe	rumen microbial ecology	pearson,ha	1969
FOSCA	16--1	21	27	odhe	browsing, rumen fermentati	oh,jh; jones,mb;/	1970
JANSA	16--2	476	480	odhe	dosh, dig, liv oak, chamis	bissell,hd: weir,	1957
JANSA	31--1	235	235	odhe	infl pesticides rum bacter	barber,ta; schwa/	1970
JCOQA	6....	56		odhe	gastrointestinal ph values	olson,jc; nagy,j	1969
JOMAA	36--3	474	476	odhe	values, alimentar canal ph	browman,lg; sears	1955
JOMAA	46--2	196	199	odhe	ruminoreticular characteri	short,hl; medin,/	1965
JWMAA	16--3	309	312	odhe	digestibil, native forages	smith,ad	1952
JWMAA	28--4	785	790	odhe	eff essen oils,sagebr micr	nagy,jg; steinho/	1964
JWMAA	35--2	205	209	odhe	diarrhea, capt fawn, e col	kramer,tt; nagy,/	1971
JWMAA	38--4	815	822	odhe	effects starvat on rum bac	decalesta,ds; na/	1974
JWMAA	39- 4	663	669	odhe	starving, refeeding mule d	decalesta,ds; na/	1975
NAWTA	36---	153	161	odhe	eff, pesticid, rumen bacte	barber,ta; nagy,j	1971

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
BJNUA	24--3	843	855	ceel	dosh, digest, nitrogen met	maloiy,gmo; kay,/	1970
JWMAA	33--1	181	186	ceel	ruminal microorganisms	mcbee,rh; johnso/	1969
JWMAA	35--4	673	680	ceel	dada, rumen characteristic	prins,ra; geelen,	1971
JWMAA	40--2	371	373	ceel	exp w/rum cann, rum analys	staines,bw	1976
JWMAA	42--3	654	659	ceel	ruminoreticular characteri	church,dc; hines,	1978

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CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
QJEPA	56--4	257	266	ceel	dosh, compar dig, cont con	maloiy, mo; kay,/	1971
SZSLA	21---	101	108	ceel	physiol of diges, metaboli	maloiy,gmo; kay,/	1968

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CJBIA	49--1	119	126	alal	isoslat, enzym, chromotogr	stevenson,kj; lan	1971
CJBIA	52--7	637	644	alal	isolatio trypsin, elastase	lievaart,pa; stev	1974
JPROA	2---3	124	134	alal	morph, divisi cilia, stoma	kraschenİnnikow,	1955
NCANA	101--	227	262	alal	ener req rumen fermentati	gasaway,wc; coady	1974
PCBSA	16---	129	129	alal	serine proteases from	lindsay,rm; steve	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AZFEA	127--	1	76	rata	rumen ciliate fauna finla	westerling,b	1970
BJNUA	29--2	245	259	rata	seas variation, gluc metab	luick,jr; person/	1973
CJZOA	36--5	819	835	rata	rumen ciliates, canad arct	lubinsky,g	1958
CJZOA	36--6	937	959	rata	rumen ciliates, canad arct	lubinsky,g	1958
CJZOA	54--1	55	64	rata	gluc metab, lactating rein	white,rg; luick,j	1976
HLTPA	21--5	657	666	rata	radiocesium, lichen, alask	holleman,df; lui/	1971
LAANA	28---	175	180	rata	comp, reindeer, sheep dige	eriksson,s; schme	1962
SZSLA	21---	109	115	rata	wint nutr, wld reind, norw	gaare,e	1968
SZSLA	21---	117	128	rata	nutr semi-domestic reindee	steen,e	1968

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	33--2	437	439	anam	ruminoreticular vfa conten	nagy,jg; williams	1969
TAMSA	72--3	248	252	anam	intestin amoeba from prong	noble,ga	1953
XARRA	148--	1	4	anam	starvation with stomach fu	pearson,ha	1969

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
APMBA	15--6	1450	1451	bibi	rumen microorganisms, utah	pearson,ha	1967

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
UCPZA	53--6	237	261	ovca	ciliates, sierra nev bigho	bush,m; kofoid,c	1948
JWMAA	36--3	924	932	ovca	env sour of var, physi val	franzmann,aw	1972

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
JWIDA	7---3	139	141	ovda	physiologic values of ston	franzmann,aw	1971

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
CJZOA	41--1	29	32	obmo	rumen ciliate, north canad	lubinsky,g	1963

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
				oram			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
ZEJAA	8---3	97	111	caca	[topog organ, neck, chest]	hofmann,r	1962

