Advances in Modeling Ruminant Nutrient Utilization

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Introduction

- Ruminants account for a third of meat and almost all of the global milk production
- Intensive research around the world
- Data generated at a rapidly increasing rate
- Quantitative approaches
  - Increase understanding further
  - Integrate various aspects
- Statistical analysis and mathematical models

Introduction

From manuscripts published in *J. Anim. Sci.*

- No ‘modeling’ papers were found before 1970
- 3.2% ‘70s, 17% ‘80s, 31.5% 90’s
- 616 papers (almost 50%) published after 2000

Mathematical spectrum

Statistics	Operations Research	Applied Mathematics	Numerical Analysis	Pure Mathematics

← Empirical Modelling →← Mechanistic Modelling →

Objective

Summarize research advances made through the use of mathematical methods

- understand the underlying concepts of nutrient utilization in ruminants at various levels of organization

Energy, protein (N), mineral (P), lactic acidosis, whole animal and farm models

Modeling Energy Utilization

Dietary CHO ------> hexoses & pentoses ----> VFA

95% VFA are acetate, propionate & butyrate

Fermentation stoichiometry must be known

Murphy et al. (1982) derived coefficients

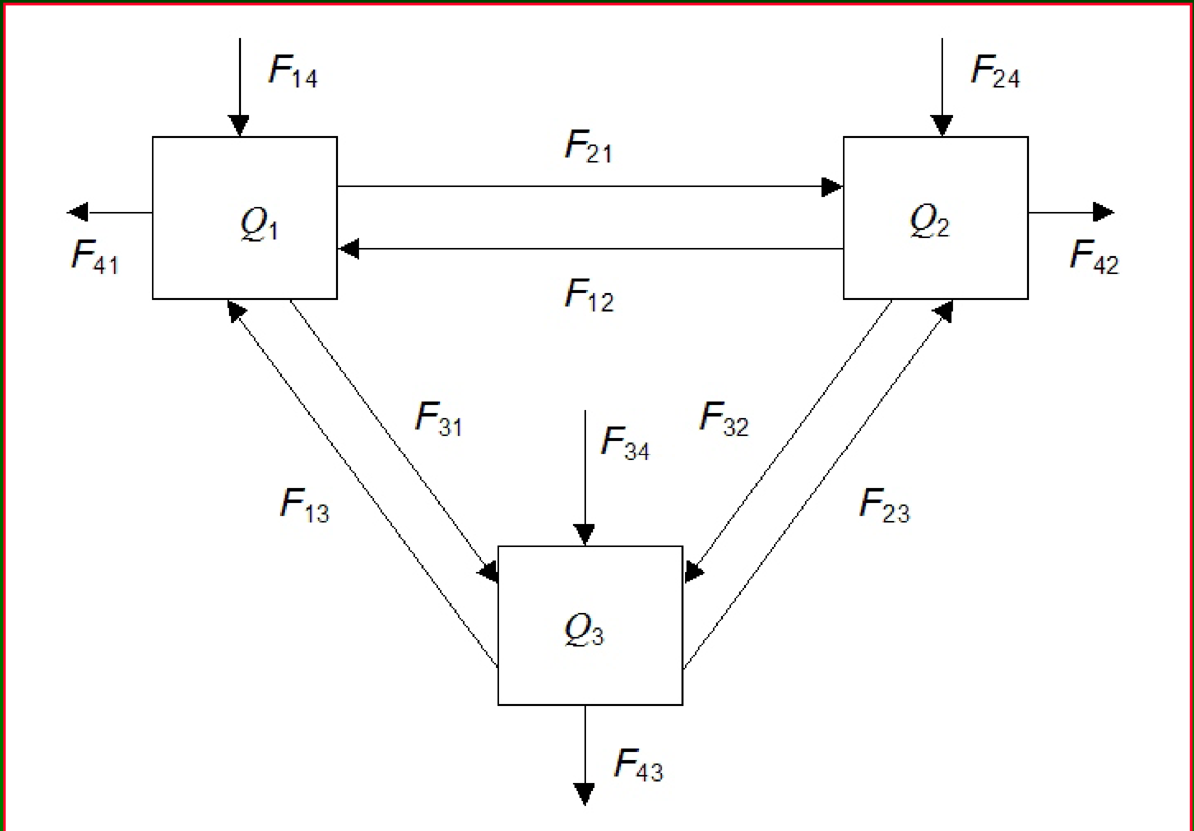
Prediction not very accurate – inadequate representation of stoichiometry

Bannink et al. (2006) used meta-analysis

Modeling VFA in the rumen

- Statistical approaches have limited power
  - No consideration of microbial population
  - Not sensitive to fermentation conditions
- France & Dijkstra (2005) developed single or three pool scheme (tracer-based)
- Current models still unsatisfactory
- Further development should include protozoal contribution

Modeling VFA in the Rumen



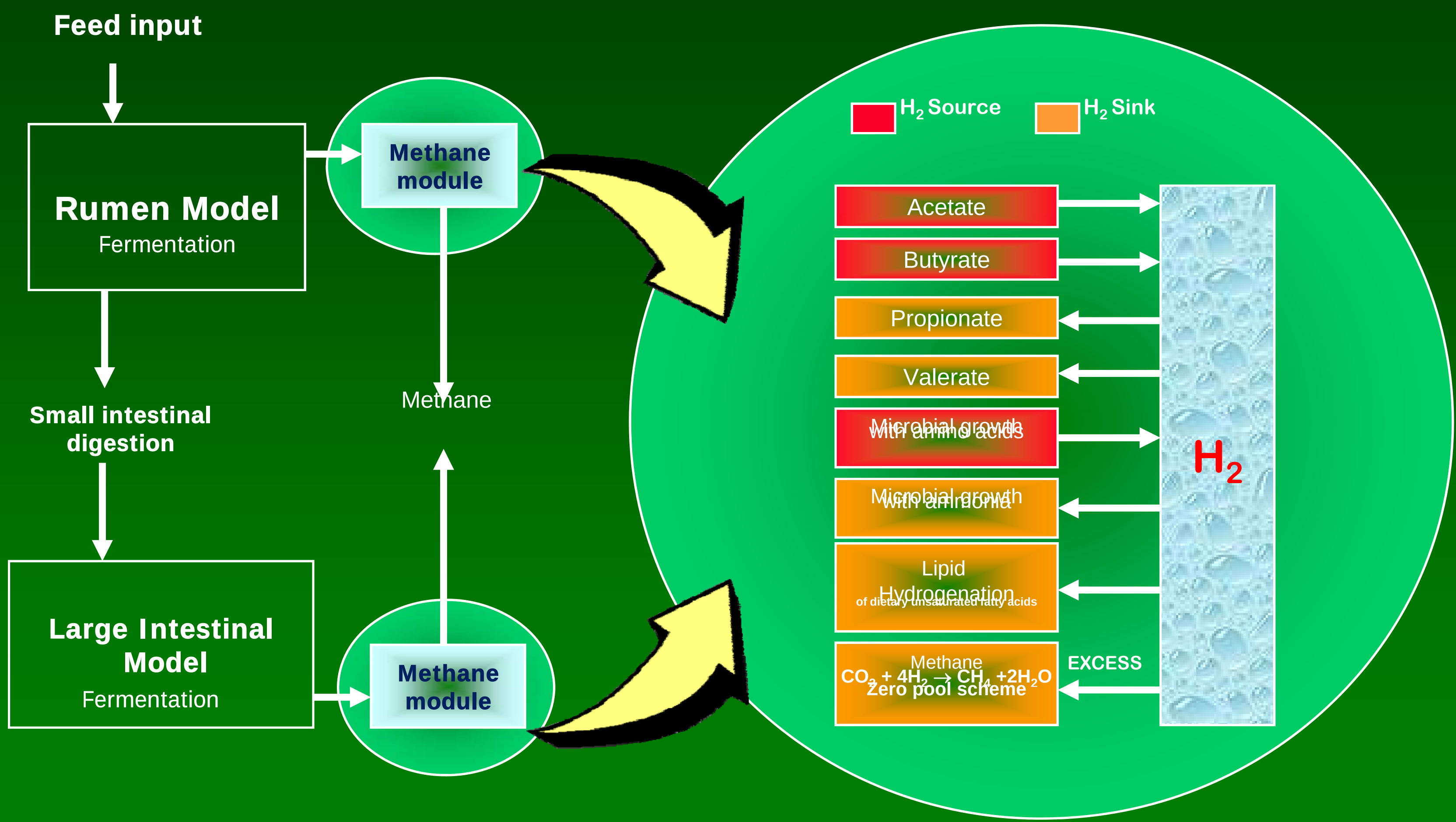
France and Dijkstra 2005. *Quantitative Aspects of Ruminant Digestion,* 157

