# LZT5853 - Structural carbohydrates and voluntary feed intake in ruminants

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# *Ruminal kinetics*

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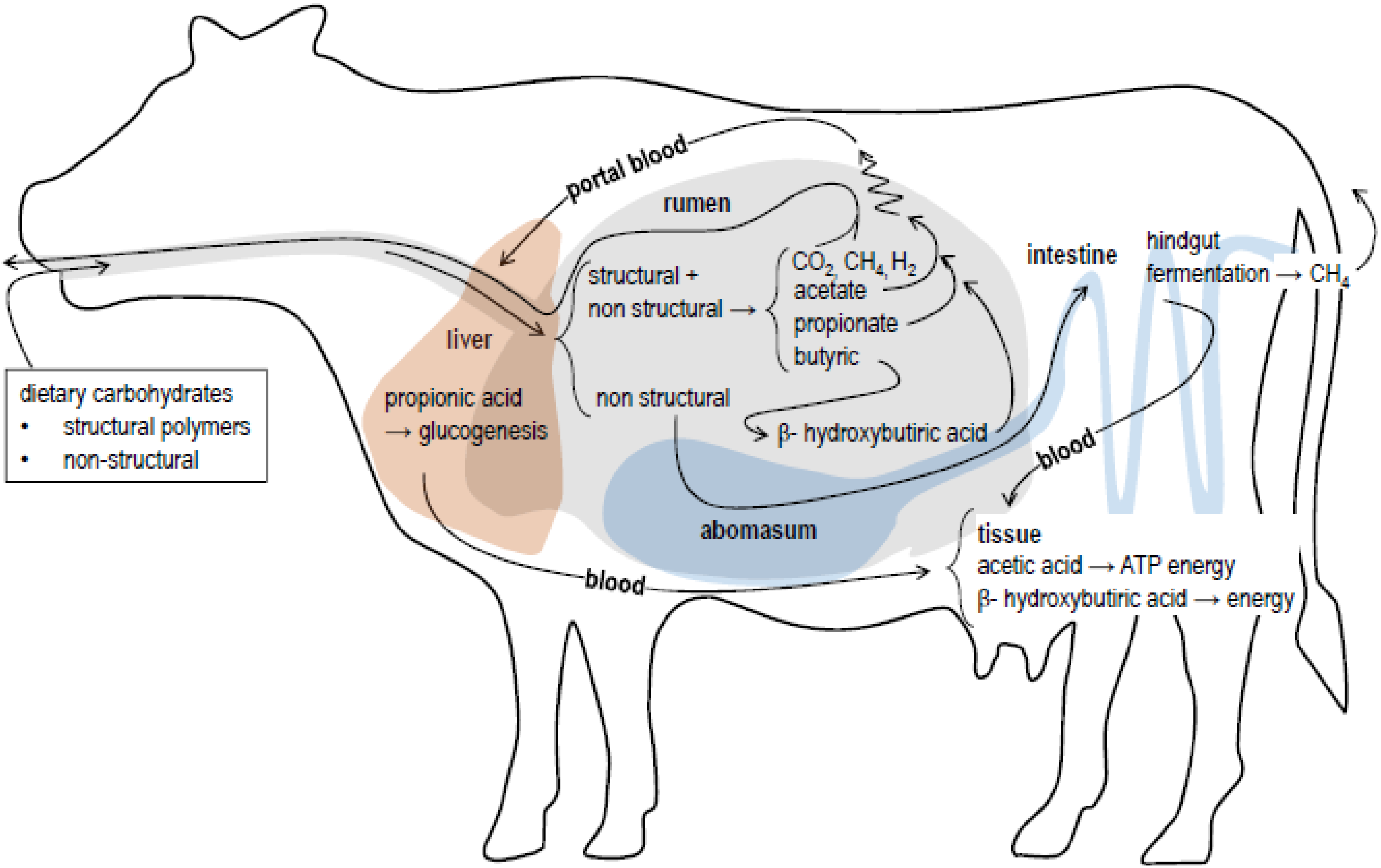

portal blood
rumen
liver
structural +
non structural →
non structural
$CO_2$, $CH_4$, $H_2$
acetate
propionate
butyric
β- hydroxybutiric acid
intestine
hindgut
fermentation → $CH_4$
propionic acid
→ glucogenesis
abomasum
blood
blood
tissue
acetic acid → ATP energy
β- hydroxybutiric acid → energy
dietary carbohydrates
• structural polymers
• non-structural

**Available presentation: Digestion kinetics in ruminants**

https://slideplayer.com/slide/6136275/#.YGiSM4yY3So.gmail

# Digestion Kinetics in Ruminants

Church: 145-170

Van Soest: 354-370; 371-384

Sejrsen et al. pp. 87-126

Firkins, J. L., M. S. Allen, B. S. Oldick, and N.R. St-Pierre. 1998. Modeling ruminal digestibility of carbohydrates and microbial protein flow to the duodenum. J. Dairy Sci. 81:3350-3369

Available at: http://jds.fass.org/cgi/reprint/81/12/3350.pdf

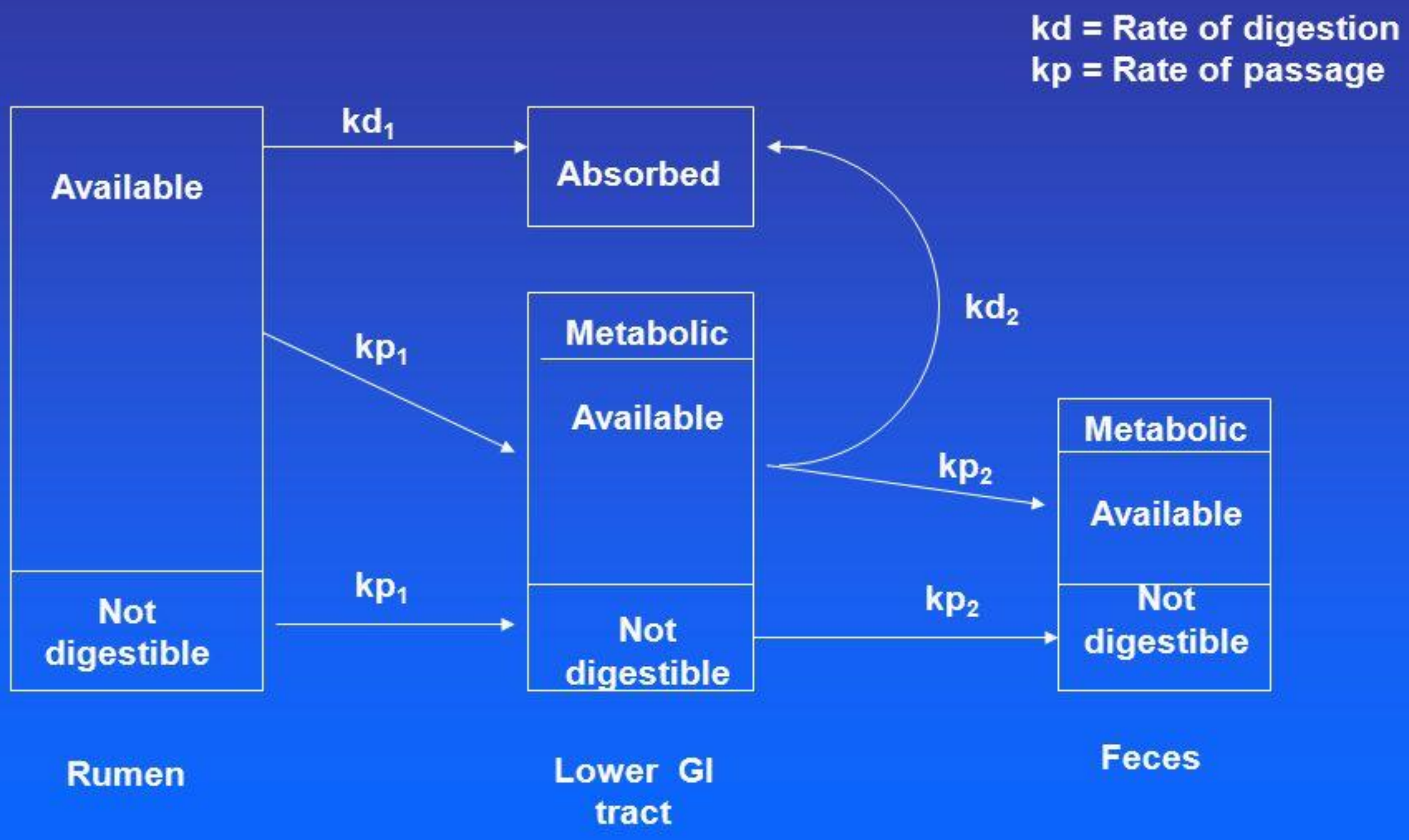
Fox, D.G., L.O. Tedeschi, T.P. Tylutki, J.B. Russell, M.E. Van Amburgh, L.E. Chase, A.N. Pell, and T.R. Overton. 2004. The Cornell Net Carbohydrate and Protein System model for evaluating herd nutrition and nutrient excretion. Anim. Feed Sci. and Tech. 112:29-78 (Read pages 51-78).

Available at: Library > Collections > e-journals > Animal Feed Science and Technology > Volume 112 Issues 1-4.

# Importance of digestive kinetics in ruminant animals

- When a feed particle enters the rumen, it can only leave by one of two mechanisms
  - Fermentative digestion
    - 61 to 85% of OM
  - Passage
- These two processes compete with each other

# Effects of rates of digestion and passage on nutrient digestion



# Implications of kp and kd

- The extent of digestion of a feed is controlled by the relationship between kp and kd

  Percent of a nutrient digested in the rumen $= kd_1 / (kp_1 + kd_1)$

  Percent of a nutrient passing from the rumen $= kp_1 / (kp_1 + kd_1)$

- Indigestible markers can be used to estimate kp
  - May be an incorrect assumption if considering two separate feeds
    - kp of the digestible portion may be less than that of the indigestible fraction if found in separate feeds
    - However, digestible and indigestible fractions are likely to be found in each feed particle
- kp and kd will affect:
  - Feed digestibility
  - Feed intake
  - Fermentation endproducts

# Mechanism of particle passage from the rumen

- Impediments to particle passage from the rumen
  - Fiber mat
  - Reticulo-omasal orifice
- Factors controlling passage from the rumen
  - The functional specific gravity of a feed particle must increase to 1.2 to drop from the mat into the liquid layer to pass from the rumen
    - The functional specific gravity increases by:
      - Hydration of the gas-filled voids within the particles
      - Reducing the amount of gas bubbles attached to the particles

| Alfalfa and orchardgrass | DM passage |
|---|---|
| | r |
| Functional specific gravity | .83 |
| Gas associated with feed particles | -.72 |
| Water holding capacity of feed | .89 |

  - The size of the particle must be reduced to 1.18 mm
    - Allows for passage through the fiber mat and the reticulo-omasal orifice
    - Particle size reduction results from rumination and microbial digestion
    - Larger particles may be found in the feces of animals with high DM intakes
    - Passage of small particles are more subject to external modifications than large particles

- Particle shape
  - Flat particles pass more readily than cylinders
  - Cuboidal particles pass more readily than long particles
- Rumen volume and motility
  - Passage rates of animals with small rumens will be greater than those of animals with large rumens

| Rumen pool size, l | Digesta flow rate, l/h | Passage rate, %/hr |
|---|---|---|
| 50 | 1 | 1 / 50 = 2 |
| 10 | 1 | 1 / 10 = 10 |