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
EJBCA	63--2	441	448	many	carbohyd, pancre ribonucle	beintema,jj; gaa/	1976
FEPRA	27--6	1361	1366	rumi	regulation of feed intake	baile,ca	1968
JANSA	35--6	1271	1274	dosh	effect of watr, nutrnt dig	asplund,jm; pfand	1972
JONUA	86--3	281	288	rumi	blood urea, protein intake	preston,rl; schn/	1965
JPROA	21--1	26	32	wiru	rumen ciliate fauna, 3 wr	dehority,ba	1974
JWMAA	32--1	198	207		meth microb diges, pos mor	bruggemann,j; gi/	1968
JWMAA	38--4	948	949	wiru	differentiatio, pellet, ph	howard,vw,jr; del	1974
NARFA	29--2	511	511	rumi	fact, rumina dur developme	tulbaev,po	1959
NCANA	101-1	227	262	many	energy req rumen fermenta	gasaway, wc; coad	1974

UNIT 1.3: PRODUCTS OF FERMENTATION

Rumen microorganisms produce heat energy, gases, volatile fatty acids, nitrogen compounds, and vitamins as end-products of their metabolism. The heat energy given off is called the heat of fermentation, and contributes to the energy balance of the ruminant host. It is the result of exothermic metabolic reactions of the rumen microflora. Its role in the energy balance of free-ranging ruminants is discussed in PART V. The other products of rumen microorganism metabolism are discussed below.

GASES

Gases given off, primarily methane (CH_4) and carbon dioxide (CO_2) are either released directly into the atmosphere by eructation or absorbed by the blood and exhaled later as part of respiratory exchange. The composition of the rumen gases eructed do not vary much with rations. The total amount of gas formed is not affected much by the ration, but the quantity rises sharply after eating and then falls gradually (Dukes 1955: 382). The significance of eructation is in the loss of energy that it represents; about 8% of the digestible energy of the diet, varying with the digestibility of the food, is released in methane (Blaxter 1967:200; and Moen 1973:154).

VOLATILE FATTY ACIDS

Three volatile fatty acids (VFA's)--acetic, butyric, and proprionic--are invariably present in the active rumen as a result of microbial fermentation of carbohydrates (Annison and Lewis 1959:60). The total concentration and the amounts of individual acids are dependent on the composition of the ration and the feeding regime. Thus seasonal differences are expected in wild ruminants, and have been observed in mule deer (Short et al. 1966:466) and white-tailed deer (Short 1963).

Higher concentrations of VFA's are observed when easily fermented foods are ingested (Short 1963:186). There is an increased rate of rumen fermentation during the summer when the range forage is succulent, and a decrease in the fall and winter.

The concentration of volatile fatty acids in the rumen is not a simple and straight forward indication of the actual rate of VFA production, however. The concentration of VFA's at a given time depends not only on their rate of production in the rumen, but also on the rate of absorption from the rumen, rate of passage from the rumen to the omasum, dilution with saliva, use of VFA's by the rumen microorganisms, and conversion to other rumen metabolites (Annison and Lewis 1959:63).

The young ruminant has glucose and VFA concentrations like those of a monogastric animal in which most of the energy is absorbed in the form of glucose from the small intestine (Annison and Lewis 1959:73). As rumen fermentation increases, glucose concentrations fall to about one-half that of non-ruminants, and VFA concentrations increase. This change in carbohydrate metabolism is a physiological indication of the weaning process (Annison and Lewis 1959:20).

Volatile fatty acids are readily absorbed from the rumen and are a major source of energy for the ruminant animal. Moen (1973:154) cites references indicating that at least 600 to 1200 Kcal of energy are absorbed as VFA's from the sheep rumen every 24 hours, and 6000 to 12000 Kcal from the cattle rumen. The latter has a much greater physical capacity than the former, of course. VFA production by deer is discussed in Short (1963) who stresses the need for additional understanding of such nutritional energy relationships in deer management.

NITROGEN COMPOUNDS

Microbial protein synthesized from amino acids and non-protein nitrogen sources is digested in the omasum and abomasum as microbial populations are rapidly turned over (Pantelouris 1967:192). A considerable portion of the protein requirement of ruminants is supplied in this way (Annison and Lewis 1959:19) as non-protein nitrogen is converted to microbial protein and digested and absorbed by the host. Urea is an example of a non-protein nitrogen compound that may be converted by rumen microbes to microbial tissue. Deer ingest urea and other non-protein nitrogenous compounds by consuming water that has been accumulating in pools where feces and urine have been deposited, by lapping urine from other deer, and by the cleaning of the fawns by the doe. Fawns at the Wildlife Ecology Laboratory have shown varying degrees of interest in lapping the urine from their penmates, sometimes refusing milk in preference for urine.