Three-pool model for VFA production in the rumen showing pools and fluxes of tracee. 1=Acetate, 2=Propionate, 3=Butyrate

Modeling Methanogenesis

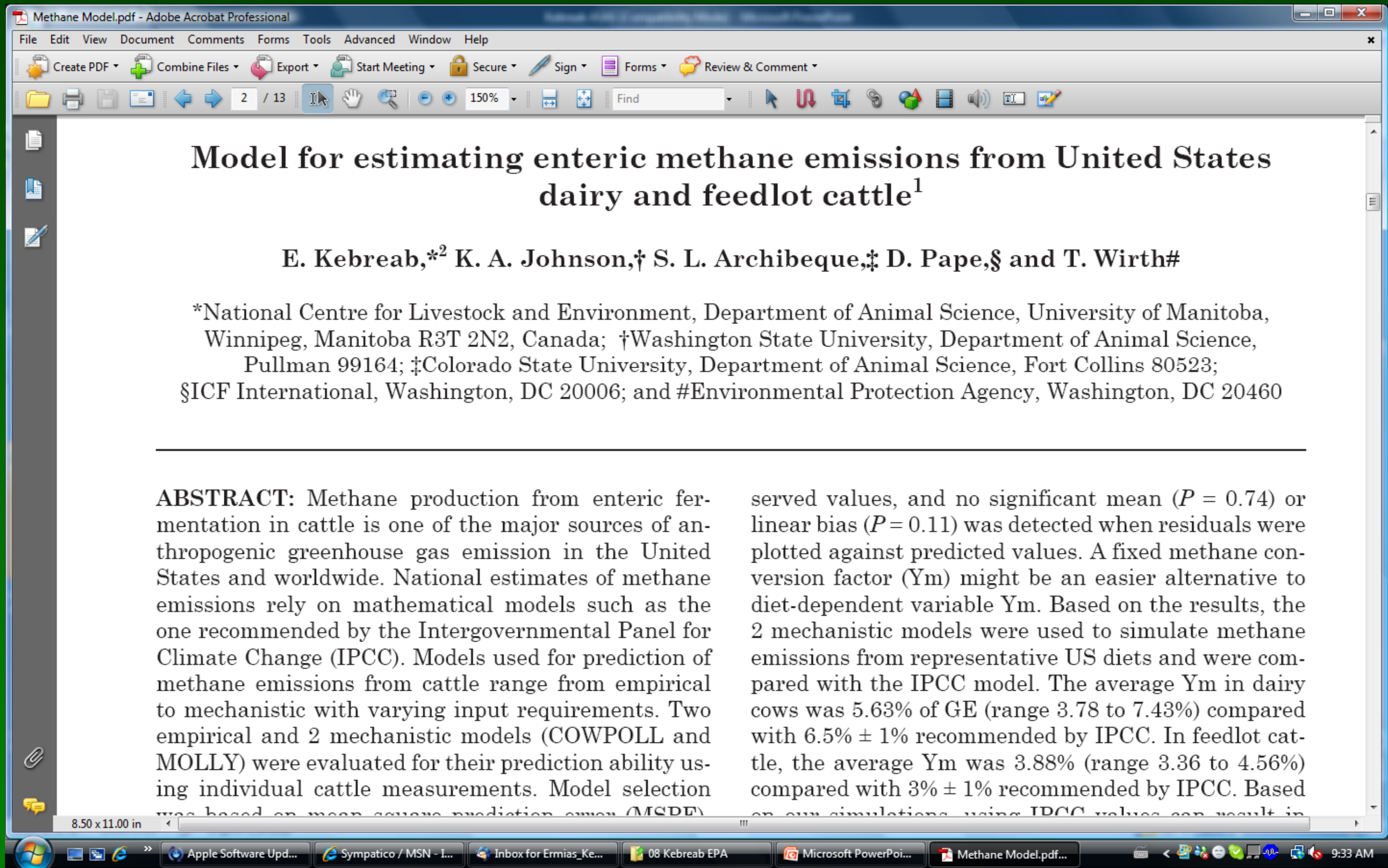
- Methane is loss of productivity (up to 12% GE)
- GHG and 21 X potent than CO_2
- Lipogenic:glucogenic VFA is important
- Measurement requires complex and often expensive equipment
- Current estimates based on IPCC models
- Methane emission models can be empirical or mechanistic

Modeling Methanogenesis



Kebreab et al. 2004. *Anim. Feed Sci. Technol.* 112: 131

Modeling Methanogenesis



Model for estimating enteric methane emissions from United States dairy and feedlot cattle[1]

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ABSTRACT: Methane production from enteric fermentation in cattle is one of the major sources of anthropogenic greenhouse gas emission in the United States and worldwide. National estimates of methane emissions rely on mathematical models such as the one recommended by the Intergovernmental Panel for Climate Change (IPCC). Models used for prediction of methane emissions from cattle range from empirical to mechanistic with varying input requirements. Two empirical and 2 mechanistic models (COWPOLL and MOLLY) were evaluated for their prediction ability using individual cattle measurements. Model selection

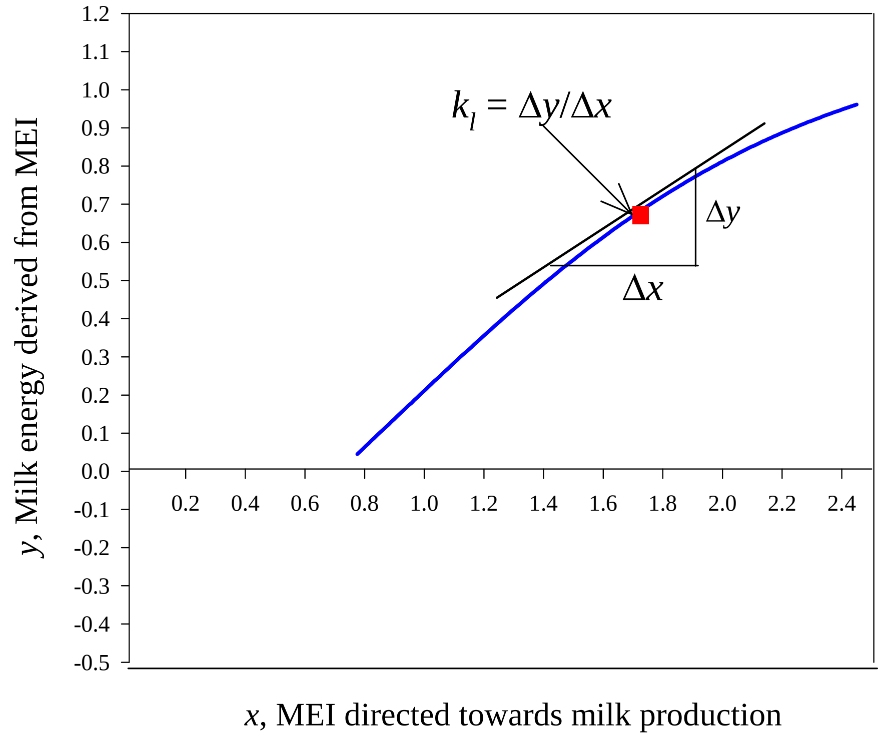
served values, and no significant mean (P = 0.74) or linear bias (P = 0.11) was detected when residuals were plotted against predicted values. A fixed methane conversion factor (Ym) might be an easier alternative to diet-dependent variable Ym. Based on the results, the 2 mechanistic models were used to simulate methane emissions from representative US diets and were compared with the IPCC model. The average Ym in dairy cows was 5.63% of GE (range 3.78 to 7.43%) compared with 6.5% ± 1% recommended by IPCC. In feedlot cattle, the average Ym was 3.88% (range 3.36 to 4.56%) compared with 3% ± 1% recommended by IPCC. Based