  - Small ruminants must be very selective grazers or concentrate selectors

ESALQ USP

# Definitions associated with digestive kinetics

- Disappearance rate
  - Also called feeding rate
  - Equals the DM consumption divided by the rumen DM content
  - Disappearance rate is the combined effects of the rate of passage and the rate of digestion

- Rate of passage
  - Also called turnover rate or, for liquid digesta, dilution rate
  - Equals the proportion of the undigested residues from a given meal that passes a given point in the gut in a set period of time
  - Calculated as the flow of undigested residues from the rumen divided by the rumen volume of digesta

- Example
  - Cow consuming 20kg/d or .83 kg/hr
  - Rumen contains 15 kg DM
  - Disappearance rate =

    .83 kg/hr / 15 kg = .055/hr or 5.5%/hr

- Example
  - Above cow has .32 kg DM/hr passing into the duodenum
  - Rate of passage =

    .35 kg/hr / 15 kg DM = .023/hr or 2.3%/hr

- Typical values

| | kp |
|---|---|
| Liquid | 4 - 10 %/hr |
| Concentrates | 2 – 7 %/hr |
| Roughages | 1 – 6 %/hr |

- CNCPS
  - Level one (Previous editions)
    - Assumes

| | kp, assuming 3x maintenance DM intake |
|---|---|
| Concentrates | 4.05 %/hr |
| Roughages | 3.43 %/hr |

  - Level two
    - Considers
      - » DM intake
      - » Body weight
      - » % forage in diet
      - » Diet eNDF concentration
- Rate of passage for feedstuffs usually determined with markers

- **Retention time**
  - Defined as the average time that digesta particles remain in the rumen
  - Usually calculated as the reciprocal of the passage rate

- **Digestion rate**
  - Defined as the proportion of the digestible fraction of a feedstuff or nutrient within that feedstuff that is digested in a set time period
  - Mathematically calculated as the difference between the disappearance rate and the passage rate
  - Commonly measured with in vitro or in situ digestion

- **Example (Continued from previous examples)**
  - Retention time =

    1 / .023/hr = 43.5 hr

- **Example**

  Digestion rate =

  5.5 %/hr – 2.3 %/hr

  = 3.2%/hr

  Proportion of

  nutrient digested = 3.2/5.5

  in the rumen = 58%

  Proportion of

  nutrient passing = 2.3/5.5

  From the rumen =42%

# EFFECTS OF NDF LEVELS AND RUMINALLY DEGRADABLE STARCH ON PERFORMANCE, RUMINAL PARAMETERS AND *IN SITU* DEGRADATION OF NUTRIENTS IN LACTATING DAIRY COWS FED SORGHUM DIETS.

by

Luiz Gustavo Nussio

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For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

1997

Table 25. Ruminal Volume. Dry Matter Intake, Body Weight, and Ruminal Turnover. (Exp.2).

| | Diet | | | | | P< | |
|---|---|---|---|---|---|---|---|
| Parameter | DR-HF | DR-LF | SF-HF | SF-LF[1] | SEM | G | F[2] |
| DMI, kg/d | 16.5[b] | 17.4[ab] | 18.0[abd] | 19.8[ac] | 0.81 | 0.05 | 0.14 |
| DMI, % BW[3] | 2.38[b] | 2.53[ab] | 2.64[ab] | 2.89[a] | 0.15 | 0.80 | 0.22 |
| BW, kg | 692 | 697 | 685 | 690 | 13.8 | 0.59 | 0.74 |
| Ruminal Contents | | | | | | | |
| Volume, L | 87.0 | 79.8 | 80.5 | 82.8 | 5.60 | 0.76 | 0.67 |
| Volume, %BW | 12.5 | 11.4 | 11.9 | 12.0 | 0.77 | 0.94 | 0.55 |
| Weight, kg | 64.4 | 58.0 | 63.6 | 61.1 | 4.16 | 0.79 | 0.33 |
| Weight, %BW | 9.26 | 8.34 | 9.43 | 8.87 | 0.61 | 0.59 | 0.27 |
| Weight, kg DM | 7.13 | 6.28 | 7.86 | 6.88 | 0.77 | 0.42 | 0.28 |
| Recovery, %[4] | 102.3 | 100.1 | 100.4 | 101.8 | 2.46 | 0.97 | 0.86 |
| Density, kg/L | 0.75[ab] | 0.73[a] | 0.79[b] | 0.74[ab] | 0.02 | 0.15 | 0.13 |
| Turnover | | | | | | | |
| times/24 h | 2.53 | 2.91 | 2.45 | 2.89 | 0.38 | 0.89 | 0.32 |
| Rate, %/h | 10.56 | 12.13 | 10.21 | 12.04 | 1.57 | 0.89 | 0.32 |

[a, b, c] Means not sharing same superscript differ ($P<0.10$).
[1] DR-HF=Dry-rolled sorghum, high forage; DR-LF=Dry-rolled sorghum, low forage; SF-HF=Steam-Flaked sorghum, high forage; SF-LF=Steam-flaked sorghum, low forage.
[2] G=grain effect (DR vs SF); F=forage level (HF vs LF).
[3] BW=Body Weight.
[4] Compared with liquid plus solid phases.

Table 25. Ruminal Volume. Dry Matter Intake, Body Weight, and Ruminal Turnover. (Exp.2).

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| BW, kg | 692 | 697 | 685 | 690 | 13.8 | 0.59 | 0.74 |
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| Volume, L | 87.0 | 79.8 | 80.5 | 82.8 | 5.60 | 0.76 | 0.67 |
| Volume, %BW | 12.5 | 11.4 | 11.9 | 12.0 | 0.77 | 0.94 | 0.55 |
| Weight, kg | 64.4 | 58.0 | 63.6 | 61.1 | 4.16 | 0.79 | 0.33 |
| Weight,%BW | 9.26 | 8.34 | 9.43 | 8.87 | 0.61 | 0.59 | 0.27 |
| Weight, kg DM | 7.13 | 6.28 | 7.86 | 6.88 | 0.77 | 0.42 | 0.28 |
| Recovery, %[4] | 102.3 | 100.1 | 100.4 | 101.8 | 2.46 | 0.97 | 0.86 |
| Density, kg/L | 0.75[ab] | 0.73[a] | 0.79[b] | 0.74[ab] | 0.02 | 0.15 | 0.13 |
| Turnover | | | | | | | |
| times/24 h | 2.53 | 2.91 | 2.45 | 2.89 | 0.38 | 0.89 | 0.32 |
| Rate, %/h | 10.56 | 12.13 | 10.21 | 12.04 | 1.57 | 0.89 | 0.32 |

[a, b, c] Means not sharing same superscript differ (P<0.10).
[1] DR-HF=Dry-rolled sorghum, high forage; DR-LF=Dry-rolled sorghum, low forage; SF-HF=Steam-Flaked sorghum, high forage; SF-LF=Steam-flaked sorghum, low forage.
[2] G=grain effect (DR vs SF); F=forage level (HF vs LF).
[3] BW=Body Weight.
[4] Compared with liquid plus solid phases.

Table 27. Passage Rate (Kp), Mean Compartmental Retention Time (MCRT)[1], and Half Life (HL)[2] for Solid and Liquid Phases in Experimental Diets (Exp.2).

| | Diet | | | | | P< | |
|---|---|---|---|---|---|---|---|
| Parameter | DR-HF | DR-LF | SF-HF | SF-LF[3] | SEM | G | F[4] |
| **Solid Phase** | | | | | | | |
| Alfalfa Hay | | | | | | | |
| Kp, %/h | 6.10[b] | 7.70[a] | 6.90[ab] | 8.20[a] | 0.56 | 0.29 | 0.04 |
| MCRT, h | 17.6[a] | 13.3[b] | 14.7[ab] | 12.4[b] | 1.5 | 0.25 | 0.07 |
| HL, h | 12.2[a] | 9.2 [b] | 10.2[ab] | 8.6[b] | 1.0 | 0.25 | 0.07 |
| Grain [5] | | | | | | | |
| Kp,%/h | 7.26 | 7.77 | 7.81 | 7.97 | 0.52 | 0.50 | 0.76 |
| MCRT, h | 13.6 | 14.1 | 13.1 | 12.7 | 0.88 | 0.33 | 0.94 |
| HL, h | 9.4 | 9.8 | 9.1 | 8.9 | 0.61 | 0.33 | 0.94 |
| **Liquid Phase** | | | | | | | |
| Kp, %/h | 12.7[a] | 10.3[ab] | 10.6[ab] | 8.2[b] | 1.0 | 0.08 | 0.06 |
| MCRT, h | 8.5[b] | 10.2[a] | 9.5[b] | 12.4[a] | 0.8 | 0.10 | 0.03 |
| HL, h | 5.9[b] | 7.1[a] | 6.6[b] | 8.6[a] | 0.6 | 0.10 | 0.03 |

[a, b, c, d] Means not sharing same superscript differ [a,b] (P<0.10); [c,d] (P<0.20).
[1] MCRT=1/Kp.
[2] HL=ln 0.5/Kp.
[3] DR-HF=Dry-rolled sorghum, high forage; DR-LF=Dry-rolled sorghum, low forage; SF-HF=Steam-Flaked sorghum, high forage; SF-LF=Steam-flaked sorghum, low forage.
[4] G=grain effect (DR vs SF); F=forage level (HF vs LF).
[5] DR sorghum grain (DR diets); SF sorghum grain (SF diets).

Table 26. Characterization of Ruminal Solid and Liquid Phases[1]. (Exp.2)

| | Diet | | | | | P< | |
|---|---|---|---|---|---|---|---|
| Parameter | DR-HF | DR-LF | SF-HF | SF-LF[2] | SEM | G | F[3] |
| Liquid Phase, L | 31.5 | 30.3 | 34.0 | 31.5 | 3.15 | 0.57 | 0.57 |
| Liquid Phase, kg | 30.2 | 27.0 | 30.3 | 28.6 | 2.81 | 0.77 | 0.42 |
| Liquid Phase, kg DM | 1.06 | 0.87 | 1.16 | 1.13 | 0.13 | 0.23 | 0.43 |
| Density, kg/L | 0.97[a] | 0.88[b] | 0.90[ab] | 0.92[ab] | 0.03 | 0.56 | 0.23 |
| Solid Phase, kg | 30.4 | 27.6 | 29.4 | 29.2 | 1.51 | 0.86 | 0.35 |
| Solid Phase, kg DM | 6.09 | 5.43 | 6.73 | 5.86 | 0.74 | 0.50 | 0.34 |
| Total Weight, kg DM | 7.15 | 6.30 | 7.89 | 6.98 | 0.76 | 0.39 | 0.29 |

[a, b] Means not sharing same superscript differ (P<0.10).

[1] Obtained by straining whole Luminal content.

[2] DR-HF=Dry-rolled sorghum, high forage; DR-LF=Dry-rolled sorghum, low forage; SF-HF=Steam-Flaked sorghum, high forage; SF-LF=Steam-flaked sorghum, low forage.

[3] G=grain effect (DR vs SF); F=forage level (HF vs LF).