The protein contents of the rumen are often higher than the protein contents of the forages being ingested. The terminal two to three inches of growth on browse sampled by Bissel (1959:57) had 6.9% crude protein, but the rumen contents of nine deer on that range averaged 17.6% crude protein. Fourteen deer studied when range plants were dormant had range and rumen protein contents of 7.1% and 17.2% respectively in January and 6.1% and 15.1% in February. Three deer fed alfalfa pellets had rumen protein contents of 21.0%, 16.2% and 14.7%. Such increases in the nitrogen contents of rumens over those of ingested food materials can be accounted for by nitrogen recycling. The percent of urea recycled by white-tailed deer ranged from 92.3% to 40.6% as dietary protein content increased from 5% to 26% (Robbins et al. 1974).

VITAMINS

The vitamin requirements of adult ruminants are satisfied in part by the rumen microorganisms. Water soluble vitamins of the B complex and fat-soluble vitamin K are synthesized in the rumen if appropriate foods are eaten (Annison and Lewis 1959:20, 155). Vitamins A, D, and E must be supplied in the diet. The provision of at least part of the adult's vitamin requirements by rumen microflora illustrates how important the symbiotic relationship between microflora and ruminant host is. All of the metabolic products of the microflora, except the gases, are used by the ruminant host as sources of different nutrients. When each individual microbe dies, the cell is then digested and nutrients, especially protein, extracted. The rumen is a closed, anaerobic system that represents the link between the animal and its range.

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PRODUCTS OF FERMENTATION

BOOKS

TYPE	PUBL	CITY	PGES	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
edbo	nhfg	conh	256	odvi	w-tail deer of new hampshi	siegler,hr,ed	1968

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CJZOA	48--6	1437	1442	cerv	rumen nitrog level, variat	klein,dr schonhe	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JANSA	38--1	186	191	odvi	nitrogen metabolism of whi	robbins,ct: prio/	1974
JWMAA	27--2	184	195	odvi	rumen ferment, energy rela	short,hl	1963
JWMAA	33--1	187	191	odvi	var ruminoreticul contents	short,hl; remmen/	1969
JWMAA	33--1	204	208	odvi	cage, metab, radioiso stud	cowan,rl; hartso/	1969
JWMAA	33--2	380	383	odvi	rumino-retic char, 2 foods	short,hl; segelq/	1969
JWMAA	36--3	885	891	odvi	digest, metaboli, aspen br	ullrey,de; youat/	1972
VJSCA	21--3	117	117	odvi	prod enrgy, comp rum diges	woodyard,gw; whel	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JANSA	39--1	236	236	odhe	effect starva on rumen bac	decalesta,ds; wa/	1974
JWMAA	14--3	285	289	odhe	sagebrush as a winter feed	smith,ad	1950
JWMAA	28--4	785	790	odhe	essen oils, sageb, rum mic	nagy,jg; steinho/	1964
JWMAA	30--3	466	470	odhe	seas varia, vol fatty acid	short,hl; medin,/	1966
JWMAA	37--3	312	326	odhe	effect nutr chan on captiv	robinette,wl; ba/	1973
JWMAA	39--3	601	604	odhe	reticulo rum char mal nour	dean,re; strickl/	1975
JWMAA	39--4	663	669	odhe	starving and re-feeding mu	decalesta,ds; na/	1975
NAWTA	36---	153	162	odhe	effects pestic, rumen bact	barber,ta; nagy,j	1971

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				ceel			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
NCANA	101-1	227	262	alal	energy req, rumen fermenta	gassaway,wc; coad	1964

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
BPURD	1----	290	296	rata	odvi, compar study rum met	bruggemann,j; dr/	1975
CJZOA	54--5	737	751	rata	dig energ in, glucos synth	mcewan,eh; white/	1976

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JWMAA	33--2	437	439	anam	ruminoreticula VFA content	nagy,jg; williams	1969

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				bibi			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				ovca			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				ovda			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				obmo			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				oram			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JASIA	60--3	393	398	doca	exper, nutri, dairy heifer	broster,wh tuck/	1963
JONUA	101--	1331	1342	doca	diet nonprot N, urea kinet	mugerwa,js; conra	1971

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AJBSA	20--5	967	973	dosh	transf nitr, blood to rume	weston,rh; hogan,	1967
BJNUA	21--2	353	371	dosh	metabolis of urea in sheep	cocimano,mr; leng	1967
BJNUA	27--1	177	194	dosh	ammonia and urea metabolis	nolan,jv; leng,ra	1972
JANSA	35--6	1271	1274	dosh	eff wat restric nutrnt dig	asplund,jm; pfand	1972
PAANA	VI---	378	383	dosh	urea metabolism in sheep	cocimano,mr; leng	1966

