Challenges in ruminant nutrition:
towards minimal nitrogen losses in cattle

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Efficiency of N utilization

- Proportion of feed N captured as milk and meat (N efficiency) inversely related to amount of N excreted
- Variation in milk N efficiency: 0.15 – 0.40

Example: N loss EU dairy production

No. of cows, x 10^6	23.1	
Average milk production per cow, kg/yr	6,692	
Average milk protein content, g/kg	33.7	
EU-27 milk N yield (MN), kg x 10^6 /yr	798	
Assumed milk N efficiency, MN / NI	0.25	0.35
EU-27 feed N intake (NI), kg x 10^6 /yr	3,195	2,282
EU-27 N loss dairying, kg x 10^6 /yr	**2,396**	**1,483**

Eurostat 2011

This presentation

Identify maximal theoretical N efficiency at animal level to minimize N excretion in faeces and urine

- ‘inevitable’ losses
  - rumen fermentation and microbial protein synthesis
  - intestinal digestion
  - post-absorptive metabolism
- challenges and opportunities to achieve maximal N efficiency in dairy cattle

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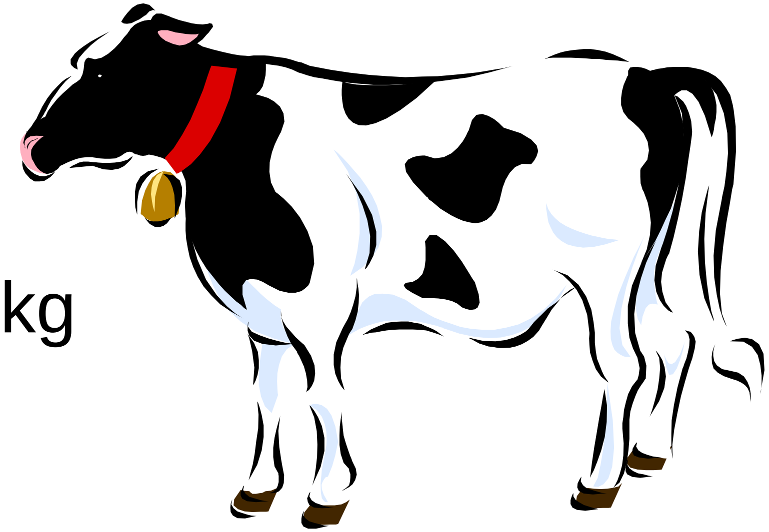
Assumptions reference cow



- Live weight 650 kg
- FPCM 40 kg/d
- Milk true protein content 31.5 g/kg
- DM intake 24 kg/d
- Diet NE content 6.9 MJ/kg DM
- Total tract DM digestibility 0.80
- Diet rumen fermentable OM 0.55
- Zero N balance

Inevitable N losses

- Digestion
  - Fermentation
  - Microbial composition
  - Undigested protein
  - Endogenous protein
- Maintenance
- Milk production

Inevitable N losses

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Minimal level of N-sources in rumen

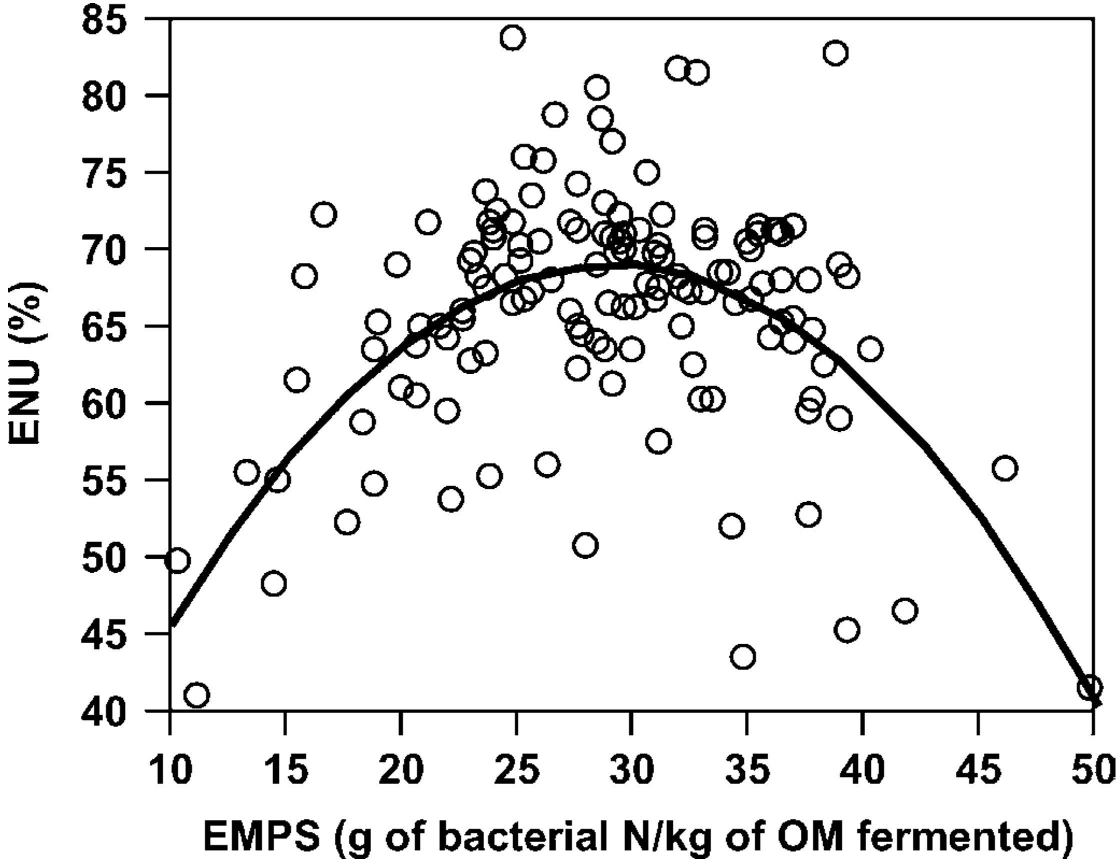
- Ammonia major source of N for microbial protein synthesis
- Insufficient N may compromise fermentation and microbial efficiency
  - minimal NH_3 level 50 g/l Satter and Slyter (1974)
  - passage and absorption of NH_3
  - reference cow: ~100 g/d NH_3-N lost from rumen
- Recycling of urea-N to rumen