Kebreab et al. 2008. *J. Anim. Sci.* 86: 2738-2748

Efficiency of Energy Utilization

- Traditionally NE and ME systems are used
- Key parameters were by linear regression
- Meta-analysis and non-linear methods used to study efficiency (Kebreab et al., 2003)
- Efficiency ME intake for milk, body gain
  - 0.55, 0.83 vs 0.64, 0.75 (NE) 0.62, 0.60 (ME) ($MJ/kg^{0.75}/d$)
- Efficiency tissue for milk, maintenance
  - 0.66, 0.59 vs 0.82, 0.51 (NE) 0.84, 0.49 (ME)

Efficiency of Energy Utilization



Kebreab et al. 2003. *J. Dairy Sci.* 86: 2904

Modeling Protein (N) Utilization

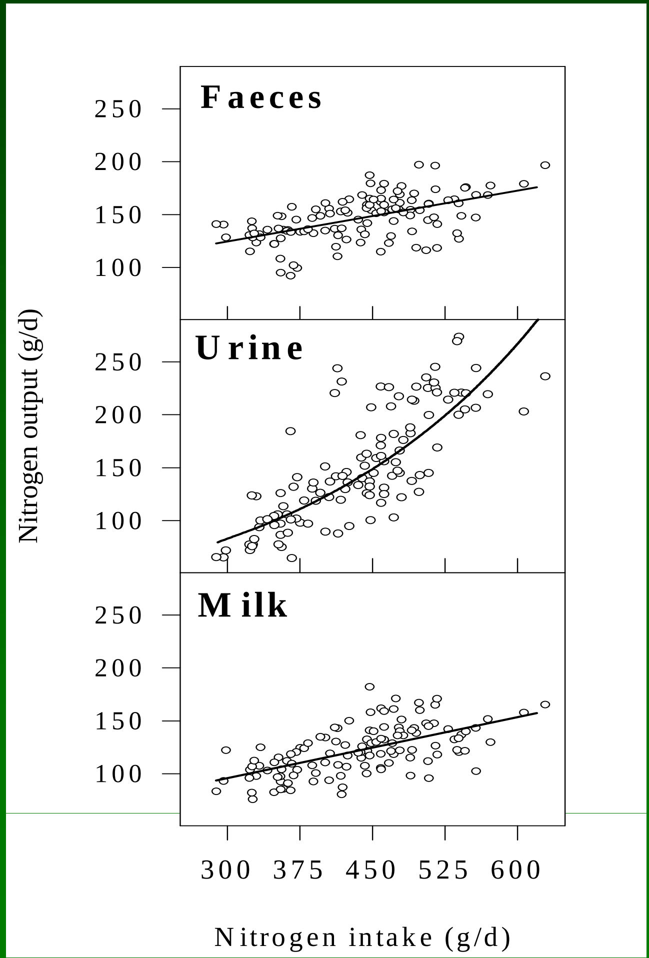
Overall efficiency of dietary N 13 - 31%

Theoretically 40 – 45%

Empirical and Mechanistic

Kebreab et al. (2001)

- 72% of dietary N is excreted
- N intake and Urine N have exponential correlation



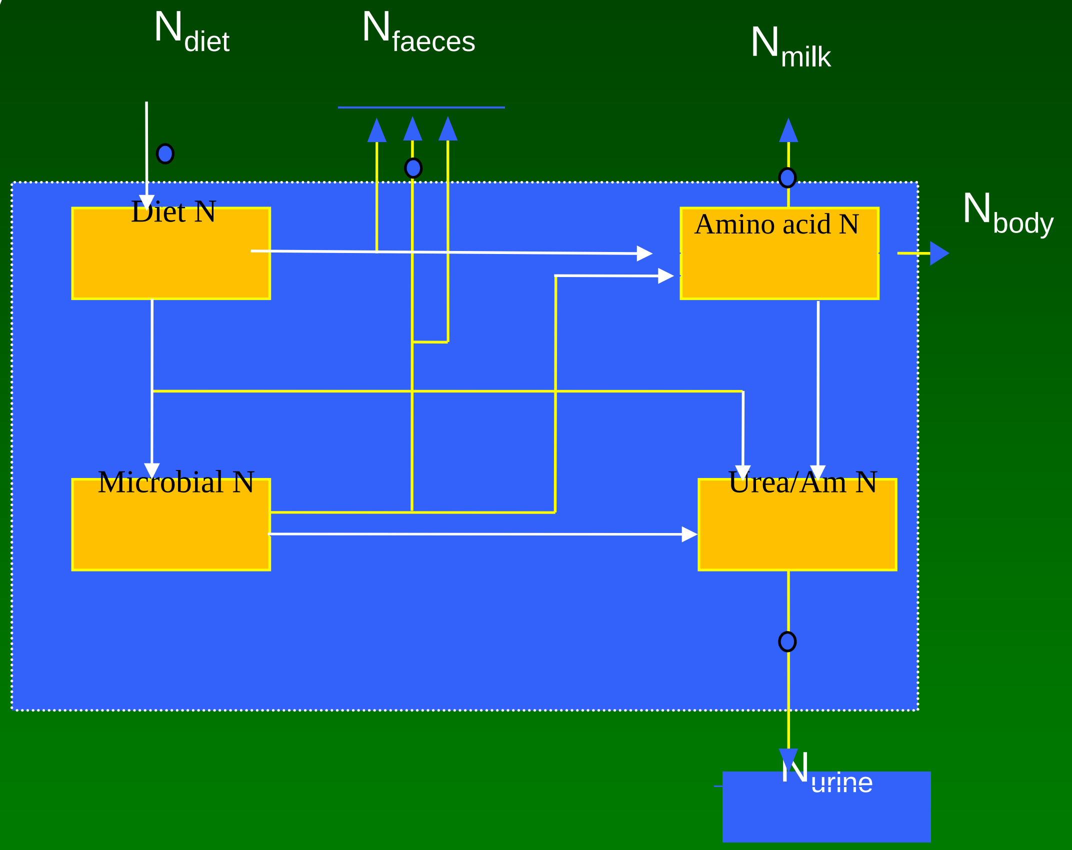
Kebreab et al. 2001. *Nut. Cycl. Agroecosyst.* 60: 275