# Digesta markers

- Necessary properties
  - Nonabsorbable
    - Amount of marker in = Amount of marker out
  - Must not affect or be affected by the GI tract or the microbial population
  - Must be physically similar and intimately associated with the material it is measuring
  - Method of determination must be specific, sensitive and not interfere with other analyses

– Internal markers
  - Defined as components within feeds themselves that can be used as digesta markers
  - Types
    - Lignin
      - » A cell wall component that is theoretically indigestible
      - » Analytical recovery in feces may be as low as 72% when measured as acid detergent lignin
      - » Alkaline hydrogen peroxide lignin represents core lignin
    - Silica
      - » Measured as acid insoluble ash
      - » Problem if there is soil contamination
    - Long-chain alkanes
      - » Acceptable
    - Indigestible acid detergent fiber
      - » Acceptable
  - Uses

    Passage rate = gm fed per hour / gm marker in rumen

    DM digestibility = (1 - % in feed / % in feces) x 100

- External markers
  - Stained feed particles
    - Feed particles stained with dyes like crystal violet, basic fuchsin, or brilliant green
    - Treat 5% of diet
    - Count particles in feces with microscope
      - » Difficult to count small particles
    - Sieving may be used to count
    - Dyes may affect digestibility
  - Plastic particles
    - Different sizes, shapes and specific gravities may be evaluated
    - Counted like dyed feed particles
  - Chromic oxide ($Cr_2O_3$)
    - Not absorbed and readily analyzed
    - May be used as a powder, gelatin boluses, continuous release boluses or impregnated paper
    - Doesn't travel with solid or liquid digesta
      - » Unacceptable to measure passage rate
    - Effective for determination of digestion in total digestion tract
      - » Example

        Feed cow 20 kg DM/day containing 0.03 gm Cr as $Cr_2O_3$ for 7 days and feces is collected during the last 3 days

        Analyze feces and find that it contains 4 mg/kg fecal DM

        Fecal output = (0.03 gm Cr x 1000 mg/gm) / 4 mg/kg fecal DM

        = 7.5 kg fecal DM

        DM digestion = (20 kg DMI – 7.5 kg fecal DM) / 20 kg DMI x 100

        = 12.5/20 x 100 = 62.5%
    - If used to measure digestibility at the duodenum, must collect digesta samples around the clock

- Chromium-mordanted fiber
  - Cr is permanently bound to fiber
  - Acceptable for determination of passage if properly prepared
    - » Treat with 2% Cr
    - » Particles contain a specific gravity of 1.2
  - Mordanting can't be done on total feedstuffs
    - » Starch-Cr complexes are soluble
  - Mordanting does make fiber indigestible
- Rare earth elements
  - Ru, Dys, Sm, La, Ce, or Yb
  - Advantages
    - » Easy to analyze by neutron activation or plasma emission spectroscopy
    - » Can label all fractions of the diet
    - » Doesn't alter feed
  - Disadvantages
    - » Cost
    - » May jump to liquid, other feed particles or microbes

      Problem can be lessened by dialyzing marker or applied to purified NDF

      Binding capacity:

      15 – 20 mg/g forages

      1 – 4 mg/d grain

- Polyethylene glycol
  - A liquid marker
  - Difficult to analyze
  - May bind to dietary organic matter
- Cr-EDTA or Co-EDTA
  - A liquid marker
  - Easily analyzed
  - 3 to 7% may be absorbed

# COMPARISON OF THREE DIGESTIBILITY MARKERS IN BEEF CATTLE FED FINISHING RATIONS CONTAINING DIFFERENT SOURCES OF SUPPLEMENTAL FAT

An Undergraduate Research Scholars Thesis

by

AMELIA LYNN CHRISTIAN

Submitted to Honors and Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

Dietary markers aid considerably when the following calculations are desired: fecal dry matter (DM) output (1), digestibility of nutrient (2), apparent crude protein digestibility (3), and DM intake (4). Merchen presents the equation of each calculation in his review *Digestion, Absorption, and Excretion in Ruminants* (1988).

1. $Fecal\ DM\ output \left(\frac{g}{d}\right) = \frac{marker\ consumed\left(\frac{g}{d}\right)}{marker\ concentration\ in\ feces\ (\frac{g}{gDM})}$

2. $Digestibility\ of\ nutrient\ (\%) = 100 - (100 * \frac{(\%\ marker\ in\ feed)}{(\%\ marker\ in\ feces)} * \frac{(\%\ nutrient\ in\ feces)}{(\%\ nutrient\ in\ feed)})$

3. $Apparent\ crude\ protein\ digestibility =$

   $100 - (100 * \frac{(\%\ marker\ in\ feed)}{(\%\ marker\ in\ feces)} * \frac{(\%\ crude\ protein\ of\ feces)}{(\%\ crude\ protein\ of\ feed)})$

4. $DM\ intake = fecal\ output * \frac{100}{\%\ indigestibility\ of\ DM}$

**Titanium dioxide**

Titanium dioxide ($TiO_2$) is a highly manufactured metal oxide that is often used in the production of sunscreen lotions, toothpastes, paints, and pigments. Although it is suspect to increase the risk of cancer, studies of human exposure to $TiO_2$ in the workplace do not indicate a carcinogenic effect on workers (Bofetta, 2004). In addition, it is a feed additive approved for use by the United States Food and Drug Administration, and is less expensive to obtain than $Cr_2O_3$. Upon combustion and acid digestion with hydrogen peroxide, organic samples containing $TiO_2$ turn a deep yellow color, which allows titanium concentration to be determined by spectrophotometer. On these bases, $TiO_2$ has recently been introduced as a dietary marker in livestock species.

**Calculations and statistical analyses**

Marker absorbencies were read in parts per million (ppm) and converted to grams per day.

Marker consumed was calculated as:

$$Marker\ consumed = \frac{marker\ in\ feed(g)}{marker\ in\ orts\ (g)}$$

Fecal output (DM) was calculated as:

$$Fecal\ output\ (DM) = \frac{marker\ consumed(g)}{marker\ in\ feces\ (\frac{g}{g}DM)}$$

Digestibility was calculated as:

$$Digestibility\ of\ nutrient\ (\%)$$

$$= 100 - (100 * \frac{(\%\ marker\ in\ feed)}{(\%\ marker\ in\ feces)} * \frac{(\%\ nutrient\ in\ feces)}{(\%\ nutrient\ in\ feed)}$$

Fecal production and digestion coefficients were analyzed using the MIXED procedure in SAS 9.2 (SAS Inst. Inc., Cary, NC). Terms in the model included treatment, marker, treatment × marker, and period, with steer as the random effect. Treatment means were calculated using the LSMEANS option and pairwise comparisons.

Prior to feeding, 10 g of both $Cr_2O_3$ and $TiO_2$ were mixed by hand into the feed. According to the proportions of each element in their respective formulas, the steers were offered 6.84 g chromium and 5.99 g titanium daily. By analysis of feed samples, the average value of chromium in feed was 5.51 g/day, indicating an 80.5% recovery rate. Average titanium found in feed was 8.79 g/day, yielding a 146.7% recovery.

Table 1. Estimates of daily fecal production, dry matter digestibility (DMD), organic matter digestibility (OMD), ADF digestibility, starch digestibility, and EE fat digestibility determined by $Cr_2O_3$, $TiO_2$, and ADIA.

Fecal Production (kg/day DM)

| Diet | Cr | Ti | ADIA | SEM | Diet | Marker | D × M |
|---|---|---|---|---|---|---|---|
| AF | 3.64 | 2.75 | 2.96 | 0.45 | 0.64 | 0.01 | 0.11 |
| IP | 3.41 | 3.09 | 2.01 | | | | |
| Phos | 3.29 | 3.45 | 2.80 | | | | |
| VOP | 4.12 | 2.40 | 3.22 | | | | |

DMD Digestion

| Diet | Cr | Ti | ADIA | SEM | Diet | Marker | D × M |
|---|---|---|---|---|---|---|---|
| AF | 0.62 | 0.69 | 0.71 | 0.04 | 0.66 | < 0.01 | 0.07 |
| IP | 0.63 | 0.67 | 0.78 | | | | |
| Phos | 0.65 | 0.63 | 0.71 | | | | |
| VOP | 0.75 | 0.57 | 0.67 | | | | |

ADF Digestion

| Diet | Cr | Ti | ADIA | SEM | Diet | Marker | D × M |
|---|---|---|---|---|---|---|---|
| AF | 0.26 | 0.44 | 0.40 | 0.09 | 0.26 | < 0.01 | 0.03 |
| IP | 0.16 | 0.24 | 0.50 | | | | |
| Phos | 0.24 | 0.19 | 0.36 | | | | |
| VOP | 0.07 | 0.45 | 0.27 | | | | |

OMD Digestion

| Diet | Cr | Ti | ADIA | SEM | Diet | Marker | D × M |
|---|---|---|---|---|---|---|---|
| AF | 0.54 | 0.35 | 0.71 | 0.04 | 0.66 | < 0.01 | 0.07 |
| IP | 0.54 | 0.17 | 0.78 | | | | |
| Phos | 0.52 | 0.07 | 0.72 | | | | |
| VOP | 0.50 | 0.41 | 0.67 | | | | |

Starch Digestion

| Diet | Cr | Ti | ADIA | SEM | Diet | Marker | D × M |
|---|---|---|---|---|---|---|---|
| AF | 0.88 | 0.91 | 0.90 | 0.02 | 0.01 | 0.01 | 0.19 |
| IP | 0.91 | 0.92 | 0.95 | | | | |
| Phos | 0.89 | 0.89 | 0.91 | | | | |
| VOP | 0.84 | 0.91 | 0.88 | | | | |

EE Digestion

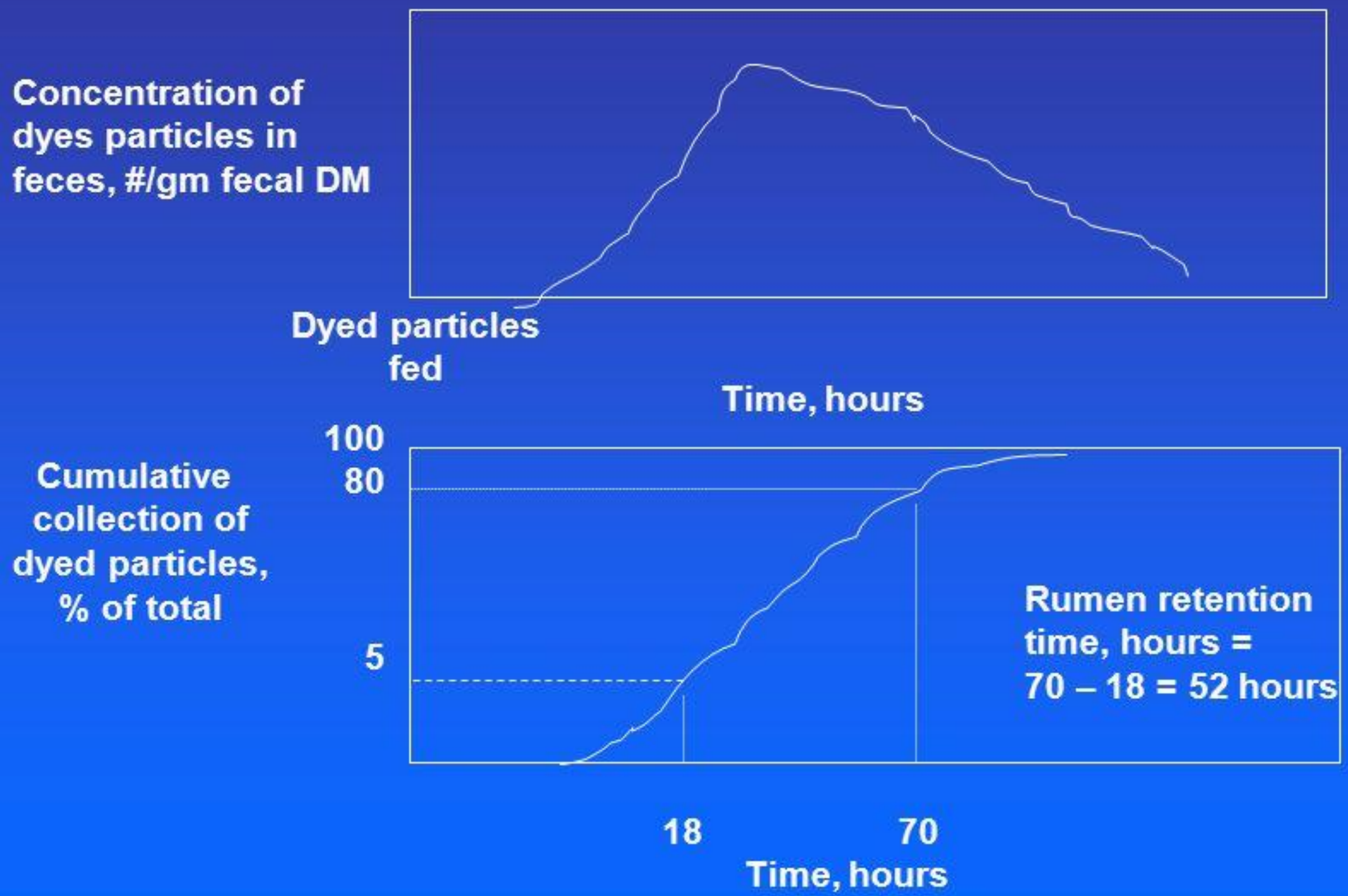
| Diet | Cr | Ti | ADIA | SEM | Diet | Marker | D × M |
|---|---|---|---|---|---|---|---|
| AF | 0.86 | 0.90 | 0.88 | 0.03 | 0.07 | 0.03 | 0.39 |
| IP | 0.81 | 0.83 | 0.89 | | | | |
| Phos | 0.84 | 0.85 | 0.86 | | | | |
| VOP | 0.79 | 0.88 | 0.84 | | | | |