Reynolds and Kristensen (2008)

- Reference cow: inevitable loss ~30 g N/d
  - excreted as urea in urine

Efficiency of N utilization in the rumen

- Optimum when microbial N / rumen available N (ENU) is maximized



Bach et al. (2005)

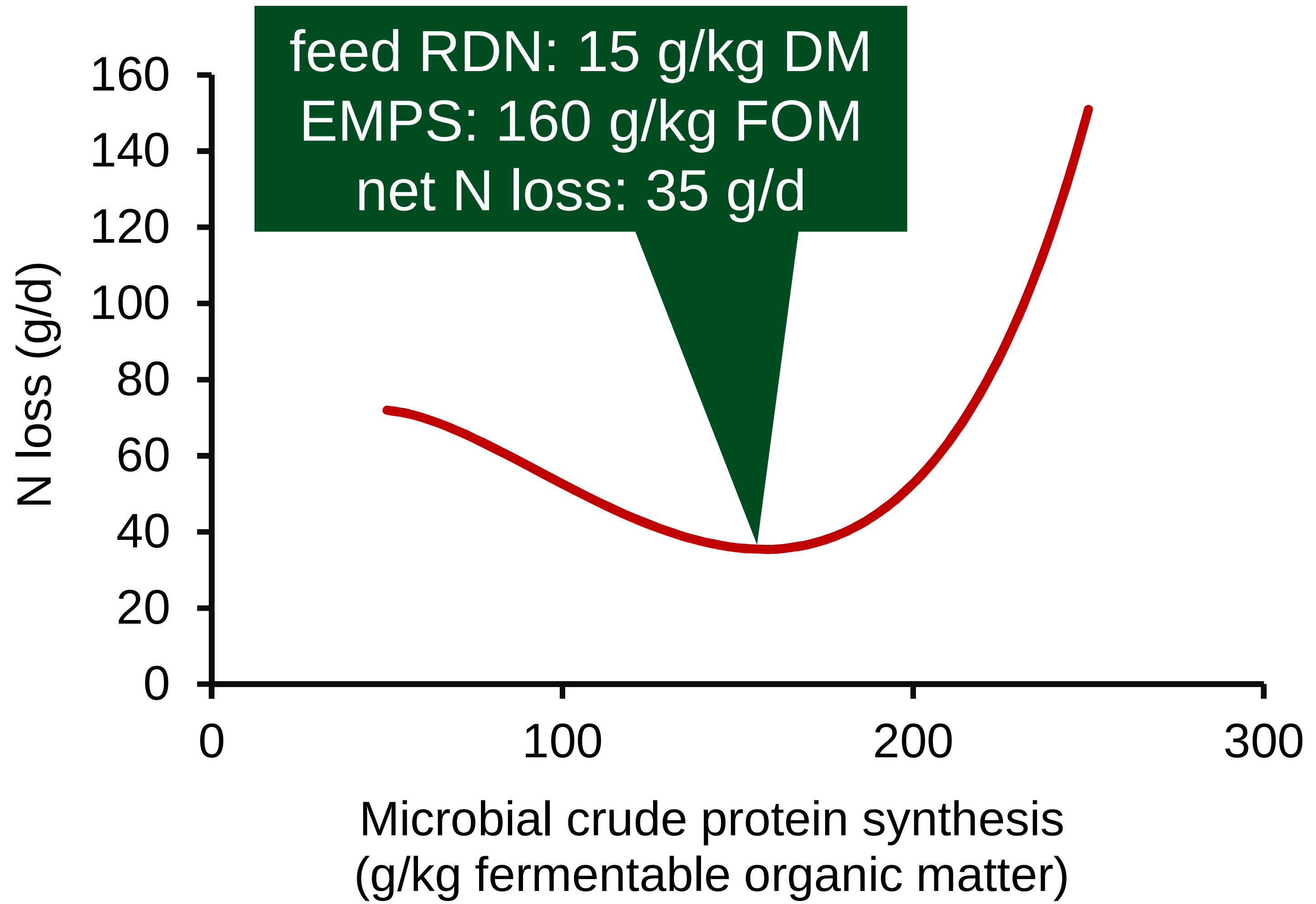
Efficiency of N utilization in the rumen

