# ASC 684 Table 50 – Major species of primary rumen bacteria – from Van Soest, 1994

| | Substrate | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **C** | **Hm** | **Pectin** | **Starch** | **Sugars** | **Lipids** | **Protein** | **Acids** | **$H_2$** | **Products** | **Requirements** |
| **Structural CHO Fermenters** | | | | | | | | | | | |
| *Ruminoccus albus* | H F C | F X | | | | | | | | 1,2,Et,$H_2$ ,$CO_2$ | $NH_3$,$CO_2$,Br,V,2± |
| *R. flavafaciens* | H F C | F X | | | | | | | | 1,2,Su,$H_2$ ,$CO_2$ | $NH_3$,$CO_2$,Br,Sta |
| *Fibrobacter succinogenes* | H F C | H Hm | | F Dx | | | | | | 1,2,Su | $NH_3$,$CO_2$,Br,2,5,VSta |
| *Butyrivibrio fibrisolvens* | H F C | F X | | | | | F Pr | | | 1,2,4,Et,La, $H_2$ ,$CO_2$ | $NH_3$,$CO_2$,Br,V,Sta |
| *Eubacterium cellulosolvens* | H F C | F X | | | | | F Pp | | | 1,2,4,La,$CO_2$ | |
| **Pectinolytic species** | | | | | | | | | | | |
| *Succinivibrio dextrinosolvens* | | F Pn | F Pc | | | | | | | 1,2,Su,La | Sta |
| *Lachnospira multiparus* | F Cb | | F Pc | | | | | | | 1,2,Et,La, $H_2$ ,$CO_2$ | 2,V,Sta |
| **Nonstructural CHO fermenters** | | | | | | | | | | | |
| *Bacteroides ruminicola* | F Cb | F X | F Pc | F S | F Hx | | F Pr | | | 1,2,3,Su | |
| *B. amylophilus* | | | | F S | | | H Pr | | | 1,2,Su | $NH_3$,$CO_2$ |
| *Selenomonas ruminantium* | F Cb | F Pn | | F S | F Hx | F Gl | F Pr | | | 2,3,4,Su,La,$H_2$ | 2,$CO_2$± |
| *Streptococcus bovis* | F Cb | | H Pc | F S | F Hx | | F Pr | | | 1,2,Et,La | |
| *Succinomonas amylolytica* | | | | F S | F G | | | | | 2,4,5,Su,$H_2$ | |
| *Eubacterium limosum* | F Cb | F Pn | F Me | | F G Fr | | | F La | U $H_2$ | 2,4 | |
| *Megasphaera elsdenii* | | | | F Ml | F Su | F Gl | F Pp | F La | | 2,3,4,5,6,$H_2$,$CO_2$ | |
| **Lipolytic species** | | | | | | | | | | | |
| *Anaerovibrio lipolytica* | | | | | F Fr | F Tg | A | F La | | 2,3,Su,$H_2$ ,$CO_2$ | A,V |
| **Proteolytic species** | | | | | | | | | | | |
| *Peptostreptococci spp.* | | | | | Fr | | F Pr A | | | 2,4,Br,$NH_3$,$CO_2$ | |
| *Clostridia spp.* | F Cb | F X± | (F Pc) | F S | F Sc Fr | | F Pr A | | | 1,2,4,Br,Et,La,$H_2$,$NH_3$,$CO_2$ | |
| **Organic acid fermenters** | | | | | | | | | | | |
| *Megasphaera elsdenii* | | | | F S | F Ml | F Gl | F Pp | F La | | 2,3,4,5,6,$H_2$,$CO_2$ | |
| *Veillonella alcalescens* | | | | | | | | F La | U $H_2$ | 2,3,$H_2$,$CO_2$ | |
| **Hydrogen utilizers** | | | | | | | | | | | |
| *Methanobacterium ruminantium* | | | | | | | | | U $H_2$ | $CH_4$ | 2,$CO_2$,Br,He,$NH_3$,V |
| *Vibrio succinogenes* | | | | | | | | | U $H_2$ | Et,$CO_2$ | |

| | | | | | |
|---|---|---|---|---|---|
| A | amino acids | H | hydrolyzes substrate but does not use products | S | starch |
| Br | branched-chain fatty acids | | | Sc | sucrose |
| C | cellulose | H2 | hydrogen | Sta | stimulated by amino acids |
| Cb | cellobiose | He | heme | Su | succinate |
| Cf | cellulosic fragments | Hm | hemicellulose | Tg | triglycerides |
| CO2 | carbon dioxide | Hx | hexose | U | utilizes |
| Dx | dextrins | la | lactate | V | vitamins |
| Et | ethanol | Ma | malate | X | xylan |
| F | ferments and utilizes substrate | Me | methanol | 1 | formate |
| | | Ml | maltose | 2 | acetate |
| Fu | fumarate | Pc | pectin | 3 | propionate |
| Fr | fructose | Pn | pentose | 4 | butyrate |
| G | glucose | Pp | peptides | 5 | valerate |
| Gl | glycerol | Pr | protein | 6 | caproate |
| | | | | ± | only in some strains |

# ASC 684

## Figure 51 – $NH_3$ and Microbial Protein in Continuous Culture

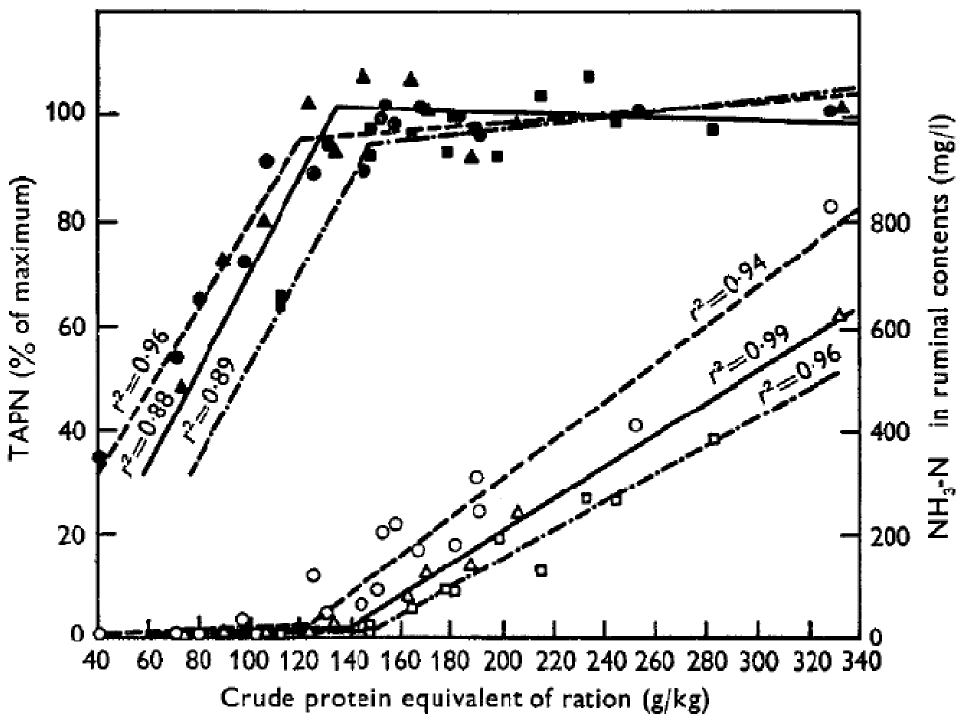
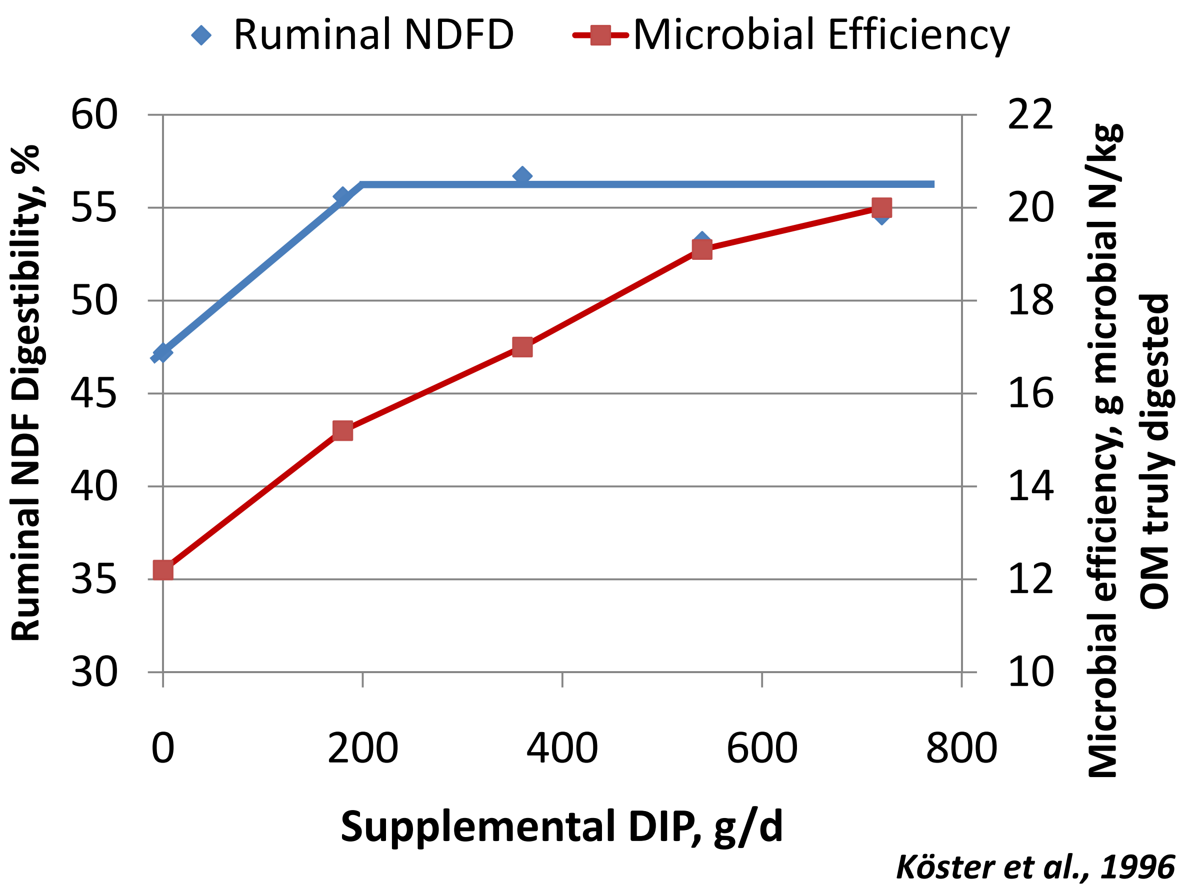



Fig. 1. Relationship between ammonia concentration ($NH_3$-N) of continuous-culture fermentor contents (open symbols) and output of tungstic acid-precipitable nitrogen (TAPN) (closed symbols) when either a purified (○ and ●), all-concentrate (□ and ■) or forage–concentrate (23:77) (△ and ▲) mixture was added to the fermentor.

From: Satter, L. D., and L. L. Slyter. 1974. Effect of ammonia concentration on rumen microbial protein production in vitro. British Journal of Nutrition 32: 199-208.

## ASC 684
## Figure 52 – Degradable protein, NDF digestion, and Efficiency of Microbial Protein Synthesis in vivo




From: Köster, H. H., R. C. Cochran, E. C. Titgemeyer, E. S. Vanzant, I. Abdelgadir, and G. St-Jean. 1996. Effect of increasing degradable intake protein on intake and digestion of low-quality, tallgrass-prairie forage by beef cows. J. Anim Sci. 74: 2473-2481.