# CONCLUSION

Recovery data was inconclusive, and it cannot be determined if $TiO_2$ would be a suitable replacement for $Cr_2O_3$ (Table 1). Nutrient digestibilities calculated from $TiO_2$ varied significantly from those calculated by $Cr_2O_3$. Except for OMD, $TiO_2$ behaved similarly to the internal marker ADIA. Although ADIA is most useful in high-forage diets, the consistency between ADIA and $TiO_2$ may support $TiO_2$ to be more reliable marker than $Cr_2O_3$. Recoveries of markers in feed samples that were inconsistent with the measured marker added imply that marker recovery procedures were erroneous.

# Methods to determine passage rate

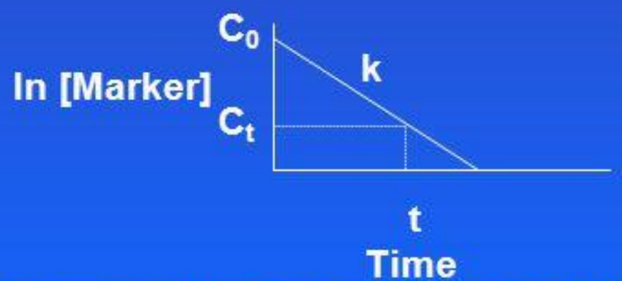
- Balch '80 – 5' time



- **Kinetic models**
  - **One-pool exponential model**
    - **Model**


$X_1(t)$ =Dose remaining at time t
$k_1$ = rate of passage
$X_0(t)$ = Dose passing at time t
Concentration of marker at time 0 = $C_0$ = Dose/ $V_1$
Concentration of marker passing at any time t = $C_t = X_o(t) / V_1$

- **Measurement**

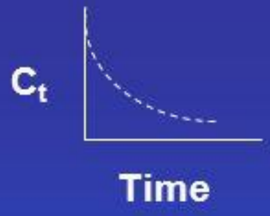



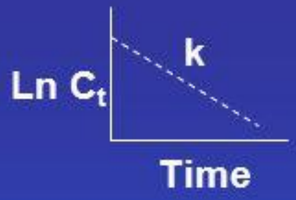

$C_t = C_0 e^{-kt}$
Retention time = 1/k
Pool volume = Dose / $C_0$
Total output = V x k

- Assumes that every feed particle has as equal opportunity to leave the pool as any other particle regardless of how long it's been in the pool
- Called age independence
- Assumption is correct for particle size reduction

- One-pool age dependent model
  - Assumes that the probability of a particle passing increases as the time (age) that the particle is in the pool (rumen) increases
  - More accurately models passage because the particles will undergo changes affecting passage including:
    - Morphology
    - Specific gravity
    - Buoyancy
    - Rate and extent of digestion

– Exponential model




- $C_t = D/V \times e^{-kt}$


- Retention time = 1 / k
- Volume = $D / C_0$
- Flow = V x k

– Age dependent model



- $C_t = D/V \times \lambda \times t \times e^{\lambda t}$ /.59635


- Retention time = 2/λ
- Volume = $D / C_0$
- Flow = V x .59635λ

ESALQ USP

- Two pool models
  - Model


$X_1t$ or $X_2t$ = Dose remaining in pool 1 or 2 at time t

$X_0t$ = Dose that passed at time t

  - Interpretation of model

| | Slow rate | Fast rate |
| --- | --- | --- |
| Theory 1 | Passage from reticulorumen, Exponential | Passage from low GI tract Exponential |
| Theory 2 | Rate of converting large particles to small particles for passage, Exponential | Rate of particle preparation, Gamma |

- Rumen flux models
  - Model
    - Kp = flow / pool size
  - Advantages
    - Accuracy
    - Ability to determine fractional kp at different times of the day
      - Allows the ability to synchronize nutrient flow and absorption
  - Limitations
    - Need accurate measure of rumen volume and duodenal flow
    - Values represent entire diet rather than components

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# Development of a mathematical model to predict pool sizes and rates of digestion of 2 pools of digestible neutral detergent fiber and an undigested neutral detergent fiber fraction within various forages

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$$\mathrm{NDF}_{(t)} = \mathrm{pdNDF}_{1(0)} \times e^{-k1(t-L)} + \mathrm{pdNDF}_{2(0)} \times e^{-k2(t-L)} + \mathrm{uNDF}, \quad [1]$$

where $\mathrm{pdNDF}_{1(0)}$ and $k_1$ are the size at time 0 and the fractional rate of the fast pool, respectively; $\mathrm{pdNDF}_{2(0)}$ and $k_2$ are the size at time 0 and the fractional rate of the slow pool, respectively; L is the lag time to establish the fermentation; and uNDF is the undigested NDF. Simultaneous estimations of the parameters $\mathrm{pdNDF}_1$, $\mathrm{pdNDF}_2$, $k_1$, $k_2$, uNDF, and L were initially obtained using PROC NLIN of SAS (version 9.3, SAS Institute, Inc., Cary, NC) and the Marquardt algorithm. The Marquardt algorithm was selected to improve the efficiency of providing least squares estimation for the nonlinear curve fitting approach. Nonlinear regression was chosen as the procedure because the method assumes equal error at each observation; by simultaneously fitting all parameters to the data, the result provides the smallest residual sums of squared deviations for the model. Due

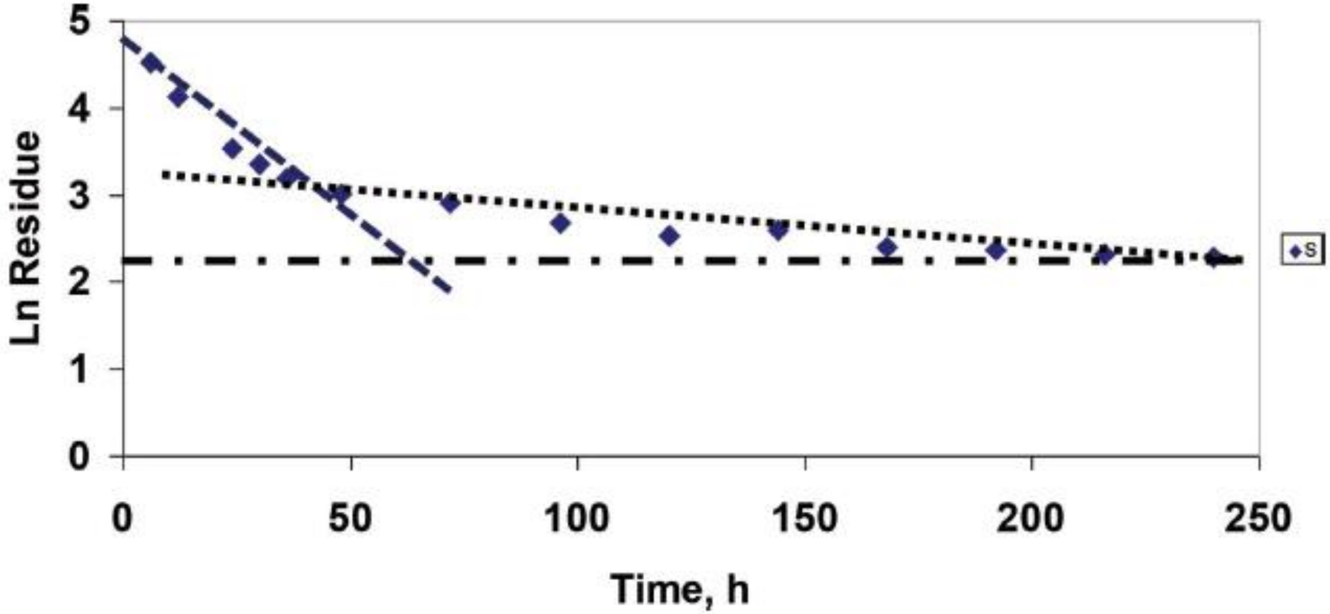



Figure 1. Example showing the partitioning of corn silage NDF into pools and rates using a simple log-transformation of the digestion curve (Ln Residue). In this example, the first pool (- - -) is exhausted by 48 h, as characterized by the inflection, and the second digestible pool (· · ·) is exhausted by 240 h, representing the unavailable NDF (– · – ·). S = substrate, corn silage NDF.