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AJPHA	197-1	115	120	rumi	utilization of blood urea	houpt,tr	1959
JDSCA	51--2	265	275	rumi	nitrogen utiliz, metabolis	waldo,dr	1968
JONUA	22--2	167	182	rumi	value, urea, synth, protei	harris,le; mitche	1941

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AJMEA	29---	832	848		design, anal, isotop exper	zilversmit,db	1960
CLCHA	17--9	921	925		singl reag meth, urea nitr	foster,lb; hochho	1971
ECOLA	52--5	935	939		model, absorp, ret ing ele	goldstein,ra; elw	1971
JANSA	25--2	593	593		dig prot est, nrc feed com	knight,ad; harris	1966
JANSA	26--1	119	128		develop, system, feed anal	van soest,pj	1967
JBCHA	58--3	873	904		meth, det biol value, prot	mitchell,hh	1924
JBCHA	58--3	905	922		biol val, prot dif int lev	mitchell,hh	1924

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
SCIEA	130--	1192	1194	mamm	microbial fermentation in	hungate,re; phil/	1959

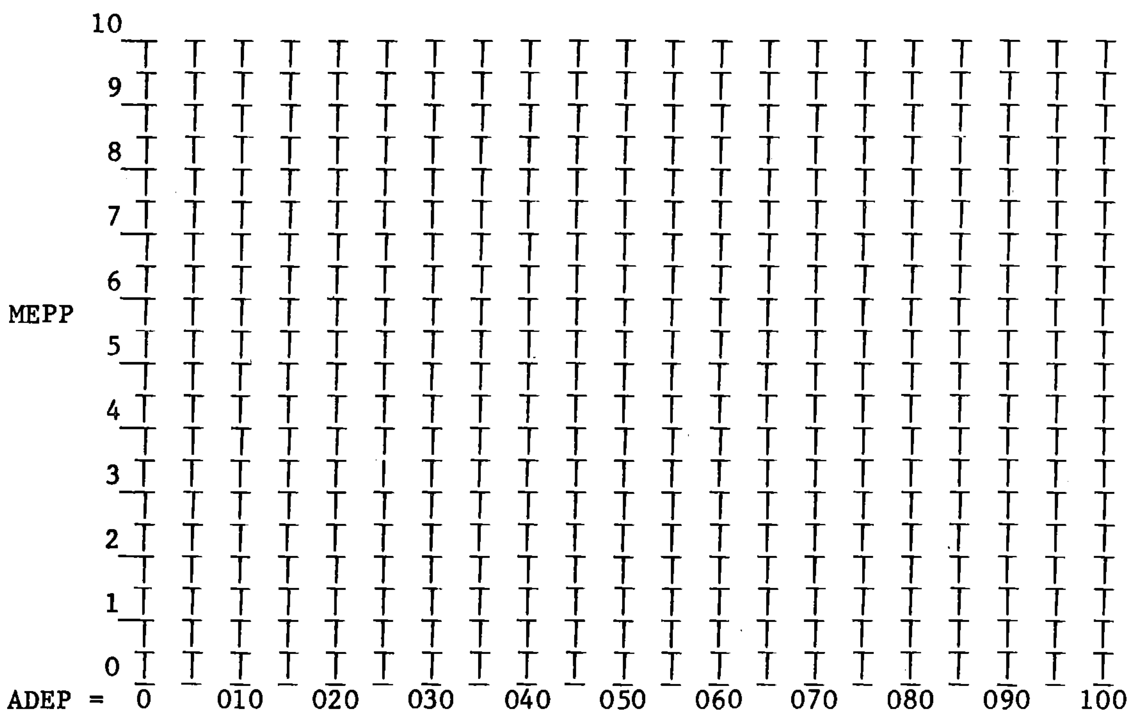
CHAPTER 6, WORKSHEET 1.3a

Estimates of methane energy

The food energy lost in the methane (CH_4) represents about 8% of the total food energy (Blaxter 1967:198-200). The amount of energy lost in methane can be estimated for animals on a roughage diet with the equation:

$$MEPP = 4.28 + 0.059\ ADEP$$

where MEPP = methane production as a percent of the gross energy of the forage ingested and ADEP is the apparent digestible energy of the forage expressed as a percent. Thus if ADEP = 50%, MEPP = 4.28 + (0.059)(50) = 72%. If ADEP = 80%, MEPP = 4.28 + (0.059)(80) = 9.0%. Note that these bracket the 8% figure given above.



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