# ASC 684

## Figures 53-54. Carbohydrate Use by Ruminal Bacteria

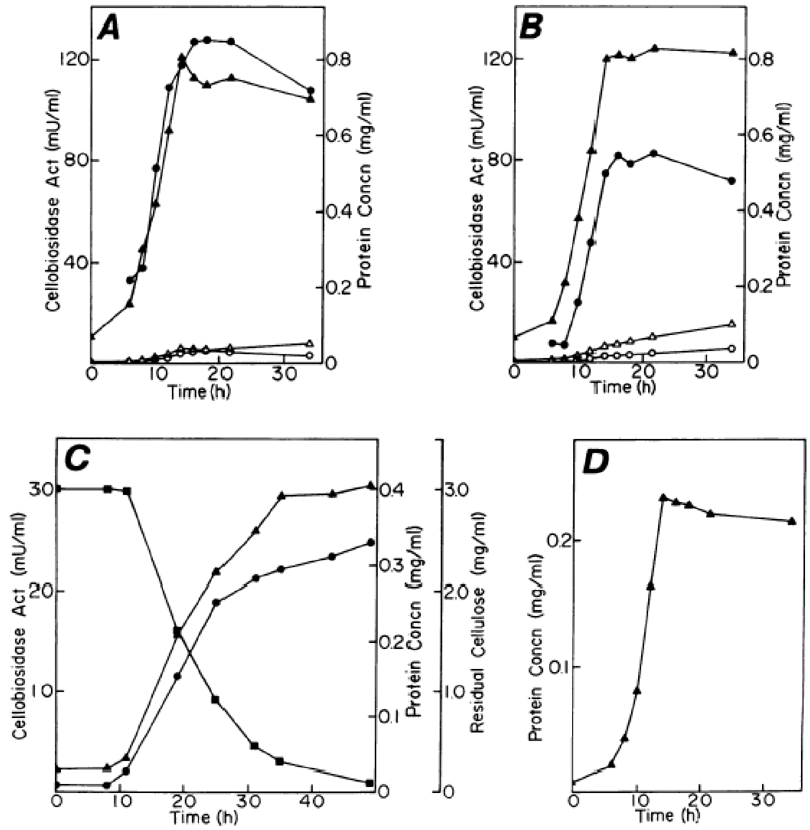



FIG. 1. Growth of *F. succinogenes* subsp. *succinogenes* S85 in batch cultures with glucose (A), cellobiose (B), Avicel microcrystalline cellulose (C), or amorphous cellulose (D) as the carbon source. Symbols: ●, total cellobiosidase activity; ▲, total protein concentration; ○, extracellular cellobiosidase activity; △, extracellular protein concentration; ■, residual cellulose concentration.

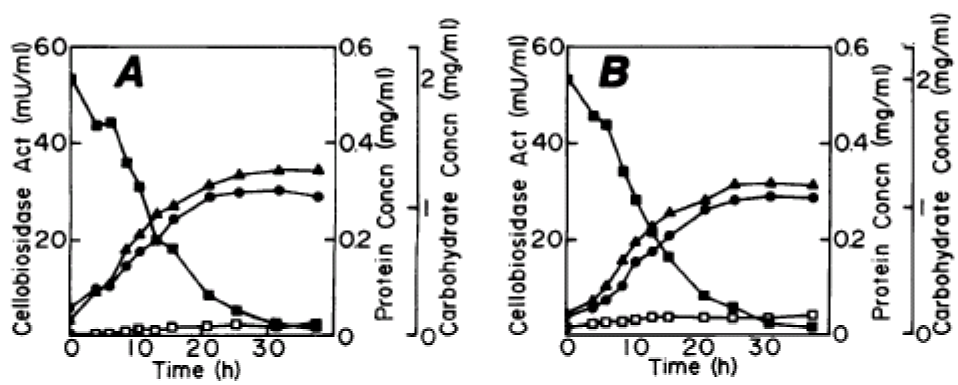



FIG. 2. Growth of *F. succinogenes* subsp. *succinogenes* S85 in batch cultures with Avicel cellulose (0.2%) as the carbon source. A glucose-grown culture (A) or a cellobiose-grown culture (B) was used as the inoculum. Symbols: ●, total cellobiosidase activity; ▲, protein content; ■, cellulose concentration; □, soluble carbohydrate.

**From Huang and Forsberg, 1990. Appl. Environ. Microbiol. 56:1221-1228.**

# ASC 684

## Figures 55-56. Carbohydrate Use by Ruminal Bacteria

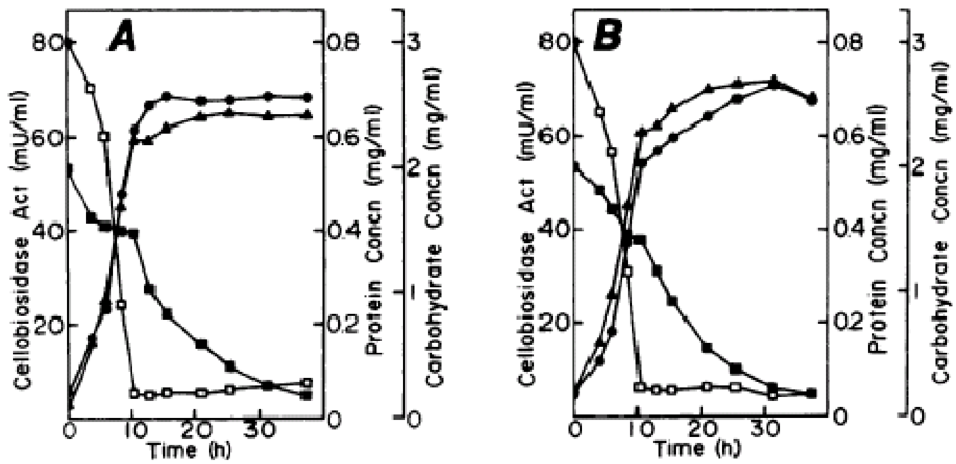



FIG. 3. Growth of *F. succinogenes* subsp. *succinogenes* S85 in batch cultures with glucose (0.3%) and Avicel cellulose (0.2%) as he carbon sources. A glucose-grown culture (A) or a cellobiose-grown culture (B) was used as the inoculum. Symbols: ●, total cellobiosidase activity; ▲, protein content; ■, cellulose concentration; □, soluble carbohydrate concentration.

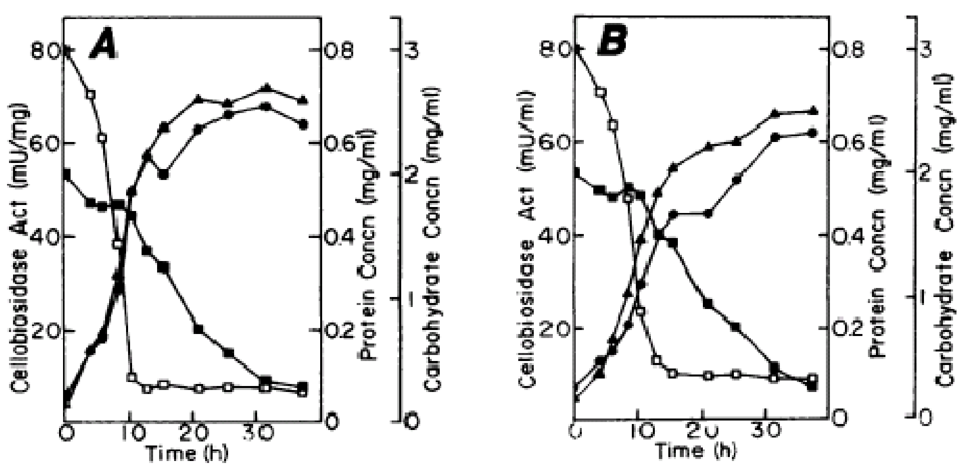
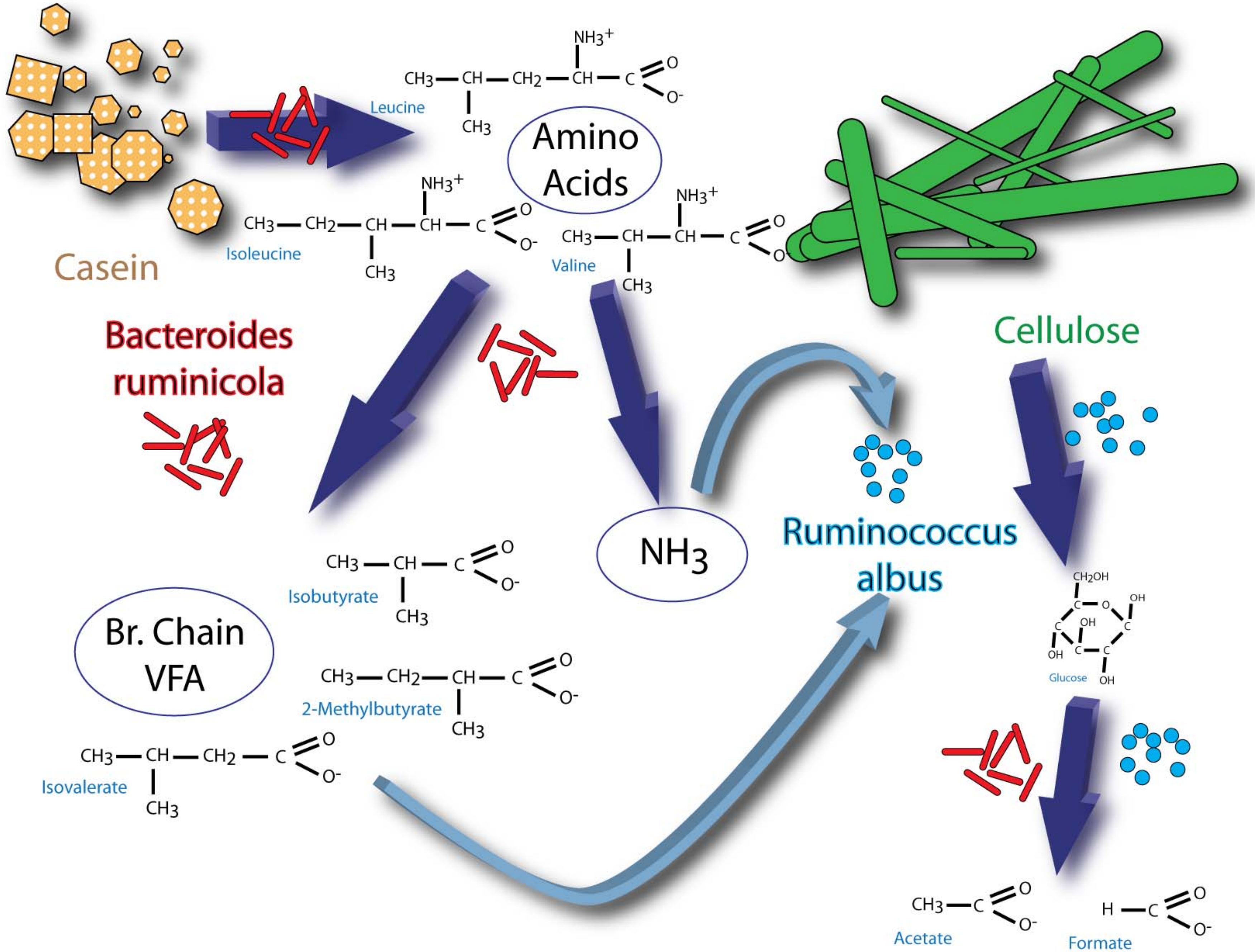



FIG. 4. Growth of *F. succinogenes* subsp. *succinogenes* S85 in batch cultures with cellobiose (0.3%) and Avicel cellulose (0.2%) as the carbon sources. A glucose-grown culture (A) or a cellobiose-grown culture (B) was used as the inoculum. Symbols: ●, total cellobiosidase activity; ▲, protein content; ■, cellulose concentration; □, soluble carbohydrate concentration.