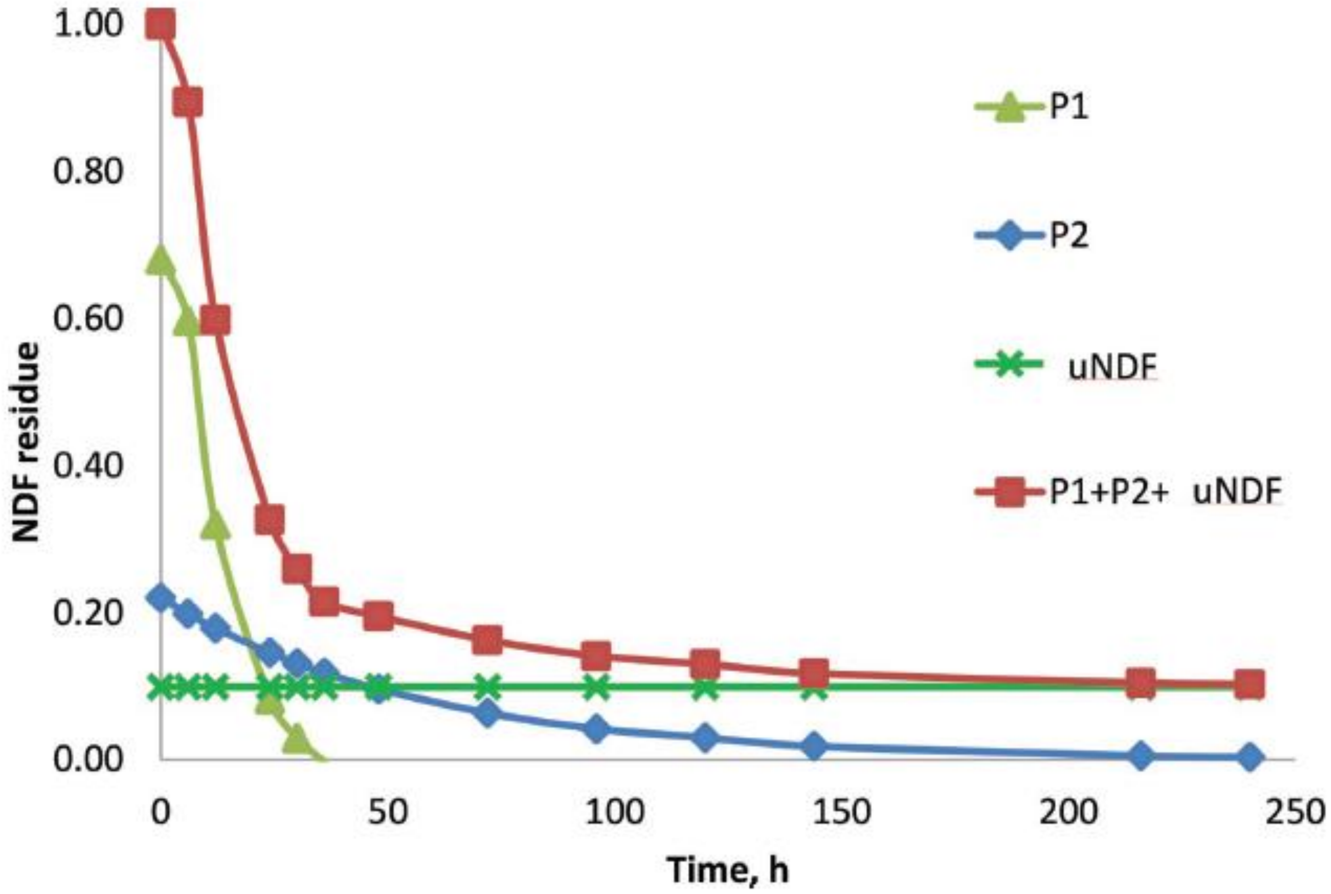



**Figure 2.** The residual NDF of a corn silage after in vitro fermentation, from 0 to 240 h, with the total NDF disappearance and the calculated amounts of the faster (P1) and the slower (P2) pool of digestible NDF and the unavailable NDF (uNDF) measured at 240 h of in vitro digestion and pool sizes calculated using the measured uNDF in place of the static calculation of lignin × 2.4/NDF.

**Table 2.** The pool sizes and rates of digestion ($k_d$, per hour) obtained from the simultaneous nonlinear estimation for the respective NDF digestion components[1]

| Type | n | $pdNDF_1$ | $pdNDF_2$ | Unavailable NDF | $k_1$ | $k_2$ | $k_d$ |
|---|---|---|---|---|---|---|---|
| Conventional corn silage | 8 | 0.607 (0.031) | 0.187 (0.032) | 0.206 (0.012) | 0.073 (0.005) | 0.016 (0.006) | 0.060 (0.004) |
| Brown midrib corn silage | 7 | 0.738 (0.026) | 0.131 (0.028) | 0.131 (0.016) | 0.087 (0.007) | 0.024 (0.012) | 0.078 (0.005) |
| Grasses | 6 | 0.544 (0.046) | 0.244 (0.051) | 0.211 (0.021) | 0.094 (0.036) | 0.016 (0.005) | 0.067 (0.018) |
| Straws and hays | 6 | 0.587 (0.024) | 0.103 (0.023) | 0.323 (0.041) | 0.040 (0.006) | 0.007 (0.003) | 0.035 (0.004) |
| Alfalfas | 7 | 0.487 (0.049) | 0.087 (0.034) | 0.425 (0.063) | 0.134 (0.018) | 0.024 (0.012) | 0.113 (0.013) |

[1]The SE for each variable are in parentheses. The $k_d$ represents a weighted average of $pdNDF_1$ and $pdNDF_2$ based on the calculated size of the respective pools (and the $k_d$ of unavailable NDF is equal to zero by definition), where $pdNDF_1$ is the potentially digestible NDF fast pool, $pdNDF_2$ is the potentially digestible slow pool, both defined as a percent of the total potentially digestible NDF.

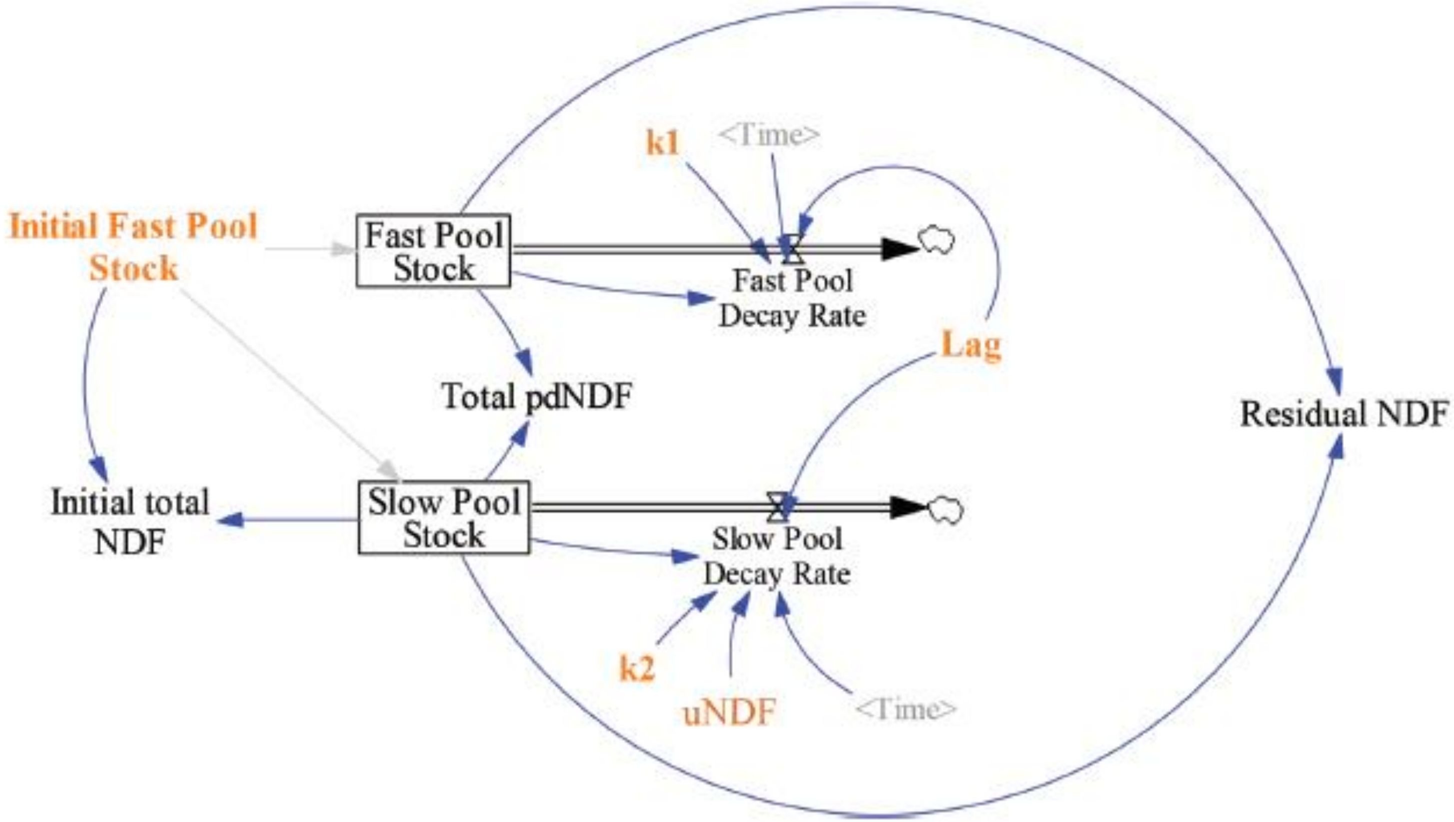



**Figure 3.** Diagrammatic representation of the composite decay model described in the text. The slow pool stock is in this case equal to $pdNDF_2$ + unavailable NDF (uNDF), and the slow-degrading pool follows a goal-seeking behavior with the goal being uNDF. In orange are the parameters that need to be optimized. The slow-degrading pool is calculated as $pdNDF_2 = 1 - (pdNDF_1 + uNDF)$. $pdNDF_1$ = potentially digestible NDF fast pool; $pdNDF_2$ = potentially digestible slow pool; $k_1$ = digestion rate in percent per hour of the fast pool; $k_2$ = digestion rate of the slow pool.

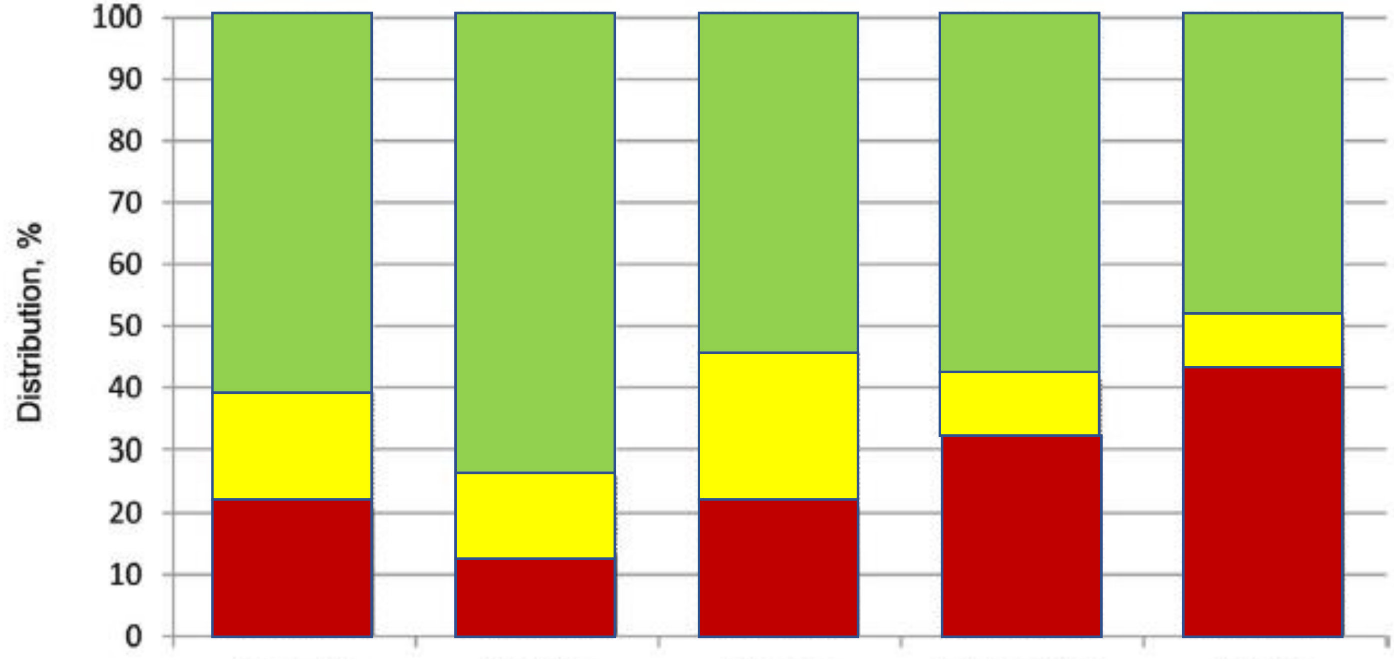



**Figure 4.** The average distribution, per forage type, of the fast (pdNDF$_1$, top light dotted bars) and slow (pdNDF$_2$, middle darker shaded bars) pools and unavailable NDF (uNDF, black dotted bottom section) fractions of the forages analyzed. Conv. CS = conventional corn silage; Bmr CS = brown midrib corn silage.