Modeling Protein (N) Utilization

N utilization affected by

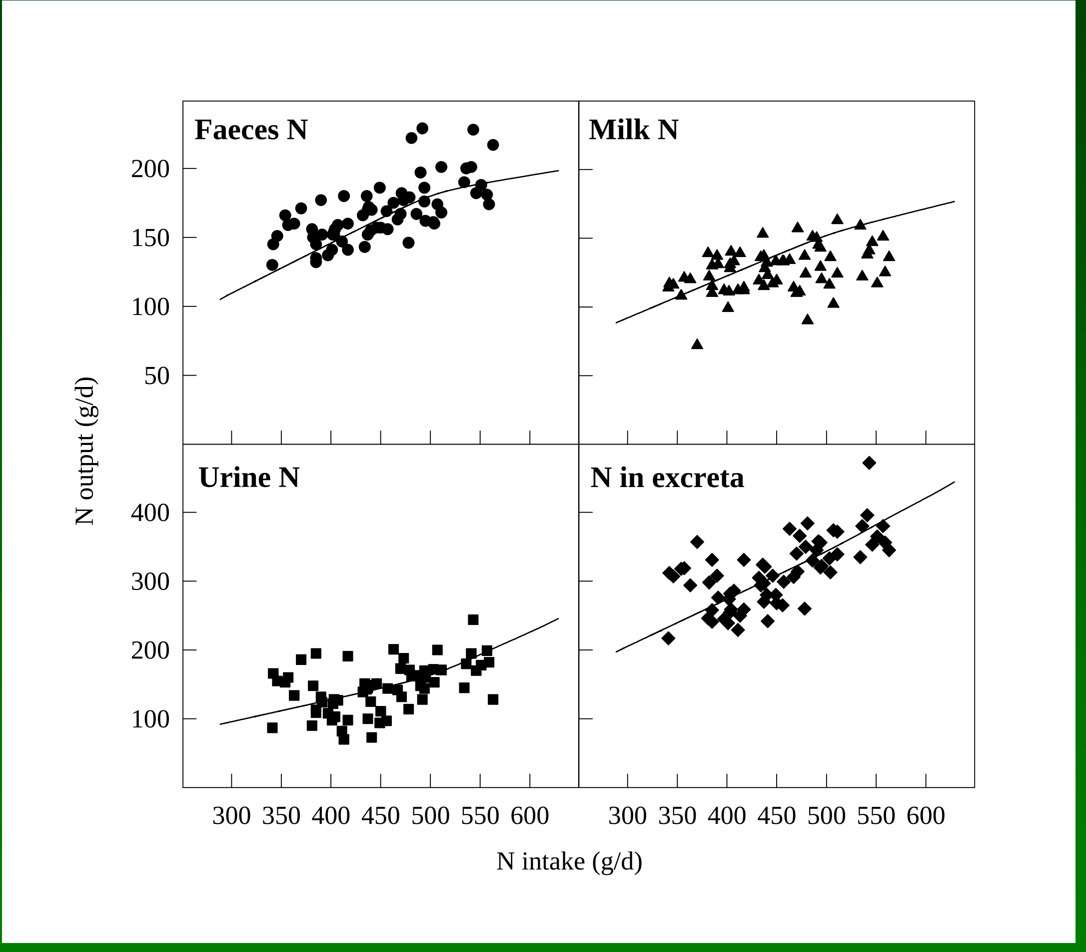
- Dietary N concentration
- Microbial community
- Urea recycling etc

Based on differential equations



Kebreab et al. 2002. *J. Anim. Sci.* 80: 248

Modeling Protein (N) Utilization

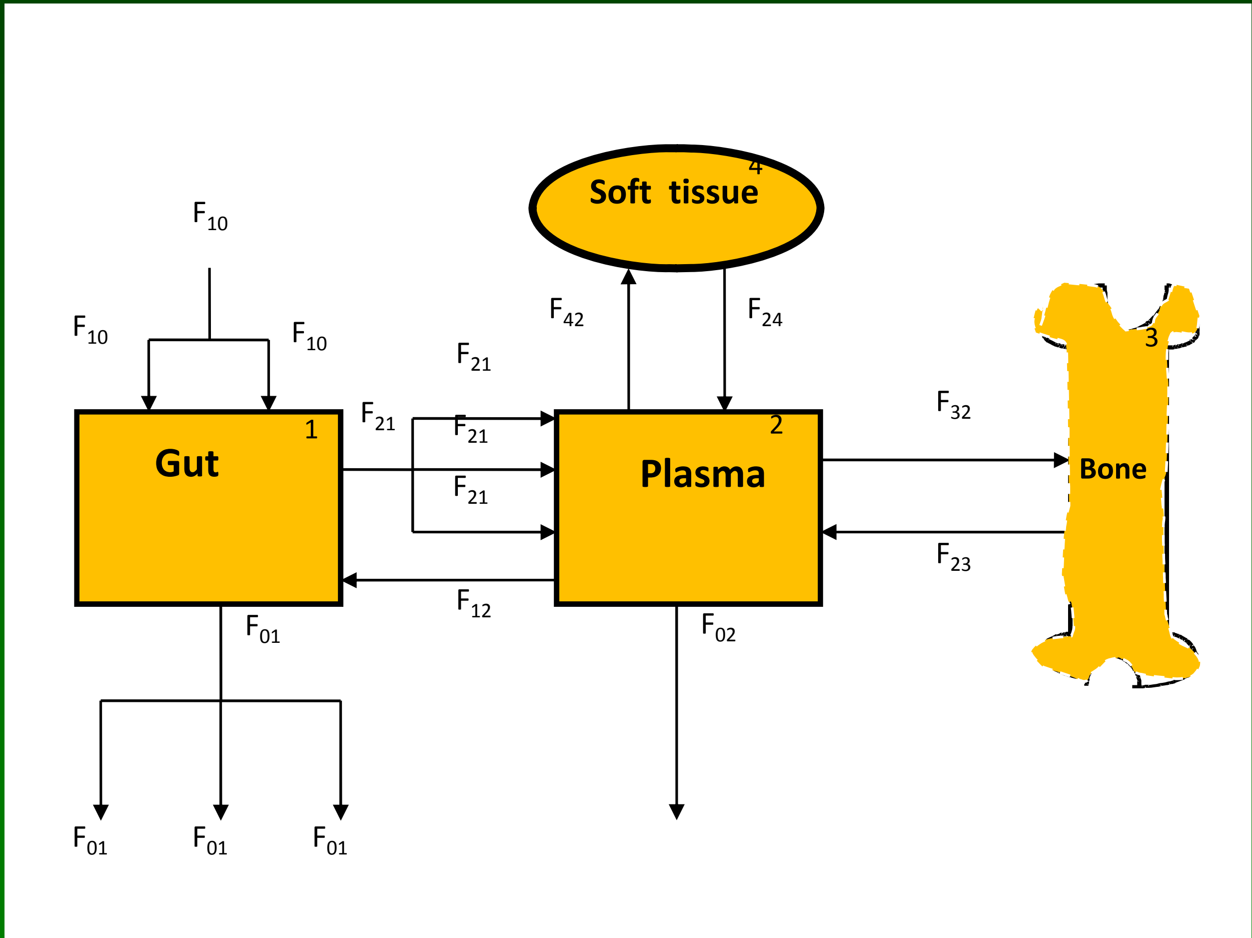


Kebreab et al. 2002. *J. Anim. Sci.* 80: 248

Modeling Phosphorus Utilization

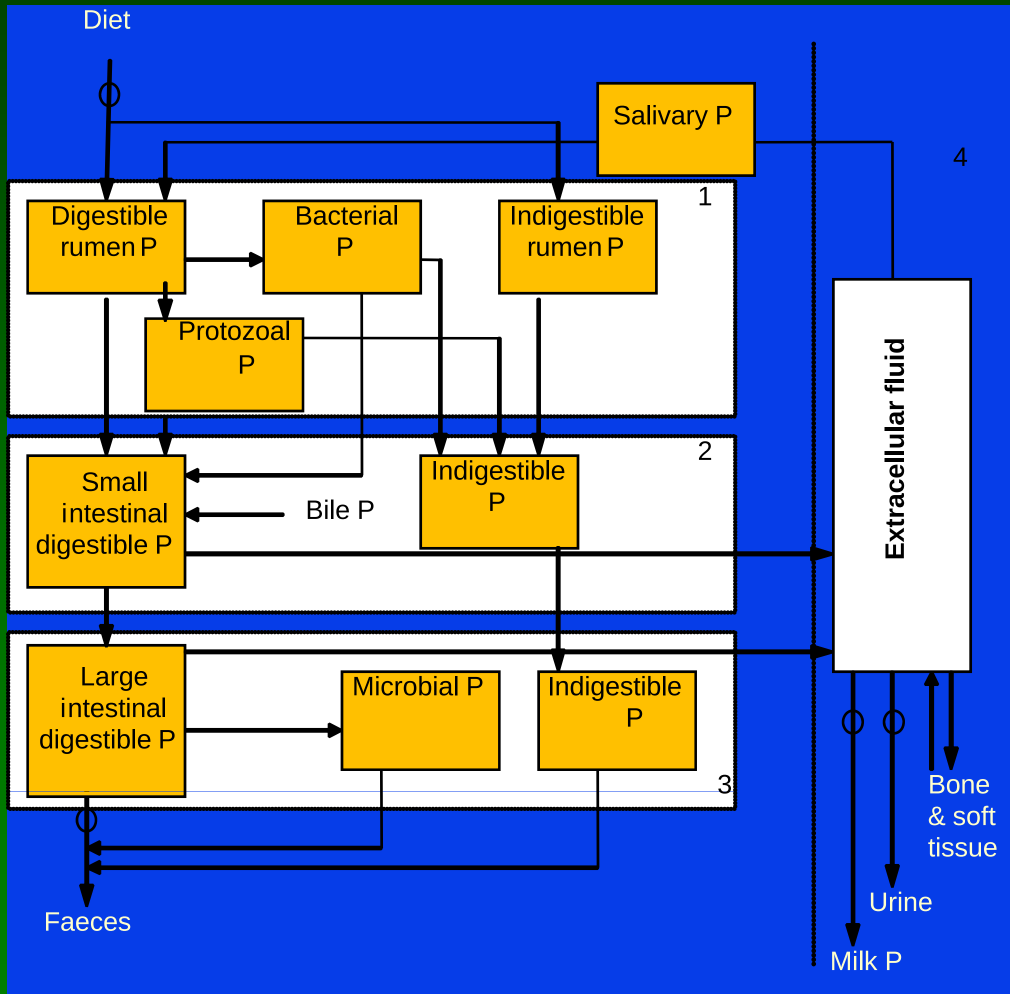
- Dairy cows use <40% of dietary P intake
- Excess P mostly excreted in feces
- Current recommendations (20 kg/d DMI)
  - 74 g/d (AFRC, 1993)
  - 64 - 84 g/d (NRC, 2001)
- Models of P utilization include:
  - Statistical
  - Kinetic and
  - Dynamic