**From Huang and Forsberg, 1990. Appl. Environ. Microbiol. 56:1221-1228.**

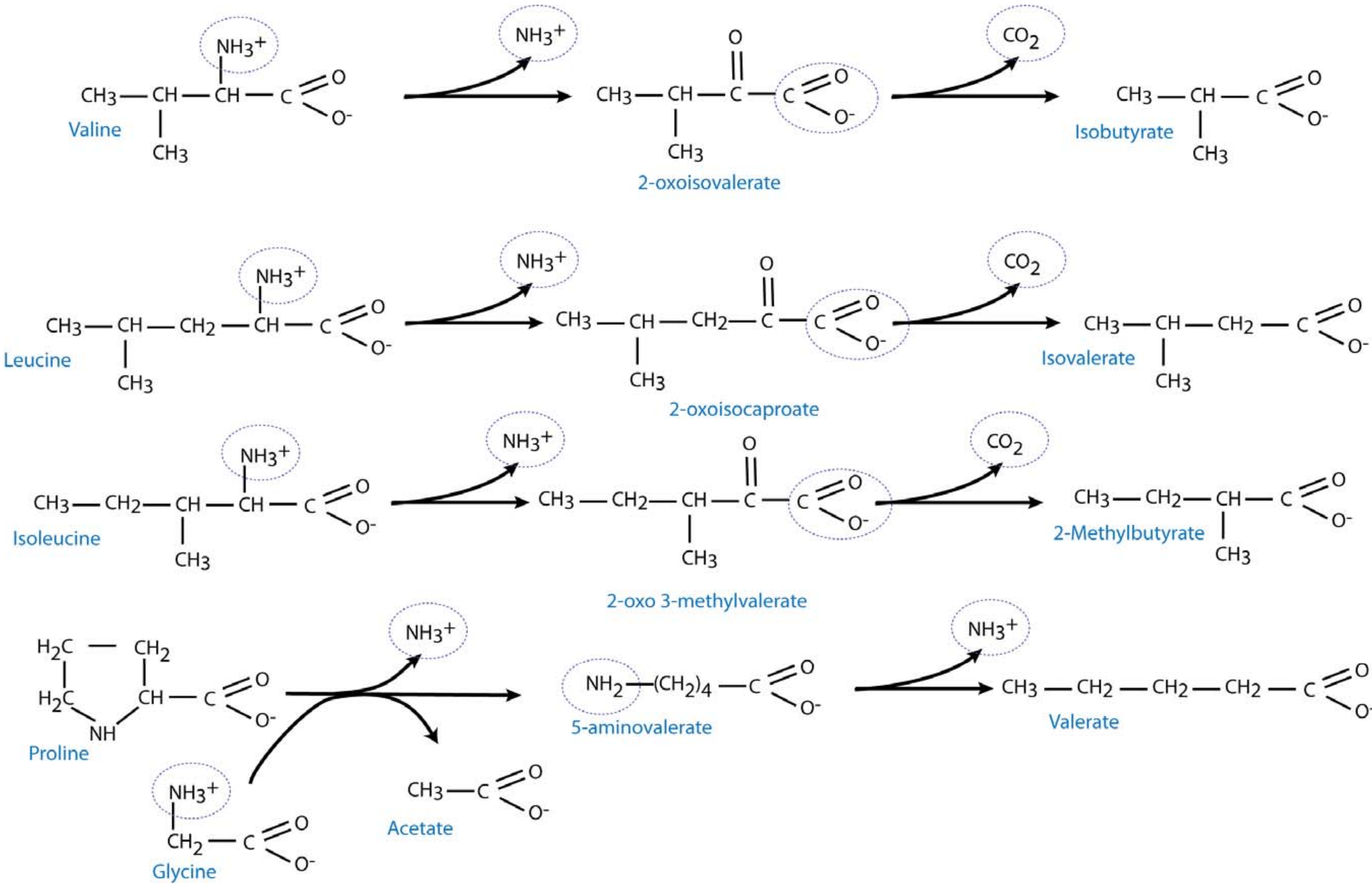
**ASC 684**

**FIGURE 57 – Interactions among rumen bacterial species**



**ASC 684**

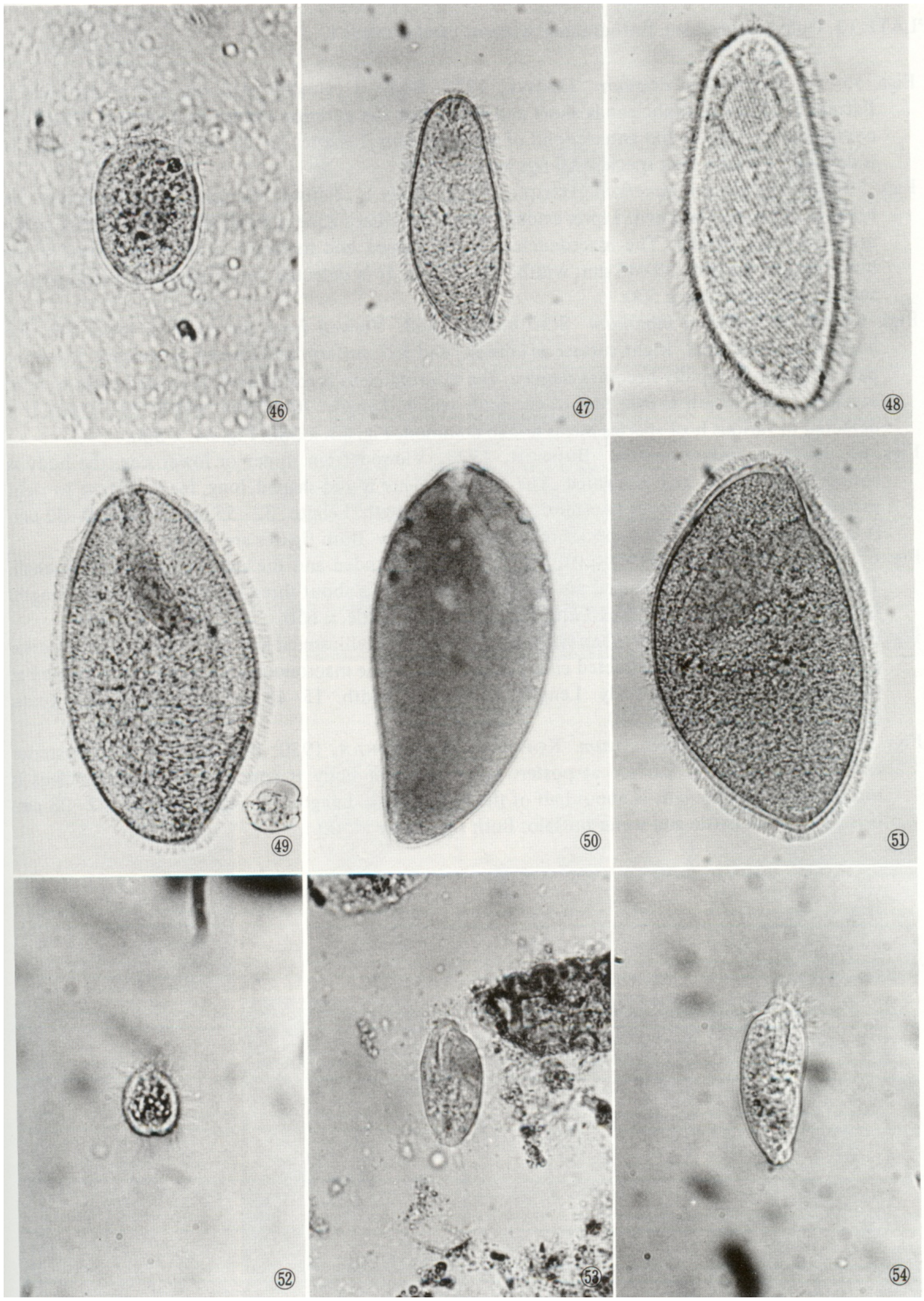
**FIGURE 58 – Ruminal fermentation of select amino acids to C4 & C5 VFA**



# ASC 684
## Table 51. Characteristics of Ruminal Protozoa

| **Characteristic** | **Holotrichs** | **Entodiniomorphs** |
|---|---|---|
| Genera | Isotricha<br>Dasytricha<br>Charonina<br>Buetschlia | Entondinium<br>Diplodinium<br>Eudiplodinium<br>Ostracodinium<br>Metadinium<br>Polyplastron<br>Ophryoscolex<br>Epidinium |
| Ciliary morphology | Distributed over entire cell surface | Restricted ciliary zones |
| Nucleus | Spherical or oval shaped macronucleus | Rod shaped with or without lobes. Useful in spp. ID |
| Skelatal plates | Absent | Present; number and location is used in generic ID |
| Proportion | 10 – 25% | 75 – 90% |
| Number | 1 to 10 x $10^4$ | 1 to 10 x $10^5$ |
| Functional | Increase after feeding<br><br>Increase in cattle fed high forage diets<br><br>Do not hydrolyze structural polysaccharides | Do not increase after feeding<br><br>Increase in cattle fed high grain diets<br><br>Hydrolyze structural polysaccharides |

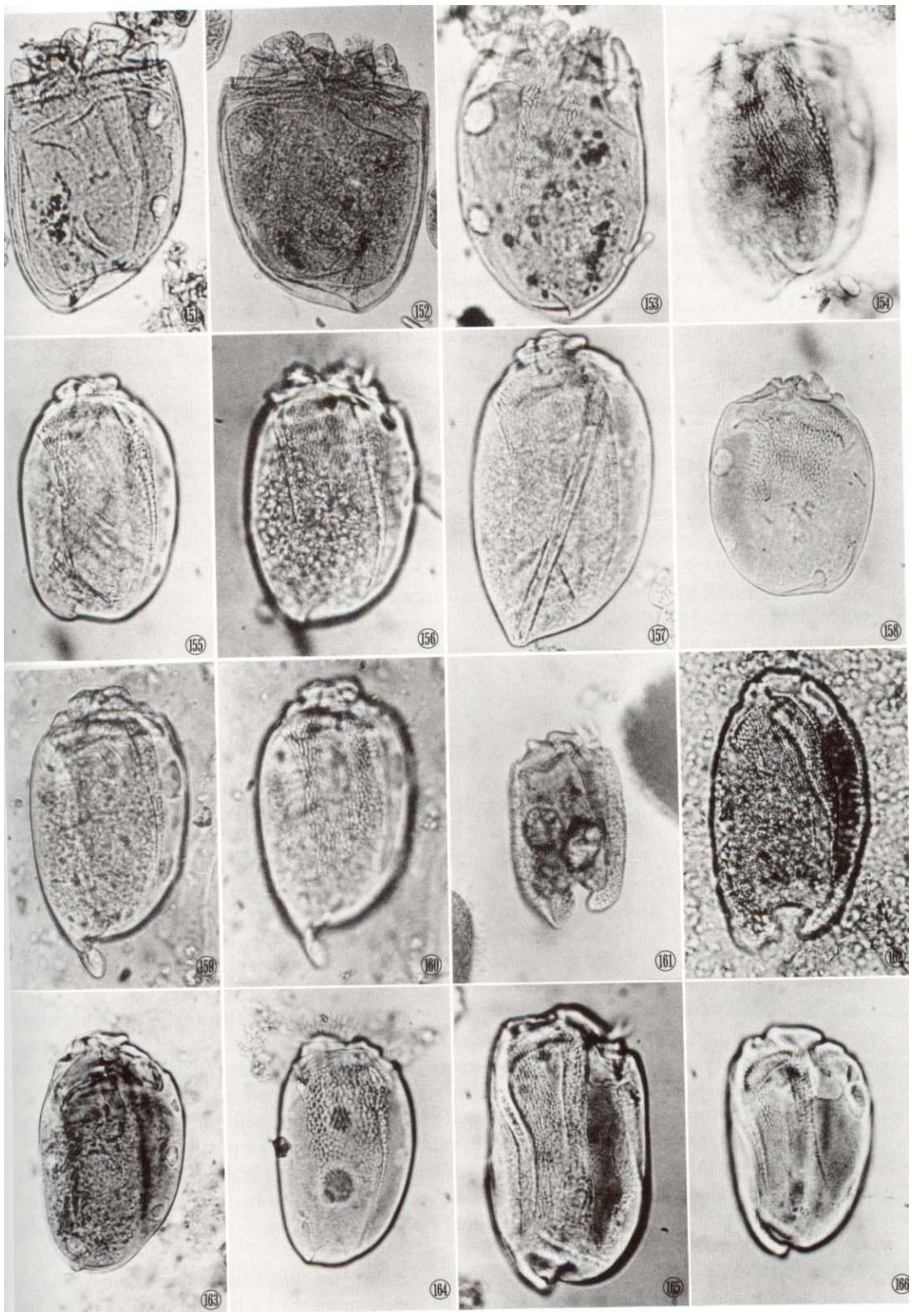
# ASC 684
# Figure 59 - Micrographs of Holotrich Protozoa*




*From Ogimoto and Imai. 1981. Atlas of Rumen Microbiology. Japan Scientific Societies Press, Tokyo.

Magnification in these images ranges from 360 to 760X.

# ASC 684
# Figure 60 – Micrographs of Entodiniomorph Protozoa*




*From Ogimoto and Imai. 1981. Atlas of Rumen Microbiology. Japan Scientific Societies Press, Tokyo.

Magnification in these images ranges from 250 to 600X

# ASC 684

## Table 52. Ciliated protozoal counts, cell volume, and generic distribution in cattle fed high-forage or high-grain diets[a,b]

| | High Forage | | High Grain | |
|---|---|---|---|---|
| Protozoa | Number x $10^4$ | Volume, mL/mL rumen fluid | Number x $10^4$ | Volume, mL/mL rumen fluid |
| Total | 3.70 | .0003 | 23.5 | .0144 |
| | Generic composition, % of total | | | |
| *Isotricha* | 2.8 | 7.9 | 2.7 | 22.2 |
| *Dasytricha* | 11.5 | 3.2 | 4.7 | 2.8 |
| *Charonina* | 4.6 | <.1 | 0 | 0 |
| *Entodinium* | 62.5 | 9.5 | 88.3 | 34.7 |
| *Ostracondinium* | .8 | 1.6 | .2 | .7 |
| *Metadinium* | 2.6 | 20.6 | .3 | 6.9 |
| *Polyplastron* | 1.5 | 9.5 | .04 | .7 |
| *Orphryoscolex* | 13.8 | 47.6 | 3.2 | 30.6 |
| *Epidinium* | 0 | 0 | .7 | 1.4 |

[a]From: Nagaraja and Towne. 1990. P. 187-194 In: The Rumen Ecosystem: The Microbial Metabolism and its Regulation. S. Hoshino et al. (Eds) Springer-Verlag, NY.