pdNDF1

pdNDF2

uNDF

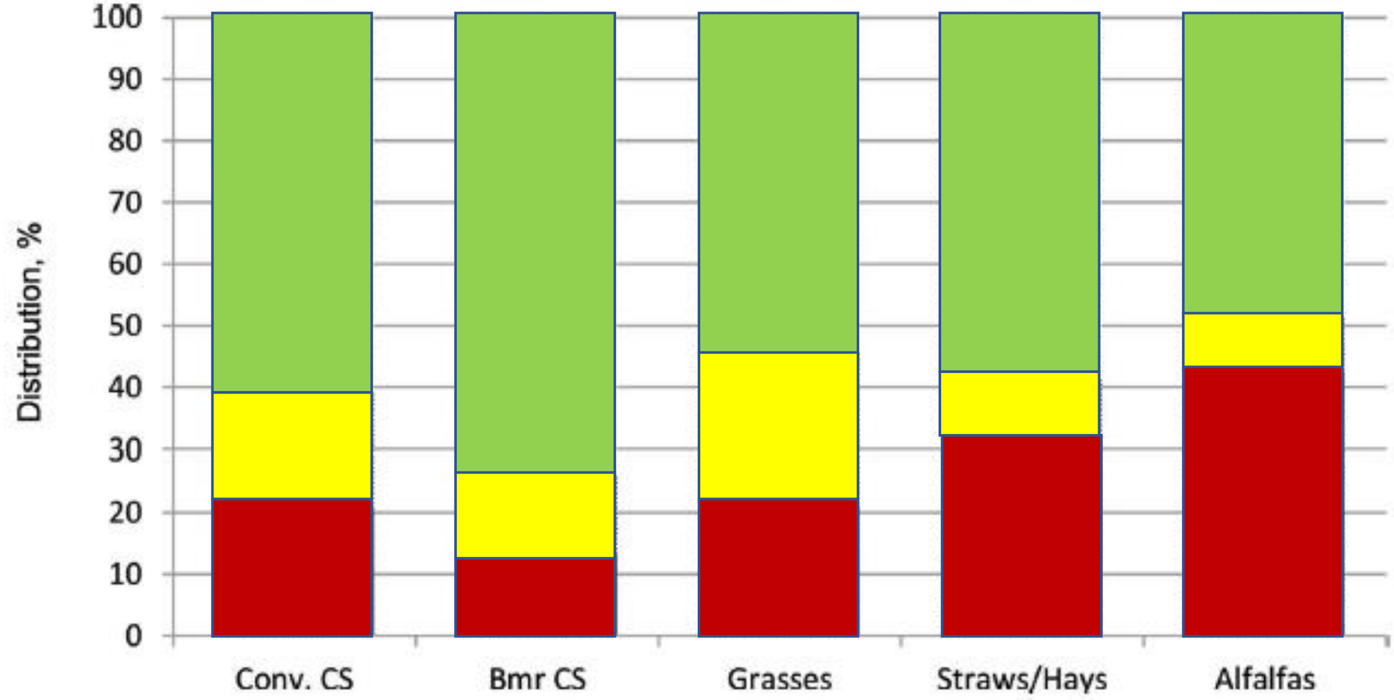



**Figure 4.** The average distribution, per forage type, of the fast ($pdNDF_1$, top light dotted bars) and slow ($pdNDF_2$, middle darker shaded bars) pools and unavailable NDF (uNDF, black dotted bottom section) fractions of the forages analyzed. Conv. CS = conventional corn silage; Bmr CS = brown midrib corn silage.

pdNDF1

pdNDF2

uNDF

# Factors influencing rate of passage

- Level of intake
  - As intake increases
    - Passage of the liquid digesta increases
    - Passage of the solid digesta increases
      - Effect greater on concentrates than forages

| | | Rate of passage, %/hr | | |
|---|---|---|---|---|
| Feed intake, % of BW | Volume, l | Liquid | Concentrate | Forage |
| < 1.24 | 58.4 | 4.4 | 3.6 | 1.8 |
| 1.25 – 1.75 | 52.4 | 6.2 | 3.6 | 3.1 |
| 1.75 – 2.25 | 45.7 | 7.8 | 4.5 | 3.9 |
| > 2.25 | 38.0 | 8.6 | 6.3 | 4.5 |

- Level of fiber in diet
  - As fiber concentration in the diet
    - Passage of the liquid digesta increases
    - Passage of the small particles increase
      - Effect on large particles is questionable

| | | Rate of passage, %/hr | | |
|---|---|---|---|---|
| Concentrate in diet, %DM | Volume, l | Liquid | Concentrate | Forage |
| < 20 | 51.9 | 8.4 | 5.0 | 3.1 |
| 20 – 50 | 50.9 | 8.0 | 6.9 | 3.7 |
| 50 – 80 | 54.7 | 6.7 | 3.4 | 3.5 |
| > 80 | 39.2 | 5.2 | 3.1 | 2.9 |

- Effect varies with roughage type
  - If alfalfa is fed as the forage:
    - Digesta separates into a liquid fraction and a fiber mat in the rumen
    - Grain particles fall into the liquid fraction
    - Increasing the amount of forage in the diet increases the amount of chewing which increase secretion of salivary buffers
    - The increased amounts of salivary buffers increases the osmotic pressure of the rumen contents and, thereby, increase passage of the liquid digesta
    - Increasing passage of the liquid fraction will increase the passage of grain decreasing the digestion of the grain particles in the rumen
  - If cottonseed hulls are fed as the forage
    - Cottonseed hulls don't ferment as rapidly as alfalfa
    - Cottonseed hulls don't form a mat
    - Cottonseed hulls form a homogeneous mixture with the liquid digesta and grain
    - Increasing the amounts of cottonseed hulls will:
      - » Reduce the passage rate of the grain
      - » Increase the amount of grain particles that are rechewed by rumination
    - The actions will increase the digestibility of the grain in the rumen

- Osmolarity
  - Increasing the osmolarity of the rumen fluid with NaCl or $NaHCO_3$
    - Increases passage of liquid digesta
    - Increases passage of the feed particles
- Physical form
  - Reducing the physical form of the diet by grinding, pelleting etc.
    - Reduces the passage rate of liquid digesta
    - Increases the passage rate of feed particles
      - May be related to increased DM intake
- Rate of digestion of feeds
  - Increasing the rate of digestion
    - Increases the passage rate of the feed particles
- Particle specific gravity
  - Increasing the specific gravity to 1.2 will increase rate of passage of particles
  - Increasing the specific gravity much above 1.2 will reduce rate of passage of particles
    - Heavy particles settle in the reticulum and ventral sac of the rumen

- Time of day of feeding
  - Feeding a protein supplement during the day will reduce rate of passage of the protein during the day, but increase the rate of passage during the night
  - Feeding a protein supplement during the night doesn't affect rate of passage during the night or day

| | Protein supplement fed at | |
|---|---|---|
| | Day | Night |
| $k_p$ during the | ($k_p$ of protein) | |
| Day | .066 | .073 |
| Night | .105 | .077 |

# Effects of passage on nutrient utilization

- Effects of passage on feed intake
  - At a given rumen volume, increasing the passage rate will increase feed intake

| | Sheep fed | | | | |
|---|---|---|---|---|---|
| | Corn crop residues | Oat-berseem clover hay | | Alfalfa hay | |
| | Ad lib | Restricted | Ad lib | Restricted | Ad lib |
| kp, /hr | .013 | .018 | .025 | .022 | .058 |
| kl, /hr | .077 | .088 | .089 | .084 | .103 |
| DMI, %BW | 1.69 | 1.80 | 3.11 | 1.81 | 4.52 |

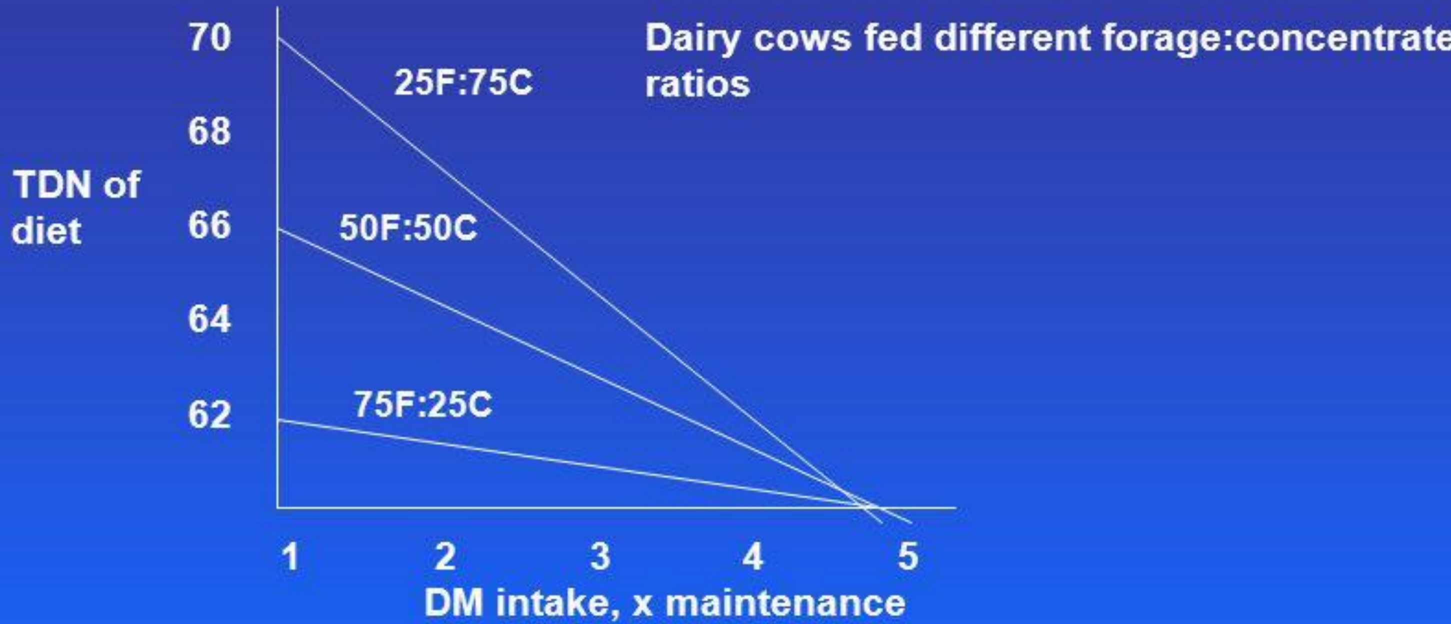
    - Factors stimulating reticular contractions like lactation or injections with somatotropin will stimulate passage and feed intake
    - Factors reducing rumen volume like small animal size or pregnancy will increase rate of passage, but reduce feed intake

- **Effects of passage on nutrient digestion**
  - Rate of passage affects both the rate and site of digestion
    - At a constant rate of digestion, increasing the rate of passage will:
      - decrease the digestibility of a feed in the total tract
      - increase the proportion of digestion occurs in the lower GI tract

| | Sheep fed grass hay | |
|---|---|---|
| | Coarse chopped | Ground pelleted |
| Passage rate, /hr | .037 | .042 |
| OM intake, gm/d | 559 | 606 |
| Digestion, | | |
| Rumen, gm | 200 | 186 |
| % | 35.8 | 30.7 |
| Total tract, gm | 288 | 309 |
| % | 53.3 | 51.0 |

  - Because of the increase in rate of passage, digestibility will decrease 1.8% for each 10°C decrease in ambient temperature below 20°C