Kinetic P model



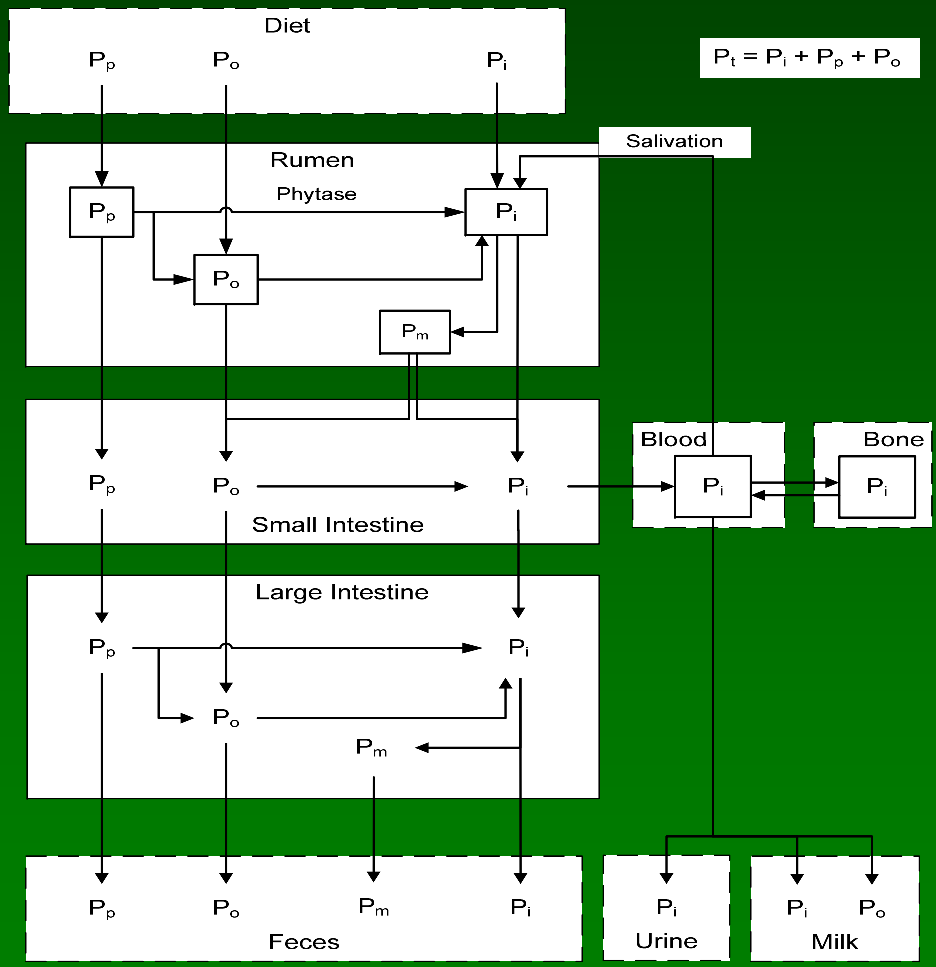
Dias, Kebreab et al. 2006. *J. Anim. Sci.* 84: 2787

Mechanistic P model



Kebreab and Vitti. 2005. *Quantitative Aspects of Ruminant Digestion*, 469

Mechanistic P model



Hill, Kebreab et al. 2008. *J. Dairy Sci.* 91: 2021

Modeling Lactic Acidosis

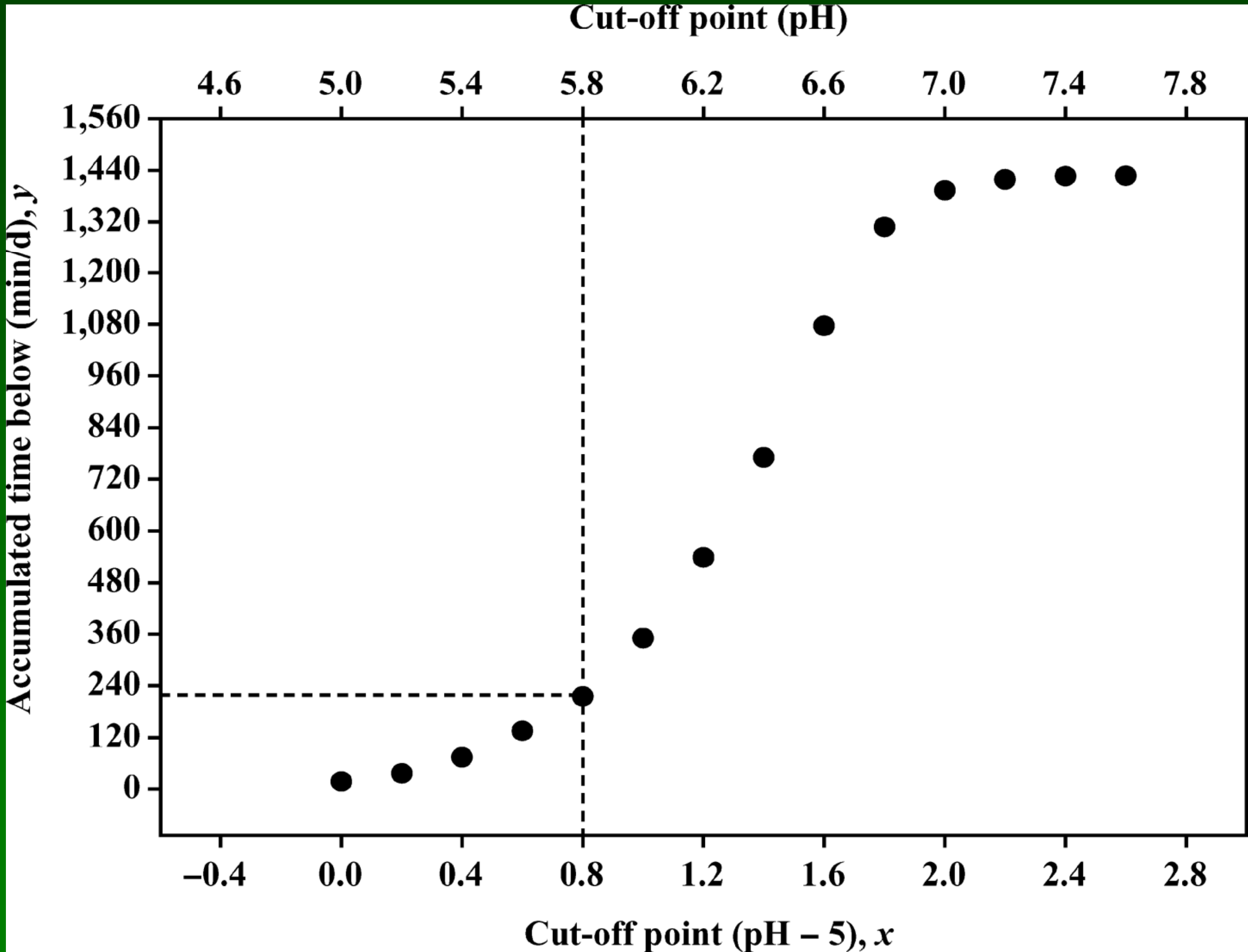
- Accumulation of lactate in rumen
- Diets rich in rapidly fermentable CHO
  - Starch
  - Water Soluble Carbohydrate
  - (organic acids – e.g. lactate in grass silage)
- Clinical or Subclinical
  - Health problems (liver abcesses, parakeratosis)
  - Production losses
  - Welfare concerns
  - Environmental impact?