[b]Alfalfa hay and corn/sorghum grain diets fed at 80:20 or 20:80.

# ASC 684
# Figure 61.

DIURNAL VARIATION IN NUMBERS OF RUMINAL HOLOTRICH POPULATION

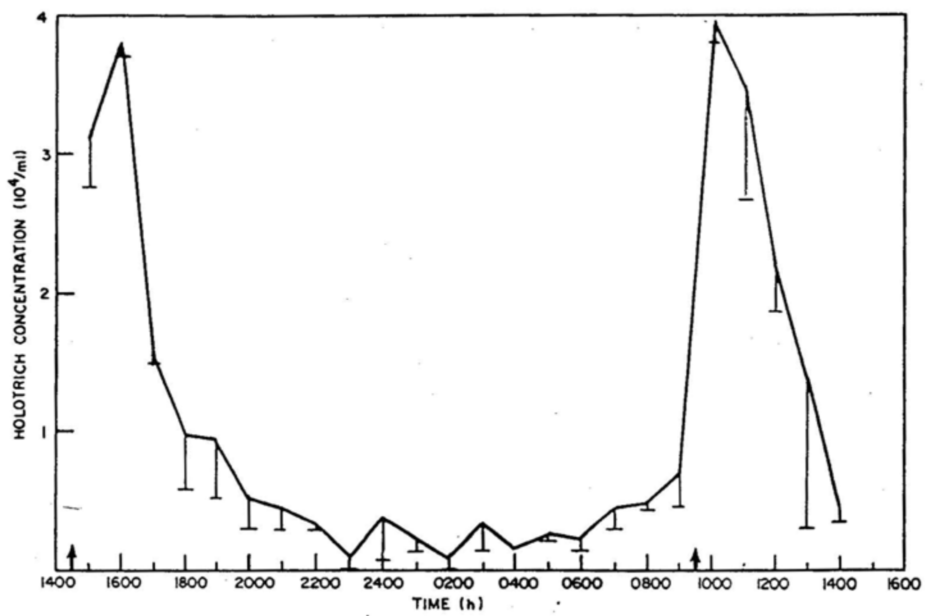
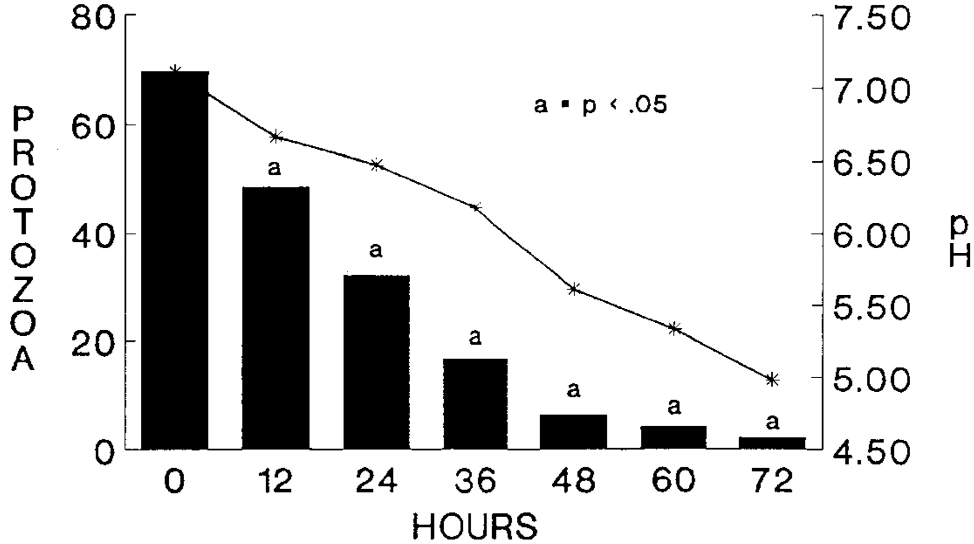



Fig. 1. Mean ruminal holotrich concentration in two steers fed (arrows) 1.5 kg of coarsely chopped wheat straw and 2 kg of grain (corn) diet (n=2) (Murphy et al., 1985. Appl. Environ. Microbiol. 49:1329.

**ASC 684**
**Figure 62.**

RUMINAL CILIATED PROTOZOAL NUMBERS IN ACUTE ACIDOSIS




Nagaraja and Towne 1990. p. 187 - 194. In : The Rumen Ecosystem : The Microbial Metabolism and Its Regulation S. Hoshino et al., (ed) Springer Verlag, NY.

# ASC 684
# Table 53

RUMINAL CILIATED PROTOZOA IN CATTLE FED HIGH GRAIN DIET[a]

| No. of protozoa | % of cattle possesing protozoa at sampling day | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 14 | 28 | 56 | 84 | 112 |
| Defaunated | 0 | 2.5 | 17.5 | 27.5 | 17.5 | 2.5 |
| $<10^4$/g | 0 | 42.5 | 45.0 | 50.0 | 30.0 | 32.5 |
| $10^4$/g | 15.0 | 20.0 | 22.5 | 17.5 | 37.5 | 37.5 |
| $10^5$/g | 85.0 | 25.0 | 10.0 | 2.5 | 7.5 | 20.0 |
| $10^6$/g | 0 | 10.0 | 5.0 | 2.5 | 7.5 | 7.5 |

[a]Towne et al., 1990. Appl. Environ. Microbiol. 56:3174-3178.
[b]Fed ad libitum a diet of 85% cracked corn 10% roughage (dehydrated alfalfa and sorghum silage) and 5% supplement.
n = 40

**Table 54.**

*Ruminal ciliated protozoa in cattle before and after feeding high-grain finishing diet*

| Genera | Sorghum forage silage | Corn grain diet (85%) |
|---|---|---|
| | % | |
| *Isotricha* | 2.2 | 37.5 |
| *Dasytricha* | 1.3 | 0 |
| *Charonina* | 2.7 | 0 |
| *Microcetus* | 3.9 | 0 |
| *Entodinium* | 86.8 | 59.0 |
| *Diplodinium* | 1.0 | 0 |
| *Eudiplodinium* | .6 | 0 |
| *Ostracodinium* | .3 | 0 |
| *Metadinium* | .7 | 0 |
| *Epidinium* | .01 | 0 |
| *Polyplastron* | .5 | 3.4 |

Towne et al., 1990. Appl. Environ. Microbiol. 56 : 3174-3178

# ASC 684
## Table 55. Contribution of Protozoa to duodenal N flow

**Table 3.** Daily intakes and duodenal flows of dry matter, organic matter (OM) and nitrogen and rumen protozoa in steers fed control silage (CS) or high-water-soluble carbohydrates silage (HS)

(Mean values and standard errors of the difference)

| | CS | HS | SED | *P* |
|---|---|---|---|---|
| Intakes | | | | |
| DM (kg/d) | 3·54 | 3·53 | 0·021 | 0·944 |
| OM (kg/d) | 3·29 | 3·28 | 0·027 | 0·952 |
| N (g/d) | 111 | 114 | 0·001 | 0·303 |
| Flows | | | | |
| DM (kg/d) | 2·68 | 2·75 | 0·562 | 0·245 |
| OM (kg/d) | 1·94 | 1·97 | 0·028 | 0·622 |
| Total N (g/d) | 115 | 118 | 0·857 | 0·611 |
| Microbial N (g/d) | 67·5 | 73·8 | 0·432 | 0·154 |
| Protozoal N (g/d) | 14·2 | 18·2 | 0·502 | 0·058 |

From Yanez-Ruiz et al. 2006. Br. J. Nutr. 96:861-869.

# ASC 684

## Table 56. Contribution of protozoa to duodenal FA flow

**Table 4.** Daily intake, duodenal flow and protozoal flow of long-chain fatty acids and biohydrogenation intermediates and protozoal fatty acid duodenal flows of steers fed control silage (CS) or high-water-soluble carbohydrates silage (HS)

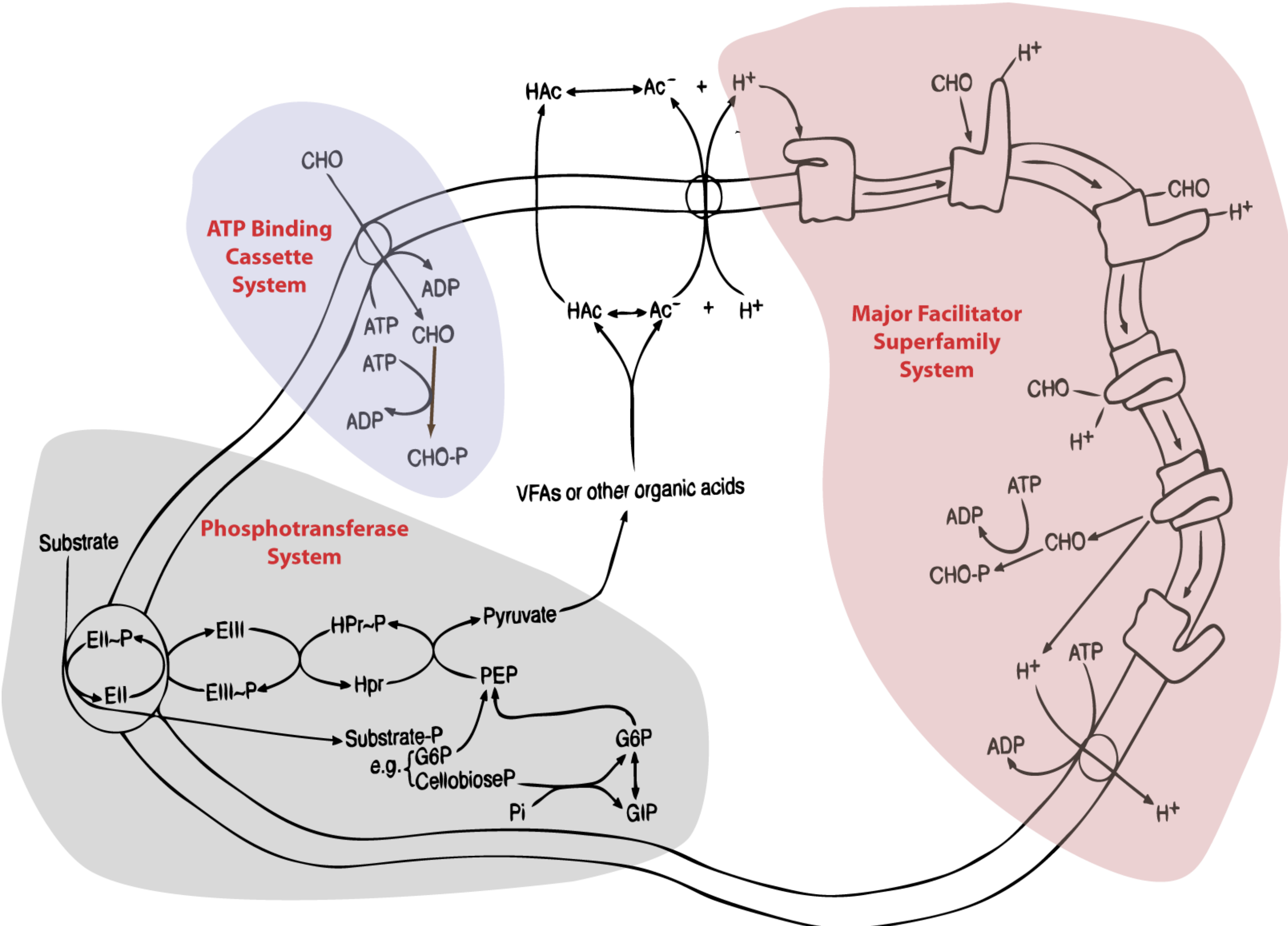
(Mean values and standard errors of the difference)