– The depression in digestibility associated with increased rate of passage is greater for starch than for cellulose




- Implications
  - Since most digestion trials are conducted at 1x maintenance, the energy values may not apply to lactating dairy cows
  - Forages are of more value to dairy cows than estimated at 1x maintenance

# Effects of passage on VFA production

- Increasing the rumen passage rate will decrease total VFA production
  - Associated with reduced DM digestion
- On a given diet, increasing the liquid dilution rate will:
  - Increase the production and concentration of acetic acid, butyric acid and methane
  - Decrease the production and concentration of propionic acid

| | Liquid turnover rate, /hr | |
|---|---|---|
| | .038 | .098 |
| VFA | (moles/day) | |
| Acetate | 3.88 | 3.95 |
| Propionate | 1.83 | 1.23 |
| Butyrate | .35 | .62 |
| Total | 6.21 | 5.95 |
| Methane | 5.76 | 6.88 |

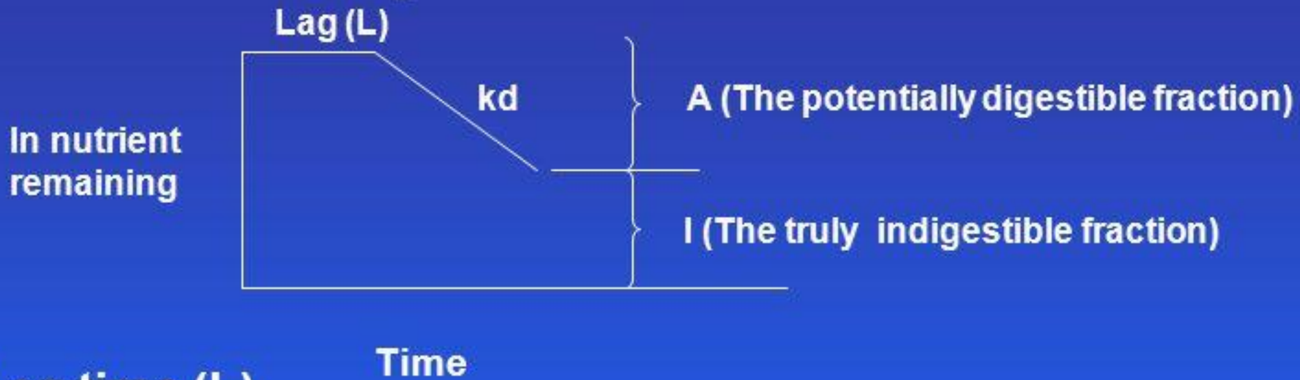
# Effects of passage on microbial growth efficiency

- Microbial efficiency is described by the term, $Y_{ATP}$
  - $Y_{ATP}$ = gm dry cells produced / mole ATP expended
  - Across most species, the theoretical $Y_{ATP}$ is 26 –32
  - In reality, $Y_{ATP}$ in the rumen is 10.5 (range 4.6 to 20.9)
    - Reason for the low value is the amount of energy that is used for maintenance of the population high on the growth curve


| Dilution rate | $Y_{ATP}$ | Proportion of ATP for maintenance |
|---|---|---|
| .02 | 8.5 | .65 |
| .06 | 13.6 | .38 |
| .12 | 20.3 | .24 |

# Rate of digestion

- Model
  - Nutrient remaining = $Ae^{-kd(t-L)} + I$




  - Lag time (L)
    - Biological factors
      - Bacterial penetration of the epidermal layer
      - Rate of hydration
      - Rate of removal of chemical and physical inhibitors
      - Diet composition
      - Rate of microbial attachment
      - Development of the microbial consortium
      - Increased numbers of bacteria and enzymes

- Rate of digestion (kd)
  - The rate of digestion of the potentially digestible fraction
  - Biological factors
    - Decreased rumen pH decreases rate of digestion
      - » Particularly affects fiber and protein
    - Grinding forages finely increases rate of digestion
    - Alkali treatment of low quality grass-based roughages increases the rate of digestion of fiber
    - Processing grains increases the rate of digestion of the grain
- Potential digestibility (A) and Indigestibility (I)
  - Biological factors
    - Lignin reduces the potential digestibility of cell walls
    - Acid detergent insoluble nitrogen reduces the potential digestibility of protein

# Methods for Determining Digestion Rates

- In vitro
  - Incubate sample in tubes in rumen fluid and buffer
  - Considerations
    - Inoculum must come from animal fed similar diet
    - Grinding
    - Incubation pH
    - Bacterial contamination

- In situ method
  - Considerations
    - Fabric pore size
      - Optimal at 50 um
    - Sample particle size
      - 2 mm
    - Sample size
      - < 10 $mg/cm^2$
    - Washing procedure
      - Done in reverse order
    - Account for microbial attachment
    - Particle influx
    - Length of incubation

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# *In situ* degradability of dry matter and fibrous fraction of sorghum silage

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Orskov and McDonald (1979).

$$Y = a + b(1 - e^{-ct})$$

where:
Y = accumulated degradability of the nutritional component analyzed, after incubation time t;
a = degradability curve interval, when t = 0, corresponding to soluble fraction of the nutritional component analyzed;
b = potential degradability of insoluble fraction of the nutritional component analyzed;
a + b = potential degradability ofthe nutritional component analyzed, when time t is not a limiting factor;
c = degradation rate by fermentative action of the fraction b.

Once calculated the constants a, b and c, they are applied to the equation proposed by Orskov and McDonald (1979);

$$P = a + \frac{b.c}{c+k}$$

where:
P =effective ruminal degradability of the nutritional component analyzed;
k = ruminal passage rate of the food (0.05% $h^{-1}$)

**Table 2.** Soluble fraction (A), potentially degradable insoluble fraction (B), degradation rate (C), indigestible fraction (Fi), potential degradation (Dp), effective degradation (De) of dry matter of silages of four sorghum genotypes with and without tannin in the grains.

| | Genotypes | | | | |
|---|---|---|---|---|---|
| Parameters | CMS-XS 165 | BR-601 | BR-700 | CMS-XS 114 | EPM |
| A (%) | 26.72a | 19.06c | 15.18d | 20.82b | 0.109 |
| B (%) | 45.89c | 55.36a | 53.83b | 43.43d | 0.141 |
| C (% $h^{-1}$) | 7.75a | 4.25c | 5.75b | 5.25bc | 0.535 |
| Fi (%) | 27.37c | 25.57d | 30.98b | 35.74a | 0.083 |
| Dp (%) | 72.62b | 74.43a | 69.01c | 64.26d | 0.082 |
| De (%) | 54.58a | 43.52b | 44.01b | 43.13b | 0.284 |

Different letters, in the same row, indicate significant differences (p > 0.05) by Tukey's test.

Source: Search result.

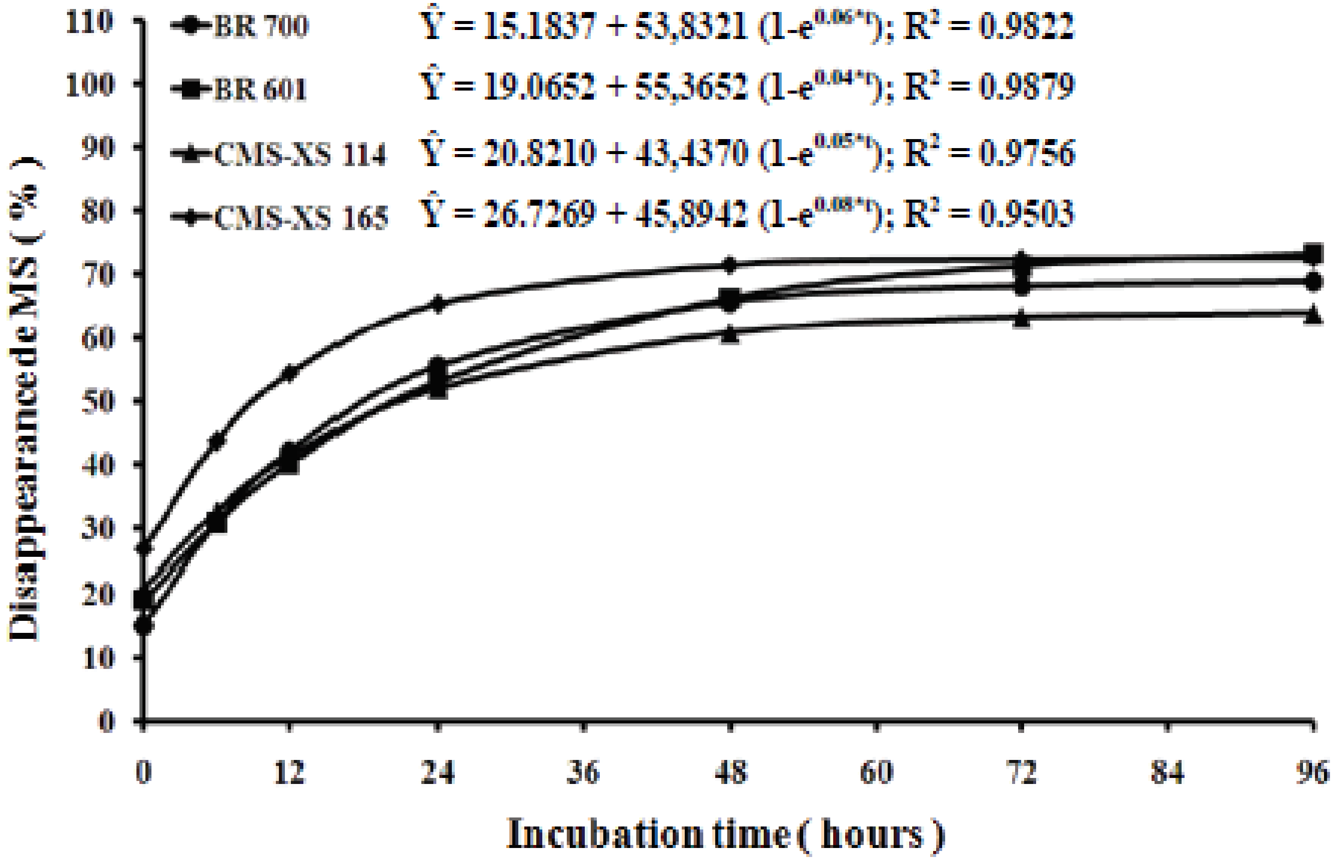


**Figure 1.** Dry matter (DM) disappearance of sorghum silages over incubation time (hours).

**Table 3.** Soluble fraction (A), potentially degradable insoluble fraction (B), degradation rate (C), indigestible fraction (Fi), potential degradation (Dp), effective degradation (De) of neutral detergent fiber of silages of four sorghum genotypes with and without tannin in the grains.

| | Genotypes | | | | |
|---|---|---|---|---|---|
| Parameters | CMS-XS 165 | BR-601 | BR-700 | CMS-XS 114 | EPM |
| A (%) | 24.72a | 4.54c | 3.26c | 6.69b | 0.156 |
| B (%) | 45.13c | 59.03a | 49.25b | 43.17c | 0.488 |
| C (% $h^{-1}$) | 12.22a | 3.50b | 2.50b | 3.75b | 0.169 |
| Fi (%) | 30.15c | 36.42b | 47.49a | 50.13a | 0.534 |
| Dp (%) | 69.85a | 63.58b | 52.51c | 49.86c | 0.533 |
| De (%) | 56.79a | 27.01b | 19.18c | 24.52bc | 0.821 |

Different letters, in the same row, indicate significant differences ($p > 0.05$) by Tukey's test.