Modeling Lactic Acidosis

Various approaches have been used

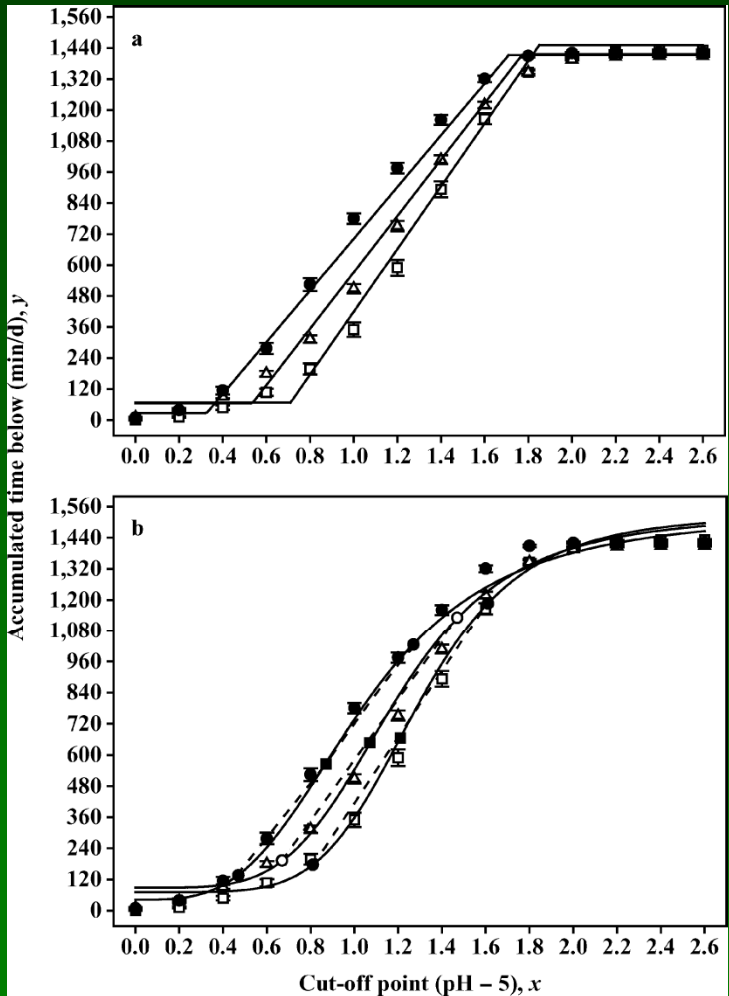
- Meta-analysis using growth curves
- Relating rumen pH with rumen temperature
- Mechanistic approach using extant rumen model

Meta-analysis – Lactic Acidosis



Alzahal, Kebreab et al. 2007. *J. Dairy Sci.* 90: 3777

Meta-analysis – Lactic Acidosis



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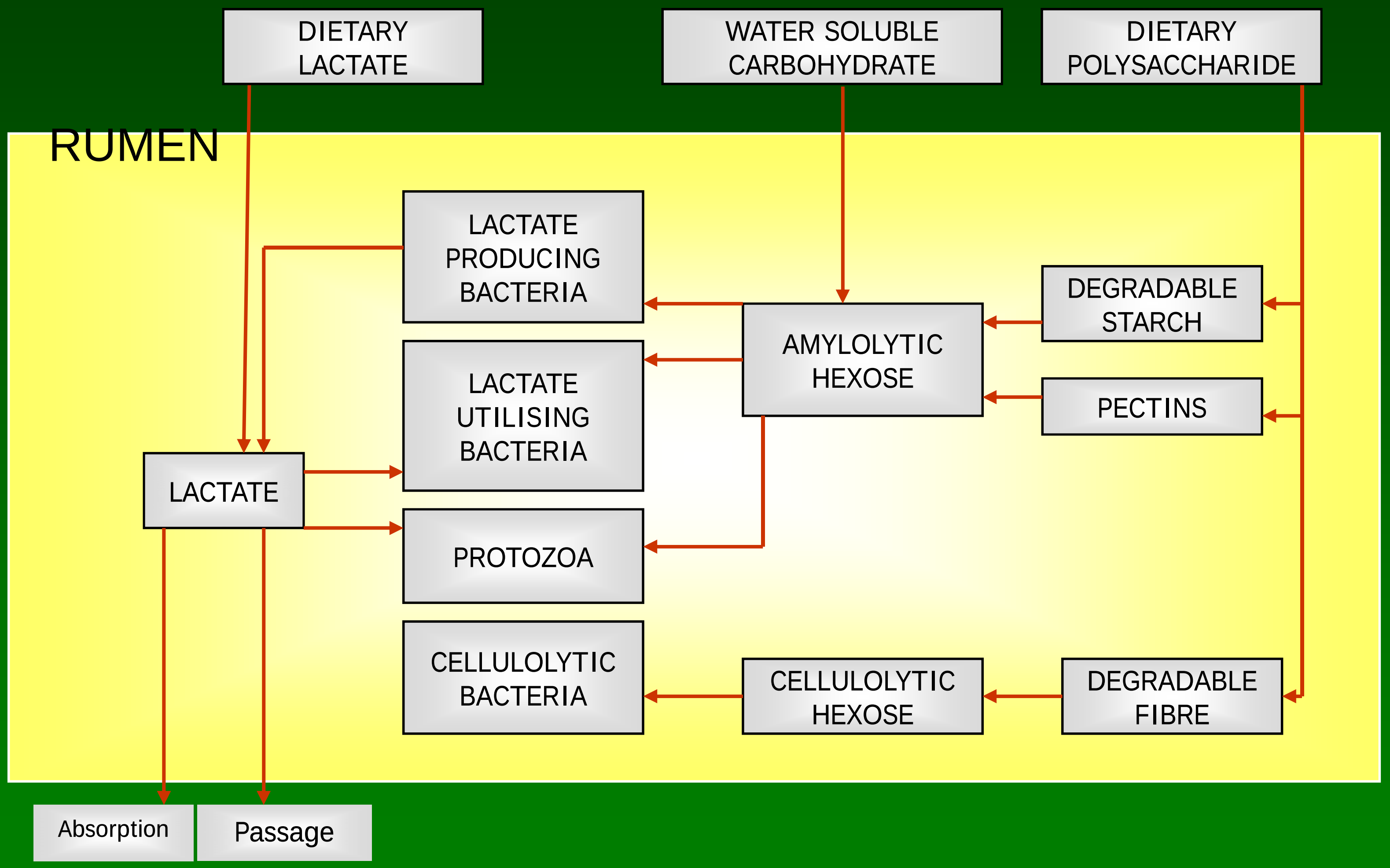
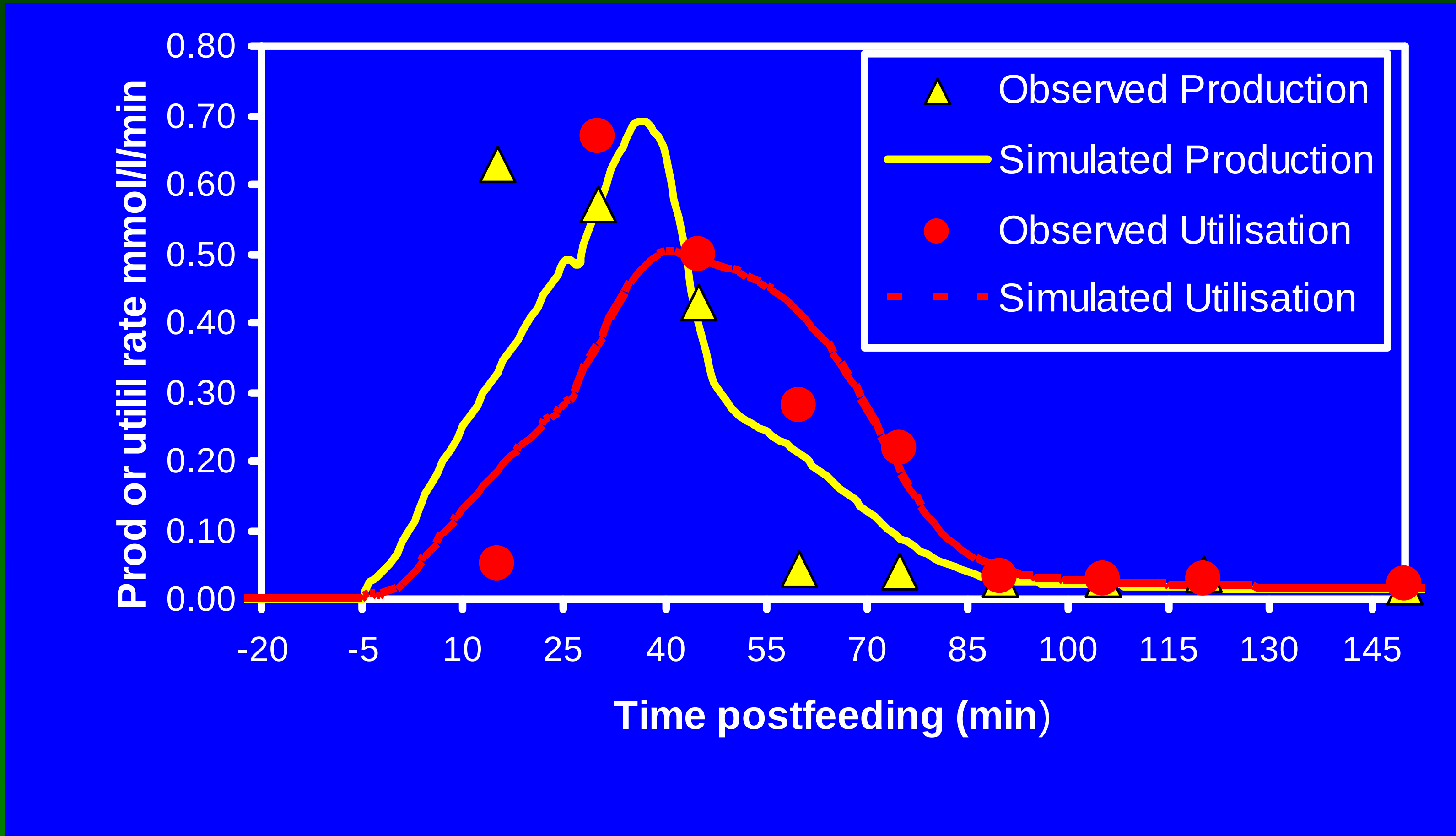
Mechanistic Model – Lactic Acidosis