| | Intake (g/d) | | | | Duodenal flow (g/d) | | | | Protozoal flow (g/d) | | | | Contribution* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fatty acids | CS | HS | SED | *P* | CS | HS | SED | *P* | CS | HS | SED | *P* | CS | HS |
| 12:0 | 0·21 | 0·35 | 0·025 | 0·514 | 0·97 | 0·74 | 0·3 | 0·335 | ND | ND | 0·3 | 0·335 | – | – |
| 14:0 | 2·05 | 2·27 | 0·181 | 0·732 | 1·25 | 0·94 | 0·2 | 0·172 | 0·14 | 0·18 | 0·1 | 0·841 | 11·2 | 19·1 |
| 16:0 | 15·0 | 13·8 | 0·62 | 0·429 | 19·8 | 22·0 | 1·7 | 0·254 | 3·45 | 4·45 | 1·5 | 0·606 | 17·4 | 20·2 |
| 17:0 | ND | ND | – | – | 1·32 | 1·31 | 0·2 | 0·968 | 0·03 | 0·04 | 0·01 | 0·541 | 2·30 | 3·10 |
| 18:0 | 1·98 | 1·56 | 0·025 | 0·156 | 67·6 | 68·2 | 2·7 | 0·421 | 4·77 | 5·19 | 3·4 | 0·626 | 7·10 | 7·60 |
| *Trans*-11-18:1 | ND | ND | – | – | 2·88 | 3·28 | 0·28 | 0·561 | 1·12 | 1·32 | 0·215 | 0·237 | 38·9 | 40·2 |
| *Cis*-9-18:1 | 2·19 | 2·01 | 0·037 | 0·481 | 3·08 | 2·66 | 0·31 | 0·402 | 1·25 | 1·27 | 0·187 | 0·408 | 40·6 | 47·7 |
| *Cis*-9, *cis*-12-18:2 | 14·9 | 13·8 | 1·01 | 0·605 | 4·48 | 4·93 | 0·007 | 0·708 | 1·65 | 1·92 | 0·033 | 0·669 | 36·8 | 38·9 |
| 18:3 | 32·5 | 36·1 | 2·58 | 0·489 | 5·28 | 6·10 | 0·284 | 0·128 | 0·85 | 0·93 | 0·157 | 0·845 | 16·1 | 15·2 |
| 20:0 | 0·78 | 0·60 | 0·025 | 0·207 | 1·25 | 1·21 | 0·061 | 0·361 | 0·45 | 0·47 | 0·032 | 0·273 | 36·0 | 38·8 |
| *Cis*-9, *trans*-11-CLA† | ND | ND | – | – | 0·26 | 0·21 | 0·34 | 0·258 | 0·09 | 0·09 | 0·003 | 0·767 | 34·6 | 42·9 |
| *Trans*-10, *cis*-12-CLA | ND | ND | – | – | 0·10 | 0·11 | 0·10 | 0·489 | 0·03 | 0·04 | 0·001 | 0·489 | 30·0 | 36·4 |
| Total fatty acids | 80·2 | 82·7 | 4·09 | 0·384 | 112·9 | 117·0 | 7·98 | 0·268 | 17·8 | 19·2 | 2·56 | 0·582 | 15·8 | 16·4 |

ND, not detected; CLA, conjugated linoleic acid.
* (Protozoal flow/duodenal flow) ×100.
† Values may be overestimated as a consequence of other isomers which co-elute on the GC column.

From Yanez-Ruiz et al. 2006. Br. J. Nutr. 96:861-869

# ASC 684 Figure 63 – Microbial Transport Systems




Adapted From Russell and Gahr, 2000

# ASC 684
## Table 57 – Microbial Transport Systems

**Table 1.** Functional comparison of the PTS, ABC and MFS transport systems.[a]

| | PTS | ABC | MFS |
|---|---|---|---|
| Function | | | |
| Sugar reception | + | + | – |
| Sugar transport | + | + | + |
| Sugar phosphorylation | + | – | – |
| Regulation | | | |
| PTS | + | – | – |
| Non-PTS permeases | + | – | – |
| Catabolic enzymes | + | – | – |
| Adenylate cyclase | + | – | – |
| Sugar-P phosphatase | + | – | – |
| Transcription factors | + | + | – |
| Carbon storage | + | – | – |
| Nitrogen utilization | + | – | – |
| Virulence[b] | + | + | + |

**a.** PTS, phosphotransferase system; ABC, ATP-binding cassette-type permeases; MFS, major facilitator superfamily.

**b.** The dependency of virulence on the PTS was examined by injection of wild-type versus *pts* or *fruR* mutants of *S. typhimurium* into mice (see Groisman and Saier, 1990; Saier and Chin, 1990). ABC transport systems are involved in export of capsular polysaccharide precursors, haemolysin secretion and resistance to antimicrobial agents. MFS permeases function in antibiotic resistance (see Dinh *et al.*, 1994).

From Saier and Reizer, 1994. Molec. Microbiol. 13:755-764

# ASC 684
# Table 58. Characteristics of PTS

TABLE 1. Structural complexity of PTS

| Protein or process | Description |
|---|---|
| IIC | Permease and receptor (sugar specific) |
| IIB | Direct phosphoryl donor (permease specific) |
| IIA | Indirect phosphoryl donor (family specific) |
| IID | Mannose family-specific auxiliary protein (essential but of unknown biochemical function) |
| EI and HPr | General energy-coupling proteins (PTS pathway specific) |
| Enolase | Upstream energy-yielding enzyme (PEP generating) |
| Phosphoglucoisomerase | Downstream substrate-converting enzyme |
| Glycolysis | Interconnecting cyclic pathway |
| PTS + glycolysis | Metabolite-induced metabolon |

From Barabote and Saier, 2005. Microb. Molec. Biol. Rev. 6608-634.

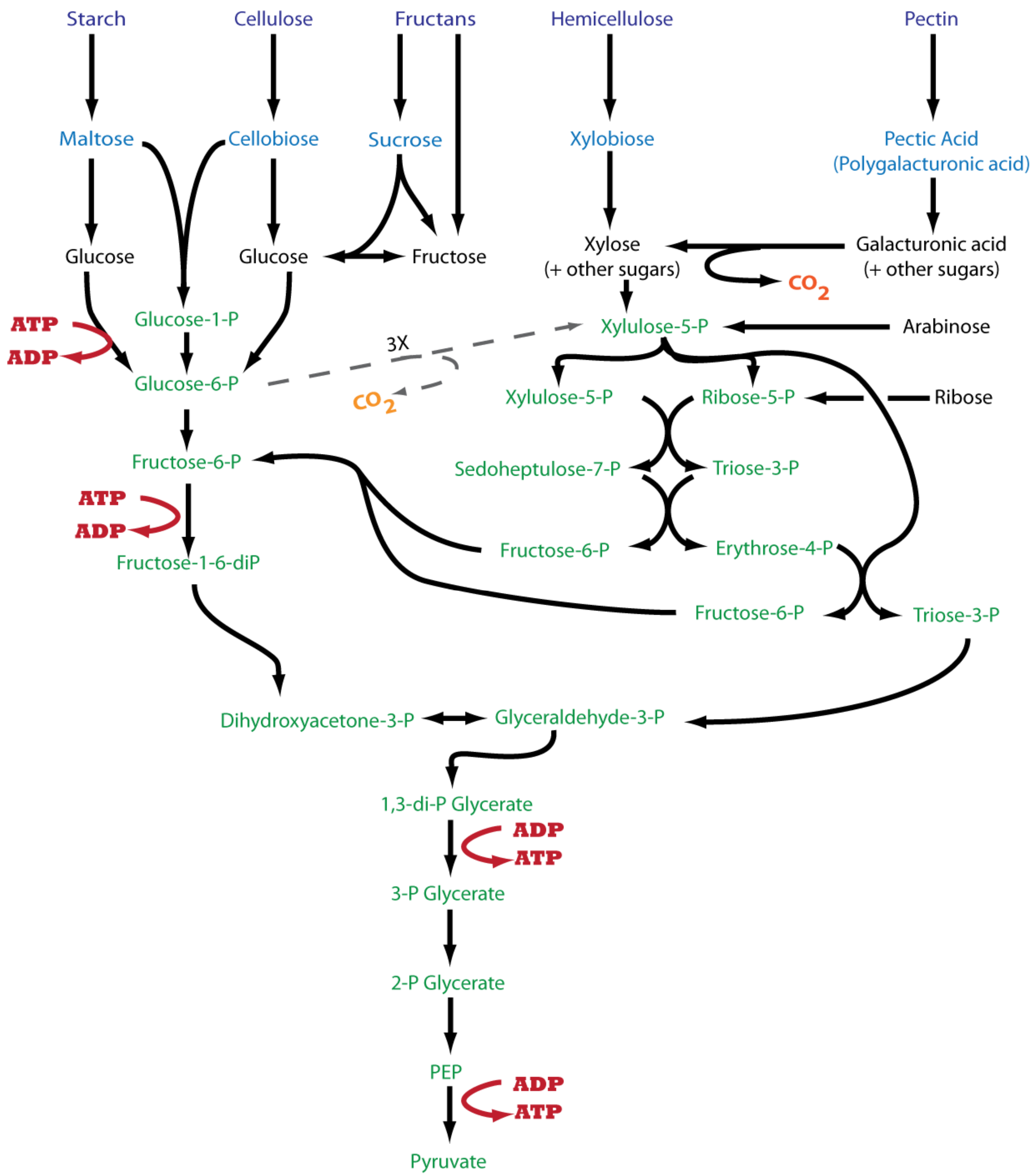
# ASC 684
# Table 59. Functions of PTS

TABLE 2. Functional complexity of PTS

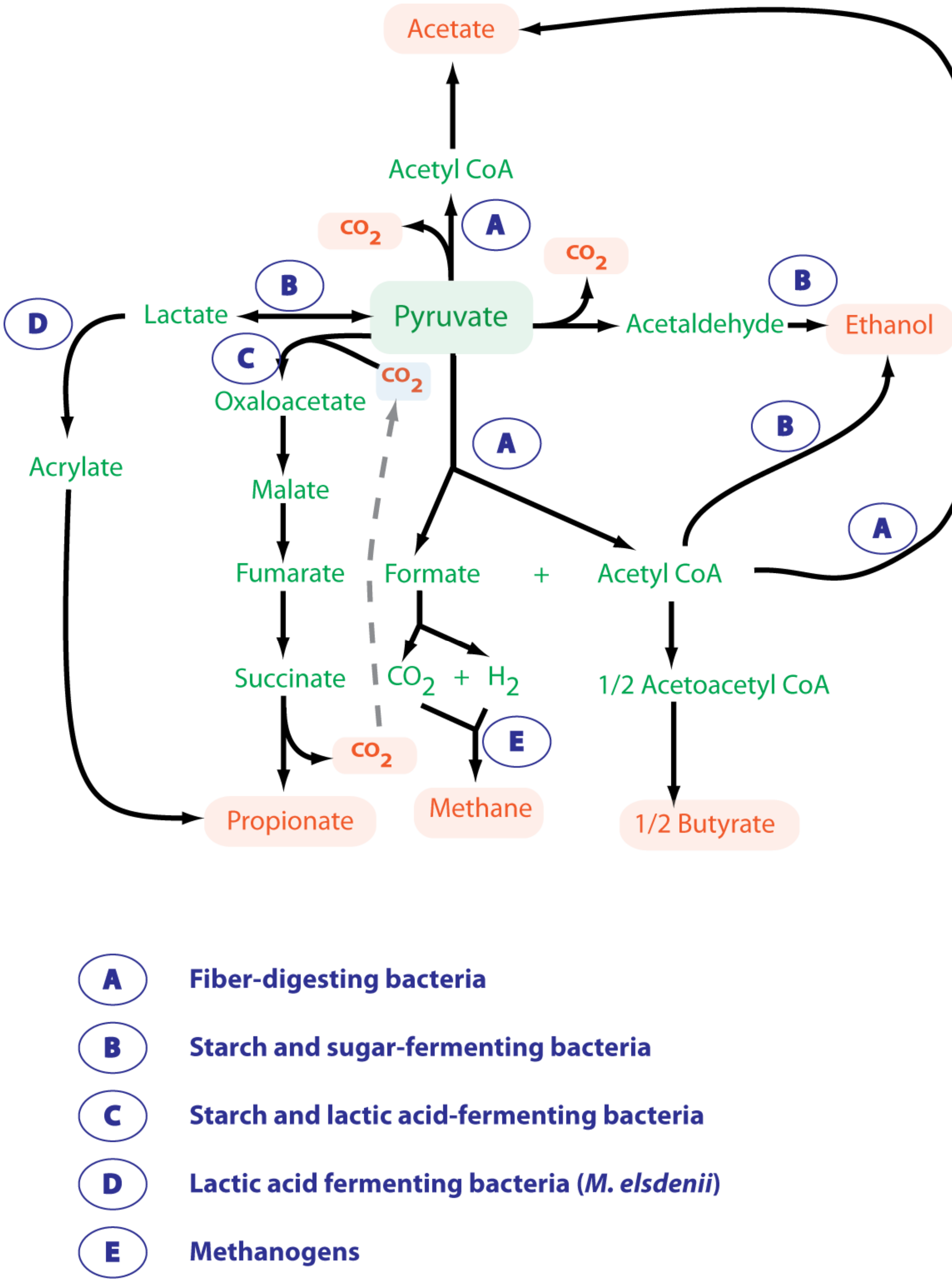
| PTS function |
|---|
| Chemoreception |
| Transport |
| Sugar phosphorylation |
| Protein phosphorylation |
| Regulation of non-PTS sugar transport and metabolism |
| Regulation of carbon metabolism |
| Regulation of carbon storage |
| Regulation of fermentation versus respiration |
| Regulation of cellular motility |
| Coordination of nitrogen and carbon metabolism |
| Regulation of non-carbon-compound transport |
| Regulation of gene expression |
| Regulation of pathogenesis |
| Regulation of cell physiology |
| Regulation of cell division |

From Barabote and Saier, 2005. Microb. Molec. Biol. Rev. 6608-634.