- Gas production
  - Advantages
    - Sensitive
    - Small sample size
  - Limitations
    - Inoculation problems similar to in vitro
    - Gas release from buffers
    - Ammonia release
    - Change in stoichiometry of fermentation overtime
    - Must be calibrated using in vitro or in situ methods
- Flux method
  - $K_d$ = (Intake rate – flow rate)/Pool size
  - Difficult to use with individual diet components

*in vivo data*

# EFFECTS OF NDF LEVELS AND RUMINALLY DEGRADABLE STARCH ON PERFORMANCE, RUMINAL PARAMETERS AND *IN SITU* DEGRADATION OF NUTRIENTS IN LACTATING DAIRY COWS FED SORGHUM DIETS.

by

Luiz Gustavo Nussio

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A dissertation Submitted to the Faculty of the

DEPARTMENT OF ANIMAL SCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

1997

# Orskov and McDonald (1979)

$$Y = A + B(1 - e^{-c(t-T)}),\ t > T;$$

$$ED = A + Bce^{-kpT}/(c+kp)$$

Table 29. Dry Matter and NDF Degradability in Alfalfa Hay Incubated in Experimental Diets (DM basis). (Exp.3).

| Parameter | Diet | | | | SEM | P< | |
|---|---|---|---|---|---|---|---|
| | DR-HF | DR-LF | SF-HF | SF-LF[1] | | G | F[2] |
| **Dry Matter** | | | | | | | |
| A[3] % | 50.3 | 54.5 | 51.0 | 56.3 | 2.8 | 0.70 | 0.20 |
| B, % | 35.6 | 31.9 | 36.0 | 29.7 | 3.0 | 0.78 | 0.20 |
| C, %/h | 12.1[c] | 9.8[cd] | 7.8[cd] | 7.2 [d] | 1.6 | 0.13 | 0.45 |
| Asymptotic (A+B), % | 85.9 | 86.4 | 87.0 | 85.9 | 0.65 | 0.65 | 0.73 |
| Residue, % | 14.1 | 13.6 | 13.0 | 14.1 | 0.65 | 0.66 | 0.73 |
| ED[4], % | 74.6[c] | 72.2[cd] | 70.5[d] | 70.0[d] | 1.50 | 0.14 | 0.42 |
| Lag, h | 5.14 | 2.91 | 3.71 | 3.22 | 4.70 | 0.38 | 0.62 |

Table 29. Dry Matter and NDF Degradability in Alfalfa Hay Incubated in Experimental Diets (DM basis). (Exp.3).

| | Diet | | | | | P< | |
|---|---|---|---|---|---|---|---|
| Parameter | DR-HF | DR-LF | SF-HF | SF-LF[1] | SEM | G | F[2] |
| **NDF** | | | | | | | |
| A, % | 28.1[ab] | 25.7[a] | 21.9[b] | 34.0[a] | 2.10 | 0.67 | 0.12 |
| B, % | 42.5[ab] | 45.3[a] | 49.6[a] | 37.8[b] | 2.50 | 0.95 | 0.17 |
| C, %/h | 7.0 [a] | 7.2[a] | 5.5[ab] | 3.5[b] | 0.21 | 0.01 | 0.15 |
| Asymptotic (A+B), % | 70.6 | 70.9 | 71.5 | 71.8 | 0.63 | 0.26 | 0.69 |
| Residue, % | 29.4 | 29.1 | 28.5 | 28.2 | 0.63 | 0.25 | 0.69 |
| ED, % | 51.8[a] | 47.0[ab] | 44.5[b] | 45.1[b] | 1.83 | 0.09 | 0.34 |
| Lag, h | 1.91[b] | 3.88[a] | 1.90[b] | 2.82[ab] | 1.23 | 0.23 | 0.11 |
| Kp[5], %/h | 5.6[d] | 7.8[d] | 6.5[cd] | 8.2[d] | 0.80 | 0.48 | 0.09 |

Calculation of rates of passage for CNCPS:
$Kpf = (.38 + (.022 \times gDMI / SBW^{.75}) + 2 \times \text{Forage in diet, }\%^2)/100$
$Kpc = (-.424 + (1.45 \times kpf)) / 100$
$Kpl = (4.413 + .191 \times DMI /SBW) / 100$
Adjustment factors (multiplied to Kpf or Kpc):
Forage
$Af_j = 100/(NDF_j \times eNDF_j + 70)$
Concentrate
$Af_j = 100/(NDF_j \times eNDF_j + 90)$

Ruminal digestion and escape:
$\text{Ruminal digestion}_j = \text{Feed Fraction}_j \times (kd/(kp + kd))$
$\text{Ruminal escape}_j = \text{Feed Fraction}_j \times (kd/(kp + kd))$

Intestinal digestion:

Intestinal $digestion_j$ = Ruminal $escape_j$ x intestinal digestibility

Intestinal digestibilities:

| Proteins | |
|---|---|
| Fraction A | 100% |
| Fraction B1 | 100% |
| Fraction B2 | 100% |
| Fraction B3 | 80% |
| Fraction C | 0% |

| Starch | 2xm | 3xm |
|---|---|---|
| Whole corn | 50% | 30% |
| Cracked corn | 70% | 50% |
| Dry rolled corn | 80% | 70% |
| Whole HM corn | 90% | 80% |
| Grnd HM corn | 95% | 85% |
| Steam-flaked corn | 97% | 92% |
| Dry rolled sorghum | 70% | 60% |
| Small grains | 90% | 90% |

| NDF | Fat |
|---|---|
| 20% | 95% |

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# Effects of source and concentration of neutral detergent fiber from roughage in beef cattle diets on feed intake, ingestive behavior, and ruminal kinetics

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**Table 6.** Effects of source and level of NDF from roughage on ruminal content characteristics and ruminal mat consistency

| Items | Experimental diets[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10CS | 20CS | SCB | SC | SH | LOCH | SEM |
| Rumen fill[2] | 2.00[b] | 1.96[b] | 4.00[a] | 3.50[ab] | 1.10[b] | 1.90[b] | 0.08 |
| Rumen content | | | | | | | |
| Rumen DM, g/kg | 155.00[c] | 195.00[ab] | 213.70[a] | 195.80[ab] | 152.80[c] | 182.90[b] | 04.50 |
| Wet weight, kg | 36.66 | 42.70 | 41.55 | 43.06 | 39.19 | 41.70 | 2.67 |
| Dry weight, kg | 5.75[b] | 8.35[a] | 8.88[a] | 8.42[a] | 6.01[b] | 7.64[a] | 0.54 |
| Ruminal mat consistency[2] | | | | | | | |
| Time[3], s | 399[d] | 1,520[bc] | 1,895[ab] | 2,060[a] | 448[d] | 1,045[c] | 140 |
| Distance[4], min/cm | 56.25[a] | 51.66[ab] | 42.45[b] | 43.00[b] | 54.40[a] | 47.01[ab] | 2.52 |
| Ascend rate[5], cm/s | 8.51[a] | 2.07[b] | 1.34[b] | 1.33[b] | 7.76[a] | 2.81[b] | 0.36 |

[1]10CS, 10% of aNDF from corn silage; 20CS, 20% of aNDF from corn silage; SCB, 10CS + 10% of aNDF from sugarcane bagasse; SC, 10CS + 10% of aNDF from sugarcane; SH, 10CS + 10% of aNDF from soybean hulls; LOCH, 10CS + 10% of aNDF from low oil cottonseed hulls.
[2]Rumen fill, grams of NDF concentration in the ruminal content/kg of BW.
[3]As described by Welch (1982).
[4]Time of weight ascension inside the rumen.
[5]Distance travel inside the rumen.
[6]Weight ascends rate inside the rumen.
[ab]Means within a row with different superscripts differ ($P < 0.05$).

**Table 9.** Effects of source and level of NDF from roughage on ruminal in situ roughage source of disappearance of aNDF

| | Experimental diets[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item[2] | 10CS | 20CS | SCB | SC | SH | LOCH | SEM | P-value |
| *MDT* | 76.25 | 63.50 | 44.05 | 35.36 | 41.40 | 41.67 | 7.881 | 0.210 |
| *An* | 61.30[a] | 64.10[a] | 22.31[b] | 37.24[b] | 60.00[a] | 54.00[a] | 0.026 | 0.003 |
| *Un* | 38.73[b] | 41.50[b] | 78.45[a] | 62.76[a] | 39.45[b] | 46.10[b] | 0.034 | 0.008 |
| $\lambda_a$ | 0.1817 | 196.20 | 0.205 | 0.388 | 293.99 | 779.78 | 80.560 | — |
| *MSP* | 20.344 | 8.643 | 10.655 | 17.917 | 5.930 | 0.002 | 5.011 | — |
| $k_d$ | 3.52 | 3.63 | 8.61 | 9.74 | 6.04 | 3.34 | 0.027 | 0.385 |
| *NDFED* | 21.62[ab] | 30.62[a] | 15.21[b] | 29.68[a] | 30.61[a] | 27.95[ab] | 0.020 | 0.015 |

[1]10CS, 10% of aNDF from corn silage; 20CS, 20% of aNDF from corn silage; SCB, 10CS + 10% of aNDF from sugarcane bagasse; SC, 10CS + 10% of aNDF from sugarcane; SH, 10CS + 10% of aNDF from soybean hulls; LOCH, 10CS + 10% of aNDF from low oil cottonseed hulls.
[2]*An*, feed potentially digestible aNDF fraction (% of DM). *Un*, indigestible aNDF fraction (% of DM); $\lambda_a$, asymptotic rate of substrate preparation (1/h); k*d*, fractional degradation rate of An (1/h); *NDFED*, effective degradability of aNDF.
[a,b]Means with different superscripts within a row differ ($P < 0.05$).

**Table 10.** Effects of source and level of NDF from roughage on solid passage rate of Yb-labeled roughage source particles

| | Experimental diets[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item[2] | 10CS | 20CS | SCB | SC | SH | LOCH | SEM | P-value |
| λ | 0.05 | 1.68 | 0.19 | 0.15 | 0.85 | 0.56 | 0.20 | 0.114 |
| k | 5.00[a] | 3.00[bc] | 2.00[c] | 4.10[abc] | 4.20[ab] | 5.70[a] | 0.003 | 0.003 |
| τ | 11.07 | 8.78 | 10.55 | 13.31 | 12.83 | 9.90 | 1.723 | 0.775 |
| RMRT[3] | 37.0[c] | 45.2[b] | 67.1[a] | 42.5[b] | 28.9[c] | 28.1[c] | 2.5 | <0.001 |
| TMRT[4] | 48.0[b] | 54.0[b] | 77.7[a] | 55.8[b] | 41.5b[bc] | 38.0[c] | 3.4 | <0.001 |

[1]10CS, 10% of aNDF from corn silage; 20CS, 20% of aNDF from corn silage; SCB, 10CS + 10% of aNDF from sugarcane bagasse; SC, 10CS + 10% of aNDF from sugarcane; SH, 10CS + 10% of aNDF from soybean hulls; LOCH, 10CS + 10% of aNDF from low oil cottonseed hulls.
[2]λ, asymptotic fractional rate of transference of particles from the raft to the pool of escapable particles (1/h); $_k$, fractional rate of escape of particles from the escapable pool; τ, transit time (h); RMRT, mean retention time of particles in the ruminoreticulum (h); TMRT, total mean retention time of particles in the gastrointestinal tract (h).
[3]The variable RMRT was scaled to body mass as follows: $Y_{adj1} = RMRT/BM_{0.578.}$
[4]The variable TMRT was scaled to body mass as follows: $Y_{adj2} = TMRT/BM_{0.334.}$
[a-c]Means with different superscripts within a row differ ($P < 0.05$).