Dijkstra et al. 2002. *Nutr. Res. Rev.* 15: 67

Mechanistic Model – Lactic Acidosis

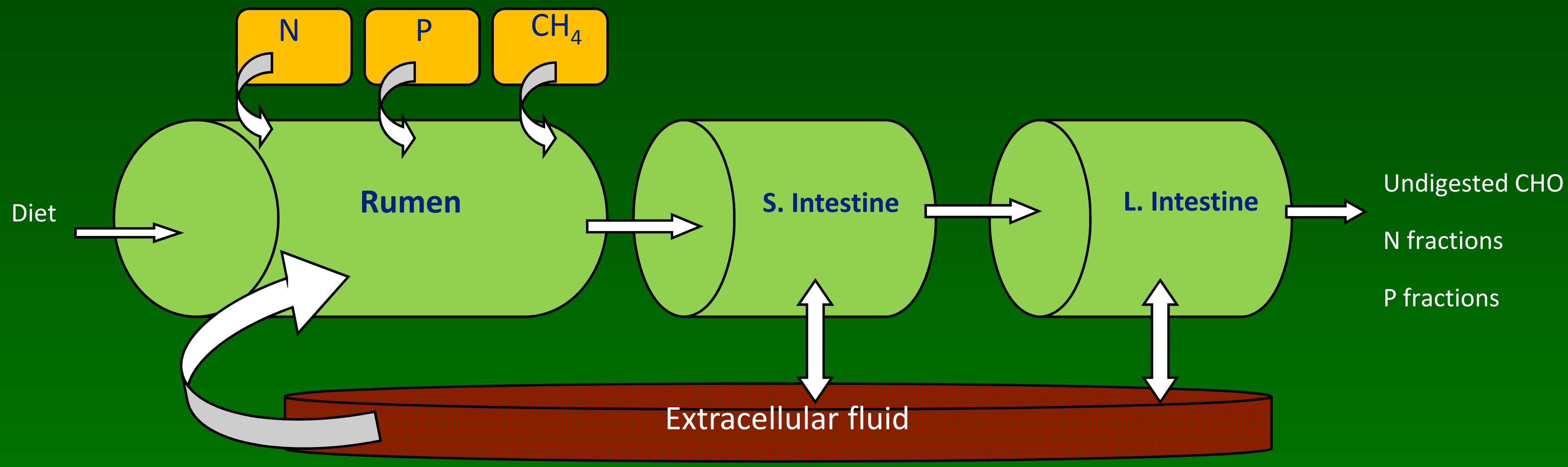


Dijkstra et al. 2002. *Nutr. Res. Rev.* 15: 67

Nutrient Utilization - Animal & Farm Level

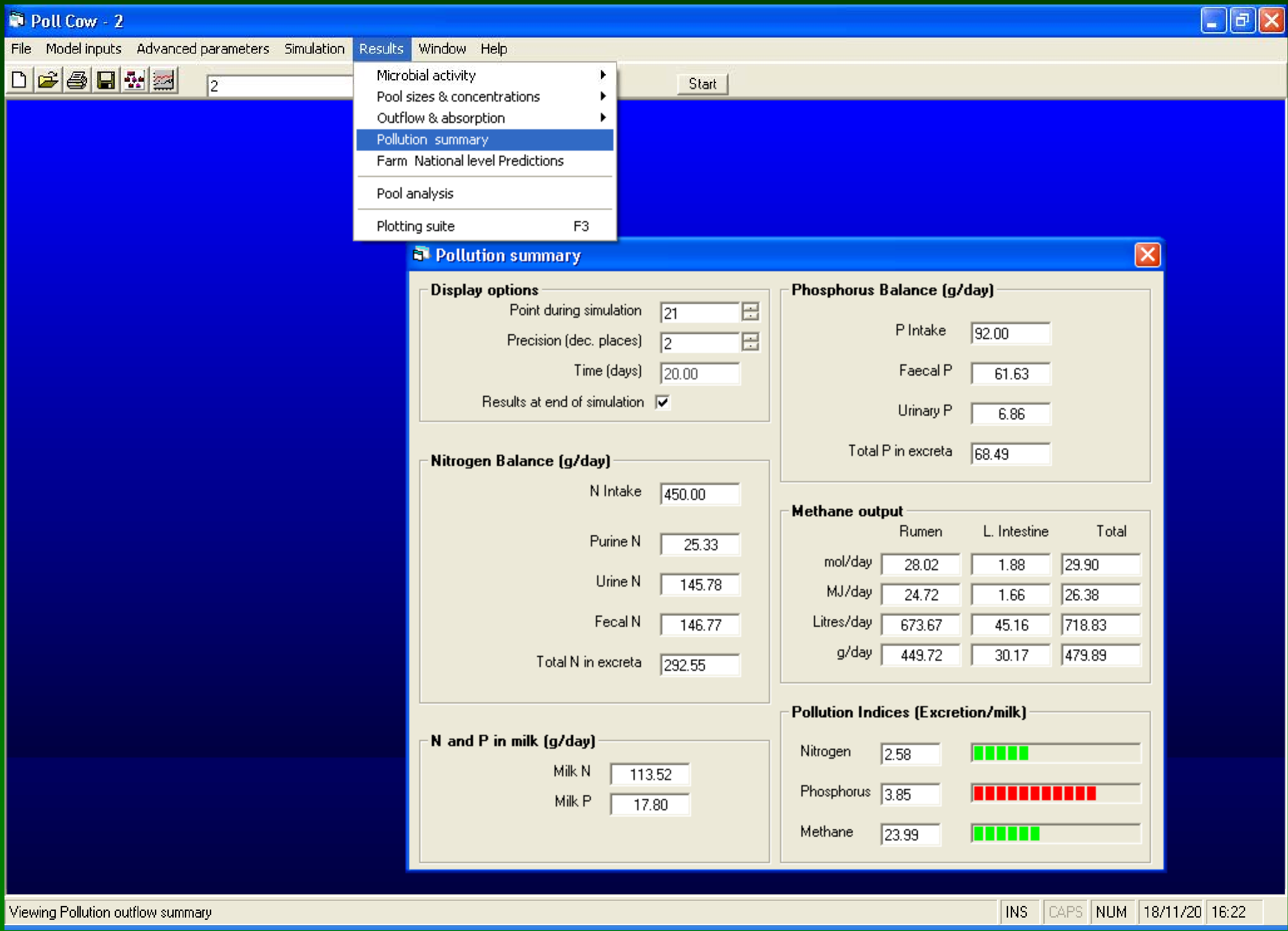
- Integrated model of nutrient utilization
  - Addition of N, P and methanogenesis to extant rumen model and extension to whole animal level (Kebreab et al. 2004)
- Nutrient utilization model for tropical cattle
  - Sugarcane based (Brazil and India)
  - Elephant grass based (Brazil)
- LP models for Mexican small-scale dairy farms

Mechanistic Model – Animal Level

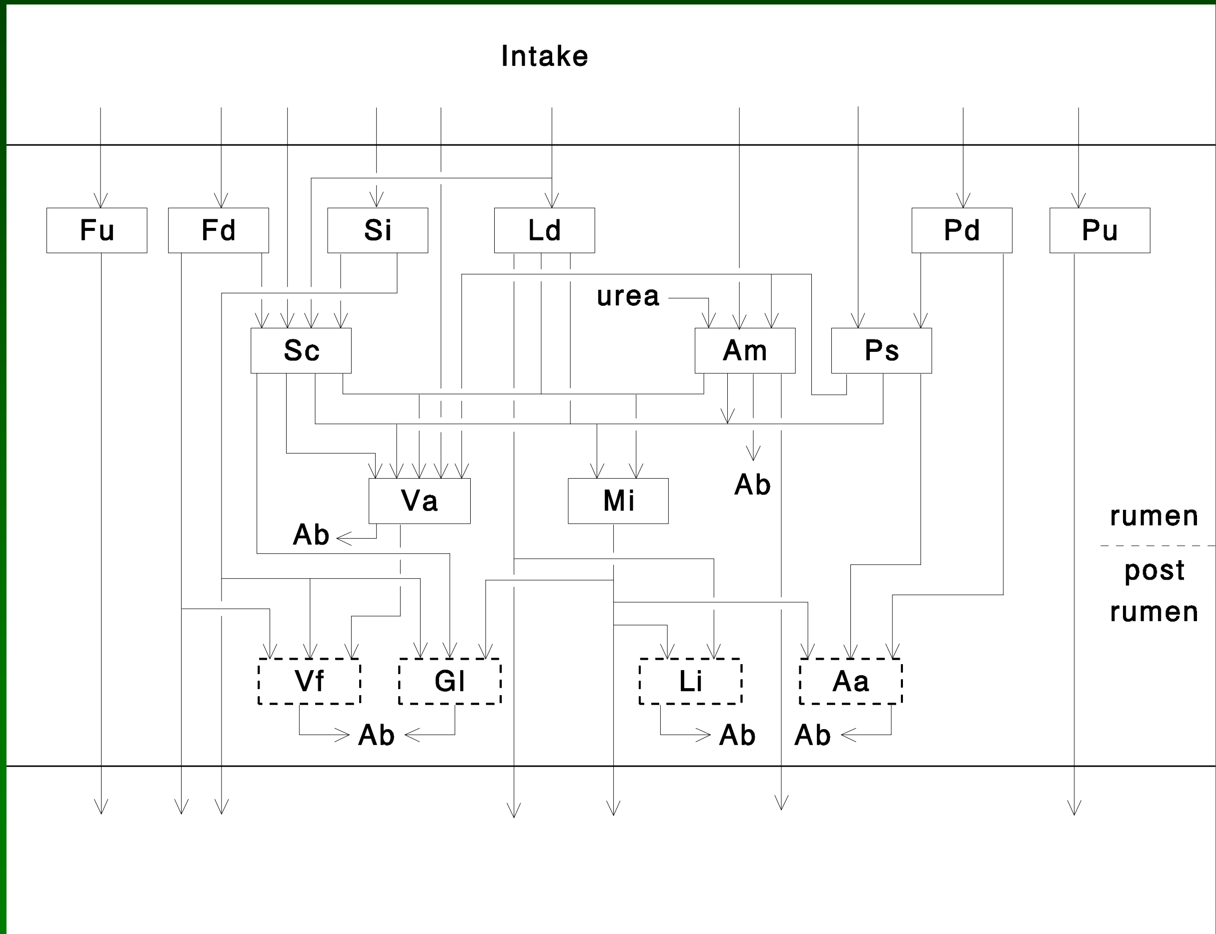


Kebreab et al. 2004. *Anim Feed Sci. Technol.* 112: 131

Mechanistic Model – GUI



Mechanistic Model – Tropical Animal



Kebreab et al. 2001. *Trop. Anim. Health Prod.* 33:127-139

Mechanistic Model – Farm Level

Compromise and goal programming

Summary of objective functions below:

Objective	Function	Description of variables
1) Maximize ME for milk production	$\sum_{j=1}^{4}\left(\sum_{k=1}^{9} ME_k y_{jk} - \sum_{i=1}^{4} NLE_i x_{ij}\right)$	
2) Maximize margin over feed cost	$\sum_{j=1}^{4}\left(\sum_{i=1}^{4} MY_i p_j x_{ij} - \sum_{k=1}^{9} c_{ik} y_{jk}\right)$	p_j= milk price in quarter j (M$/kg).
3) Maximize MP for milk production	$\sum_{j=1}^{4}\left(\sum_{k=1}^{9} MP_k y_{jk} - \sum_{i=1}^{4} NLE_i x_{ij}\right)$	
4) Minimize purchased feeds	$\sum_{j=1}^{4}\sum_{k} c_{jk} y_{jk}$	k summed over purchased feeds

Val-Arreola , Kebreab et al. 2006. *J. Dairy Sci.* 89:1662

Future Research Direction

More integration of tissue-organ-animal models and upscaling to farm level

Move towards modeling discontinuous feeding and its effect on fermentation etc.

Nutrient based feed evaluation models instead of factorial approach (NRC, AFRC)

Better graphical user interface to models for general use

Thank you

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