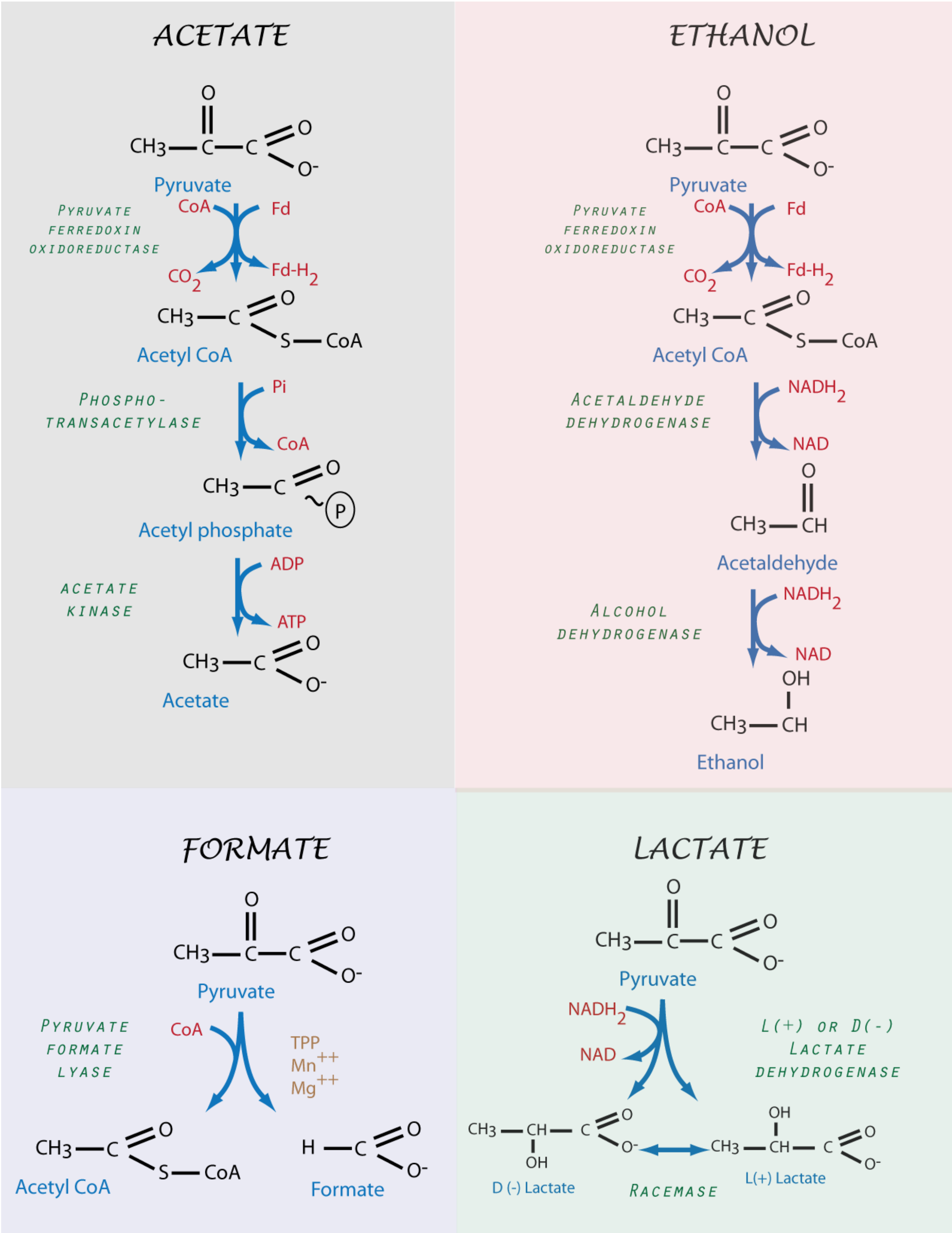
# ASC 684 Figure 64. Carbohydrate Metabolism in Ruminal Bacteria



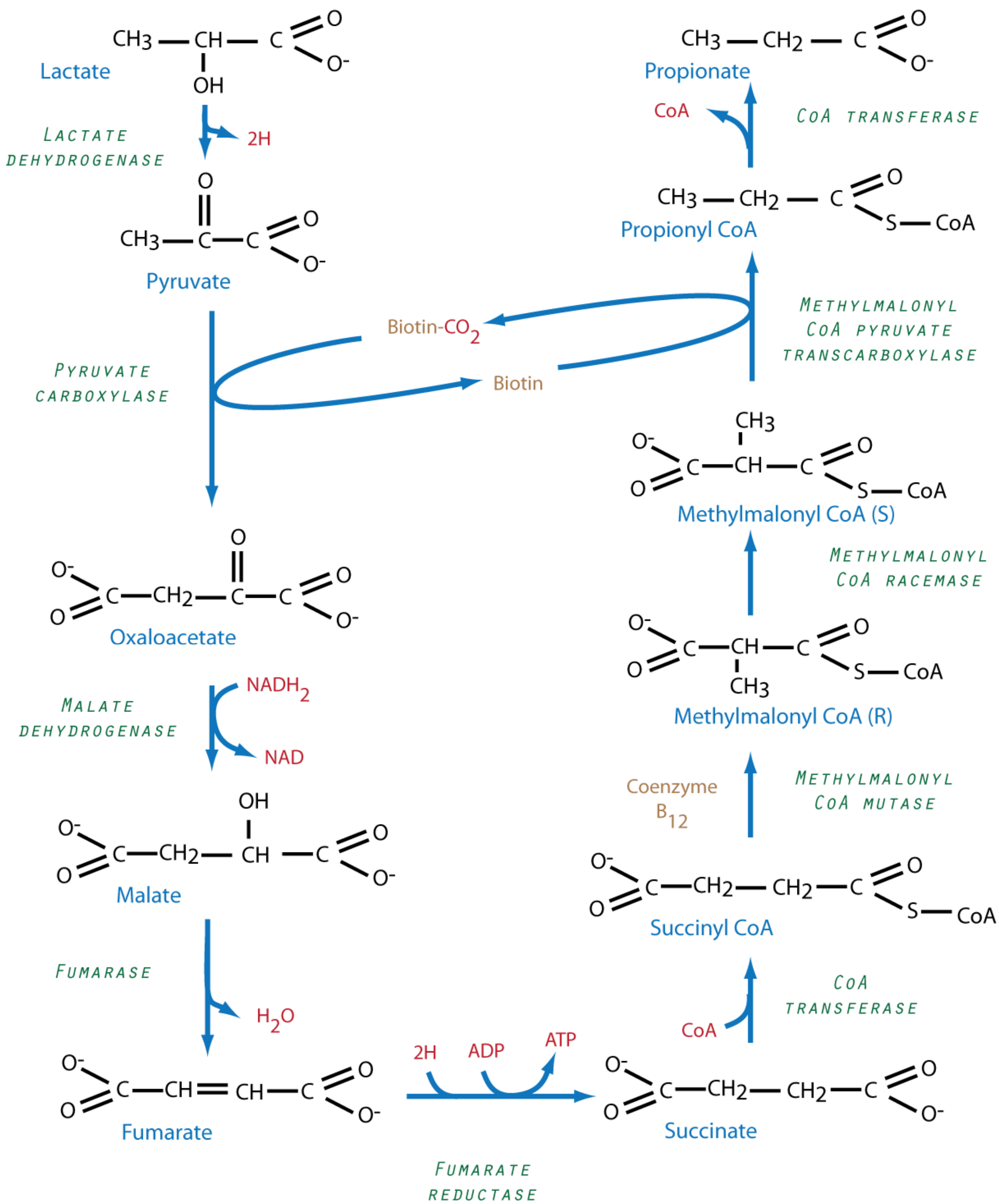
## ASC 684. Figure 65. Pyruvate Metabolic Alternatives



# ASC 684. Figure 66.

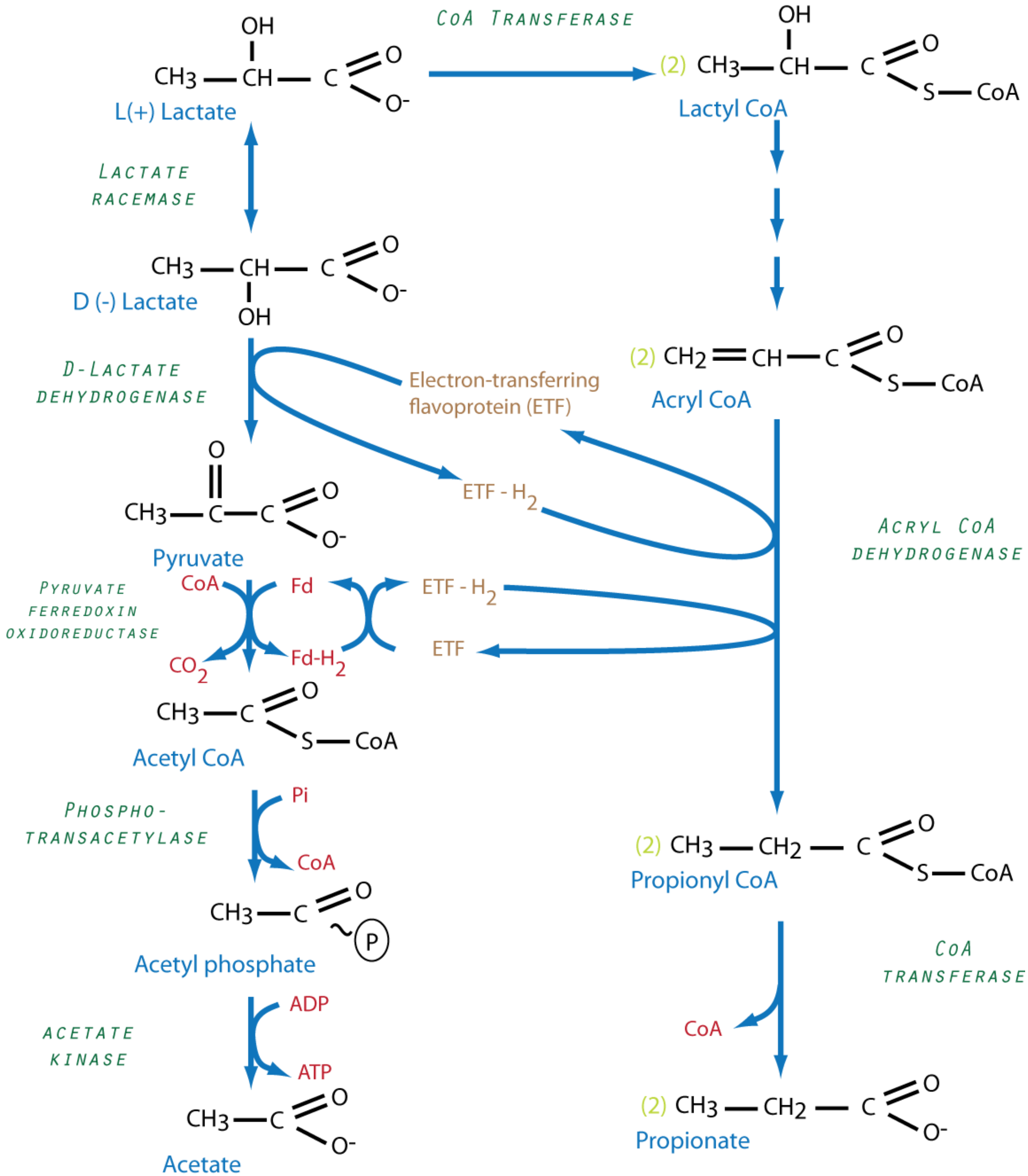


# ASC 684 Figure 67 – Succinate Pathway for Propionate Production



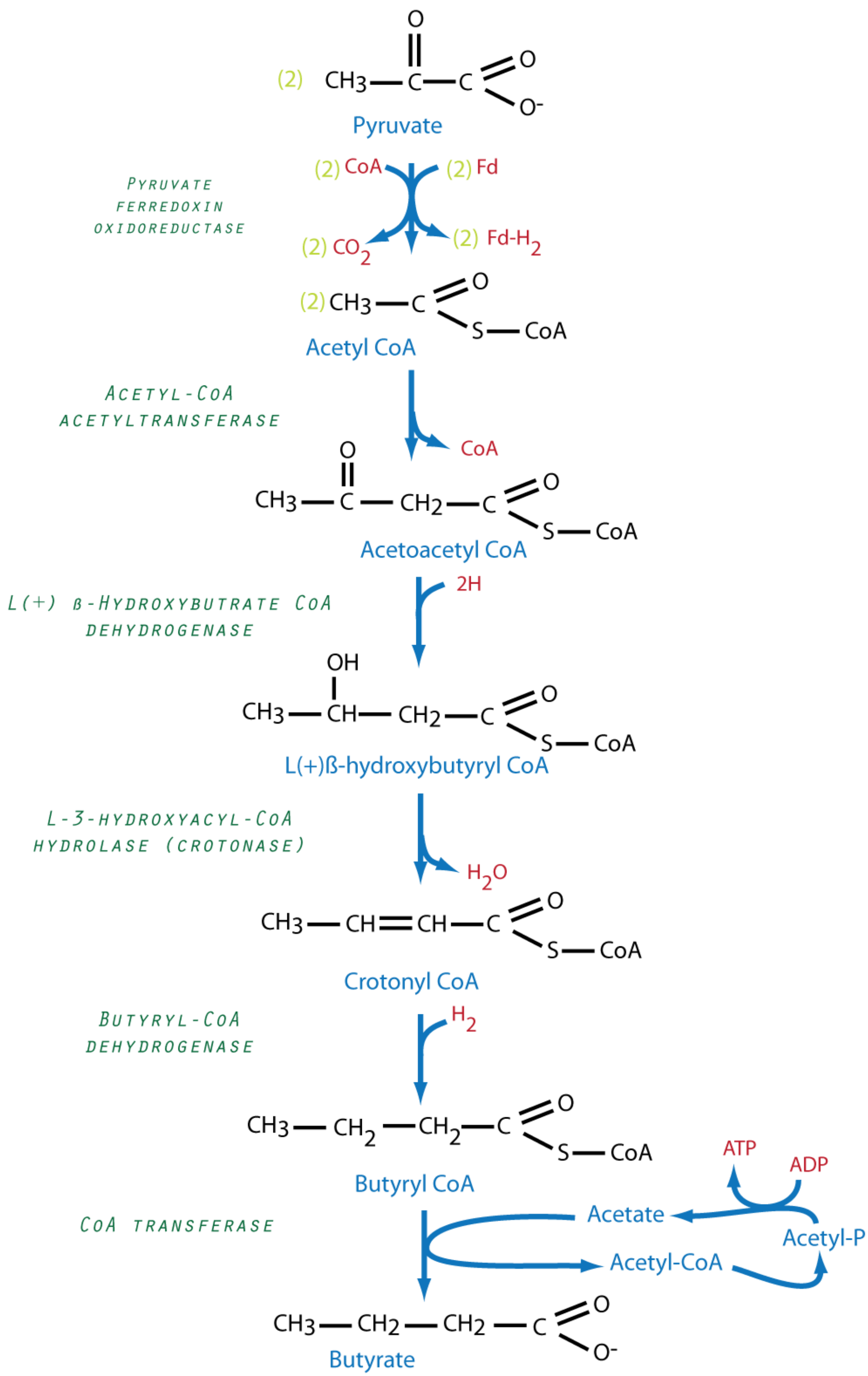

NET RXN: Lactate + $NADH_2$ + ADP + Pi → Propionate + NAD + ATP

# ASC 684 Figure 68. Acrylate Pathway for Propionate Production




NET RXN: 3 Lactate + ADP + Pi → 2 Propionate + Acetate + $CO_2$ + ATP

# ASC 684 Figure 69. Butyrate Production



# ASC 684

## Table 60. Summary of CHO Metabolic Pathways in Ruminal Bacteria

**Table 1**

Enzymatic Reactions Producing ATP (~P) or Reducing Equivalents (2H) and the Balance of these Reactions in Various Fermentations[a]

| *Enzyme* | *Final product* | | | | | |
|---|---|---|---|---|---|---|
| | *Lactate* | *Acetate* | *Propionate*[b] | *Butyrate* | *Ethanol* | *Valerate* |
| Glucokinase | −1 | −1 | −1 | −1 | −1 | −1 |
| Phosphofructokinase | −1 | −1 | −1 | −1 | −1 | −1 |
| Glycerate kinase | 2 | 2 | 2 | 2 | 2 | 2 |
| Pyruvate kinase | 2 | 2 | 2 | 2 | 2 | 2 |
| Acetate kinase | — | 2 | — | — | — | — |
| Fumarate reductase[c] | — | — | 2 | — | — | — |
| Butyrate kinase | — | — | — | 1 | — | — |
| Total (~P) | 2 | 4 | 4 | 3 | 2 | 2 |
| Glyceraldehyde 3-phosphate dehydrogenase | 2 | 2 | 2 | 2 | 2 | 2 |
| Lactate dehydrogenase | −2 | — | — | — | — | — |
| Pyruvate oxidoreductase | — | 2 | — | 2 | 2 | 1 |
| Alcohol dehydrogenase | — | — | — | — | −4 | — |
| Malate dehydrogenase | — | — | −2 | — | — | −1 |
| Fumarate reductase | — | — | −2 | — | — | −1 |
| β-Hydroxybutyrate dehydrogenase | — | — | — | −1 | — | — |
| Butyryl-CoA dehydrogenase | — | — | — | −1 | — | — |
| β-Hydroxyvalerate dehydrogenase | — | — | — | — | — | −1 |
| Valeryl-CoA dehydrogenase | — | — | — | — | — | −1 |
| Total (2H) | 0 | 4 | −2 | 2 | 0 | −1 |

[a] From 1 molecule of hexose via Embden–Meyerhof–Parnas pathway.

[b] The randomizing pathway employing succinate as an intermediate. If the non-randomizing pathway via acrylyl-CoA reductase were used, the (2H) balance would be the same, but the ~P is thought to be only 2.

[c] Assumes an ATP-linked fumarate reductase reaction; *Megasphaera elsdenii*, the predominant organism making valerate, does not have this enzyme since it uses the acrylate pathway to make propionyl-CoA.

# ASC 684 Table 61. Protozoal Effects

**Table 4**
Survey of Some Reported Effects of the Absence of Rumen Ciliate Protozoa

| *Animal or metabolic parameter* | *Reported change in characteristic when ciliate protozoa absent*[a] | | |
|---|---|---|---|
| | *Increase* | *Decrease* | *No effect* |
| *1. Effect on rumen environment* | | | |
| Rumen volume | 27 65 | 84 | |
| Retention time | 27 65 | 47 84 | |
| Bacterial population | 10 25 26 32 47 49 52 53 62 65 70 71 72 | | |
| ATP levels | | 63 92 | |
| Ammonia concentration | | 1 9 13 14 20 25 28 32 34 35 39 40 41 45 47 48 49 52 53 55 57 58 62 66 84 87 88 89 90 | |
| Volatile fatty acid concentration | 25 29 76 87 88 | 1 9 12 14 39 40 43 45 47 52 53 57 62 66 73 85 90 95 97 | |
| Acetic acid (molar proportion) | 1 14 32 72 95 | 12 20 29 31 58 76 85 93 94 97 | |
| Propionic acid (molar proportion) | 18 20 29 31 34 47 48 53 58 76 84 85 93 94 97 | 1 12 13 14 22 25 32 35 57 72 87 95 | |
| Butyric acid (molar proportion) | 1 12 13 22 35 39 49 70 72 93 | 14 18 20 28 29 31 34 48 58 62 84 85 94 97 | |
| Formic acid concentration | | 1 | |
| Lactic acid concentration | 11 12 22 47 60 62 79 96 | 31 | |
| Bicarbonate concentration | 72 | | |
| Rumen pH | 14 97 | 18 25 29 45 87 88 | |
| *2. Effects on blood components* | | | |
| Blood haemoglobin levels | 93 | 2 80 | 25 |
| Plasma levels of: | | | |
| urea | 2 80 | 67 89 93 | |
| oleic acid | | 49 56 | |
| linoleic acid | 56 | | |
| linolenic acid | 49 56 | | |
| amino acids | 33 49 93 | 2 80 | |
| glucose | 2 34 75 80 93 | 35 | |
| volatile fatty acids | | 73 | 25 |
| bicarbonate/$CO_2$ | | | 72 |
| copper | 37 | | |
| insulin | 34 | | |
| albumin | | 73 | |
| β-globulin | 73 | | |
| γ-globulin | | 73 | |
| *3. Effect on ruminal metabolism* | | | |
| Organic matter digestibility — rumen | 50 | 2 22 43 47 48 49 50 55 67 78 83 84 87 88 89 | |
| Organic matter digestibility — intestinal | 48 55 84 | | |
| ADF breakdown | | 21 40 43 46 48 67 89 | |
| Cellulose breakdown | | 2 16 18 38 39 42 53 | 4 51 |
| Starch breakdown | | 17 39 60 87 88 89 | |
| ME supply | | 71 | |
| Methanogenesis | | 20 35 50 85 94 | |
| Biohydrogenation | | | 19 |
| Formation of choline-containing and other specific phospholipids | | 19 61 | |
| Ruminal nitrogen digestibility | | | 23 25 41 58 |
| Proteolytic activity | | 74 81 82 | 44 |
| Urea utilisation | 79 | | |
| Nitrate/nitrite reduction | | 96 | |
| Lysine synthesis | | 64 | |
| Selenomethionine metabolism | | | 30 |
| Efficiency of bacterial protein synthesis | 20 21 48 54 59 77 83 84 86 91 | | |
| Nitrogen flow to duodenum | 44 48 54 59 70 71 77 83 84 87 88 89 90 91 | | |
| Zn, Mn, Cu, Fe flow to lower tract | | | 36 |
| *4. Effect on host ruminant* | | | |
| Food conversion efficiency | 5 6 7 8 22 | 66 69 | |
| Live weight gain | 3 5 6 7 8 22 24 | 1 9 14 37 66 68 69 | 5 25 95 |
| Wool growth | 6 7 8 | | |
| Quantity of carcass fat | | 87 | 69 |
| Susceptibility to, and severity of, bloat | | 15 | |
| Incidence of scours | | 68 | |
| Hepatic copper levels | | 37 | |
| Physical condition | | 68 | 4 |

[a] The references are given in Appendix 1.

From Williams, A.G., and G.S. Coleman. 1988. The rumen protozoa. In: Hobson, P.N. (Ed.) The Rumen Microbial Ecosystem. Elsevier Applied Science. London and New York.

# ASC 684
# Figure 70. The Life Cycle of an Anaerobic Fungi

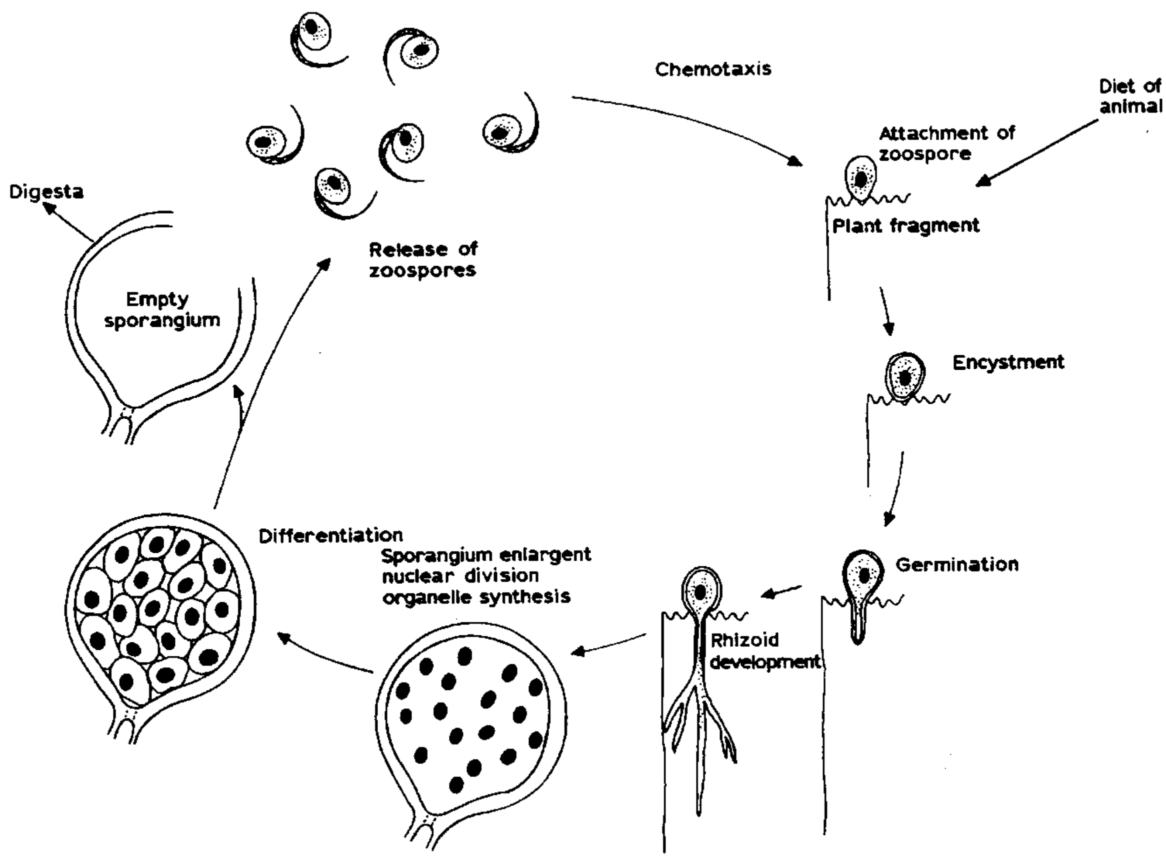



**Fig. 2.** Life cycle of *Neocallimastix*.

From Orpin, G.C., and K.N. Joblin. 1988. The rumen anaerobic fungi. In: Hobson, P.N. (Ed.) The Rumen Microbial Ecosystem. Elsevier Applied Science. London and New York.

# ASC 684
## Figure 71. Vegetative and zoospore stages of rumen fungi

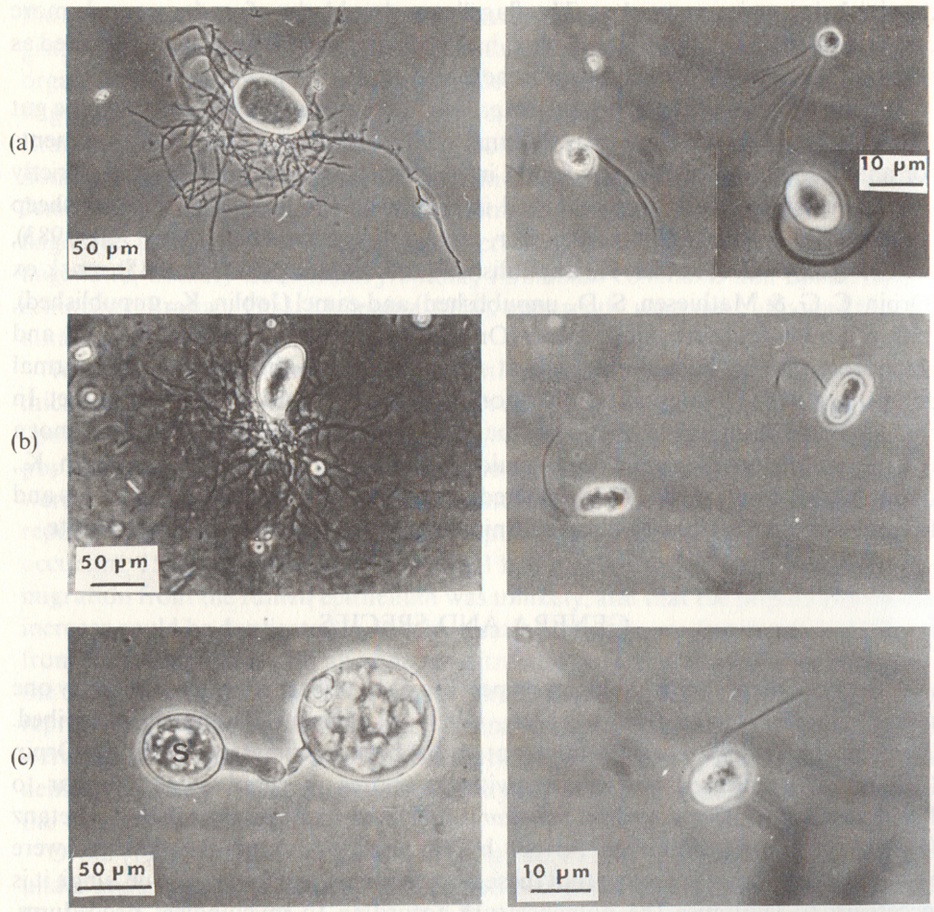
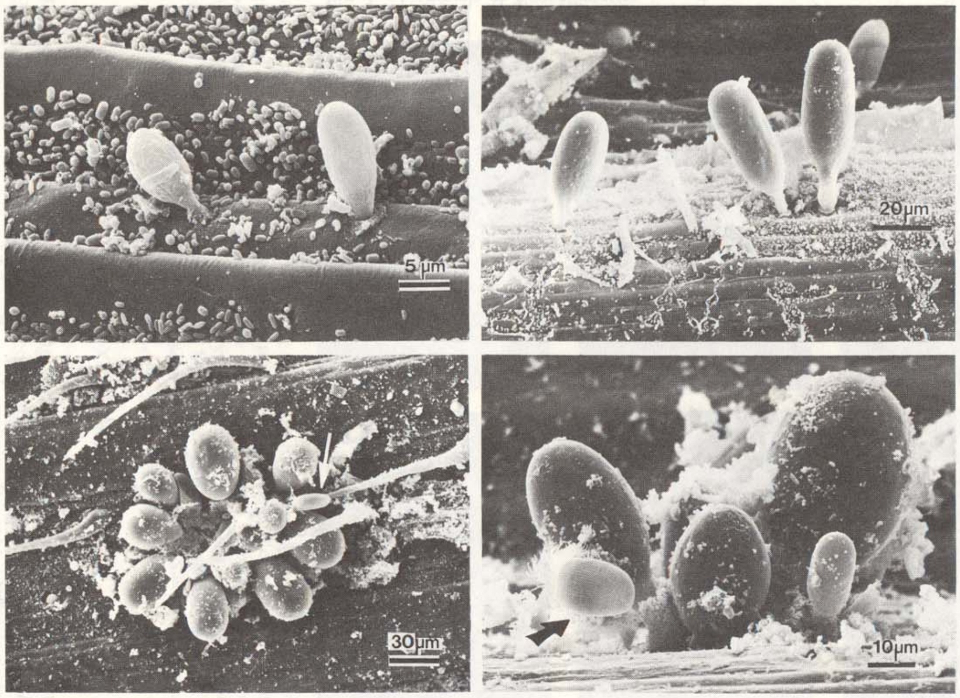



**Fig. 1.** Light micrographs of vegetative (left) and zoospore stages (right) of rumen fungi cultured *in vitro*. Glutaraldehyde-fixed preparations, except the inset photograph of *N. patriciarum* zoospore. (a) *Neocallimastix patriciarum*; inset, living zoospore showing the flagella united to form a single locomotory organelle. (b) *Piromonas communis*; the vegetative stage is in culture with a methanogenic bacterium. (c) *Sphaeromonas communis*; note the limited rhizoidal system and associated spherical body; S = sporangium.

From Orpin, G.C., and K.N. Joblin. 1988. The rumen anaerobic fungi. In: Hobson, P.N. (Ed.) The Rumen Microbial Ecosystem. Elsevier Applied Science. London and New York.

# ASC 684
# Figure 72. Micrographs of Ruminal Fungi




g. 3. Scanning electron micrographs of sporangia of rumen fungi growing together with bacteria and protozoa (arrowed) on ryegrass stems from rumen digesta of a sheep fed on meadow hay.

From Orpin, G.C., and K.N. Joblin. 1988. The rumen anaerobic fungi. In: Hobson, P.N. (Ed.) The Rumen Microbial Ecosystem. Elsevier Applied Science. London and New York.

# ASC 684
## Figure 73 – Dilution Rate and Microbial Yield

From Van Soest (1994)

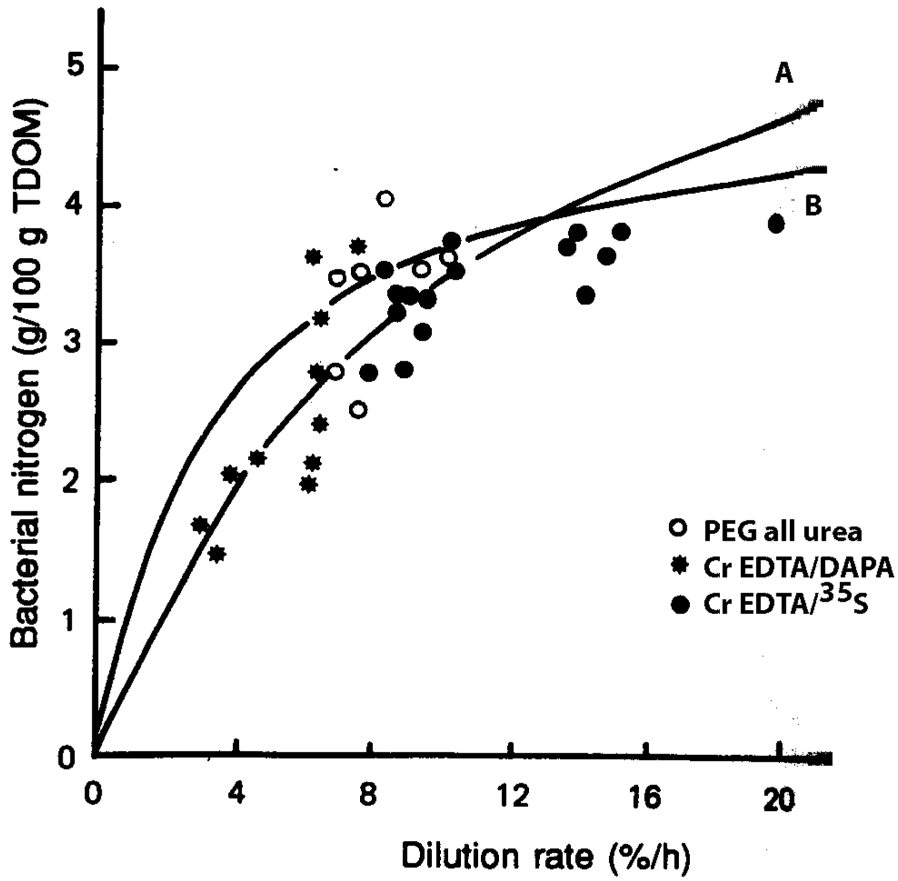



**Figure 16.10.** Relation between in vivo microbial yield and liquid turnover rate as summarized from the literature (courtesy of P. H. Robinson). Yield values have been recalculated uniformly to g N × 6.25 per 100 g true digestible organic matter (TDOM). Values obtained using Cr-EDTA and diaminopimelic acid (DAPA) are denoted by an asterisk, and those obtained with polyethylene glycol and all-urea diets are open circles. Line A is the best fit to Michaelis-Menten kinetics: $1/y = 0.14 + 0.015(1/x)$, $R^2 = 0.76$. Line B is the regression obtained by van Nevel and Demeyer (1979) using a chemostat. Note that overestimation of rumen turnover by the liquid markers could lead to substantial error at low dilution rates but negligible error at high dilution rates. Maximal yield ($y_g$) and maintenance (M) cost can be calculated from the above regression according to the equation $1/y = (M/K) + (1/y_g)$ (Hespell and Bryant, 1979), where K is the dilution rate. Maintenance (slope of regression) is 0.015 g N/100 g carbohydrate fermented; and maximum yield is 7.11 g N/100 g carbohydrate fermented.

# ASC 684
# Table 62. Composition of Ruminal Microorganisms

Table 16.9. Composition of microbes (on a dry matter basis unless otherwise indicated)

| Constituent | Bacteria | | Protozoa |
|---|---|---|---|
| | Probable[a] | Range | Range |
| Total nitrogen | 10[b] | 5.0[c]–12.4[d] | 3.8–7.9[d] |
| True protein | 47.5[e] | 38–55 | — |
| RNA | 24.2[e] | — | — |
| DNA | 3.4[e] | — | — |
| Lipid | 7.0[e] | 4[f]–25[e] | — |
| Polysaccharide | 11.5[e] | 6–23[e] | — |
| Peptidoglycan | 2 | — | 0 |
| Nitrogen digestibility | 71[g] | 44–86[g] | 76–85[h] |

[a]Many discordant values have been recorded, possibly reflecting contamination or inclusion of plant material.
[b]Isaacson et al., 1975.
[c]R. H. Smith and McAllan, 1973.
[d]Weller, 1957.
[e]Summarized by Hespell and Bryant, 1979.
[f]Abdo et al., 1964; also reported 6% crude fiber.
[g]Bergen et al., 1968; values as percentage of total N.
[h]Bergen et al., 1967.

From Van Soest (1994)