- Optimum when microbial N / rumen available N (ENU) is maximized
- Rumen available N = RDN_{feed} + recycled urea-N
- Recycled urea-N related to N intake

Reynolds and Kristensen (2008)

- N loss = RDN_{feed} − microbial N synthesised

Efficiency of N utilization in the rumen



Efficiency of N utilization in the rumen

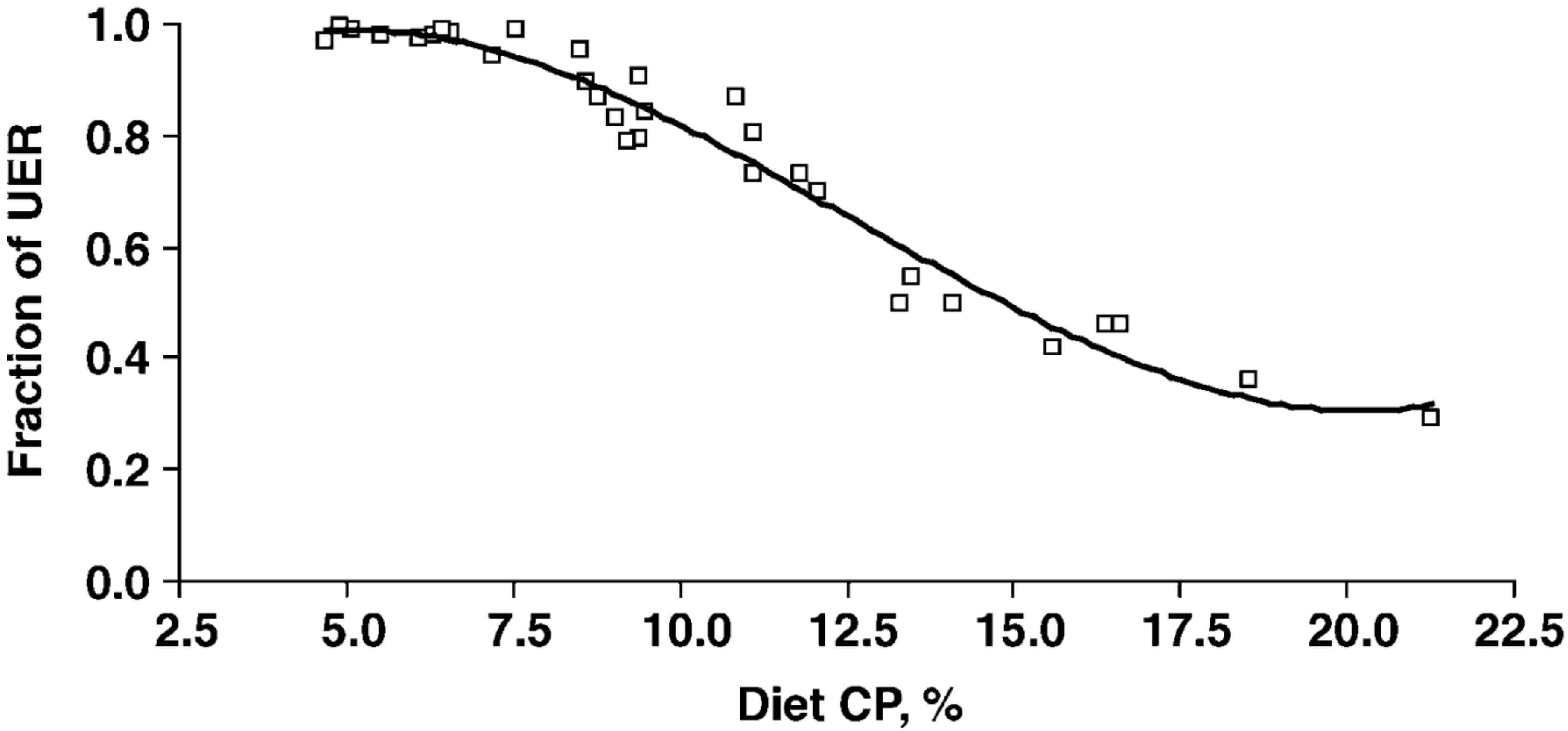
- Inevitable loss reference cow: **35 g N/d** at optimal rumen N efficiency
  - excreted as urea in urine
  - previously calculated based on NH_3: > 30 g N/d

Impact of N recycling

- Urea-N major contributor to total N recycling to rumen
- Advantageous if recycled N is used for microbial protein synthesis and subsequently absorbed
- 30 to nearly 100% of urea entering blood pool returned to gut
  - via saliva and across gut epithelia

Reynolds and Kristensen (2008)

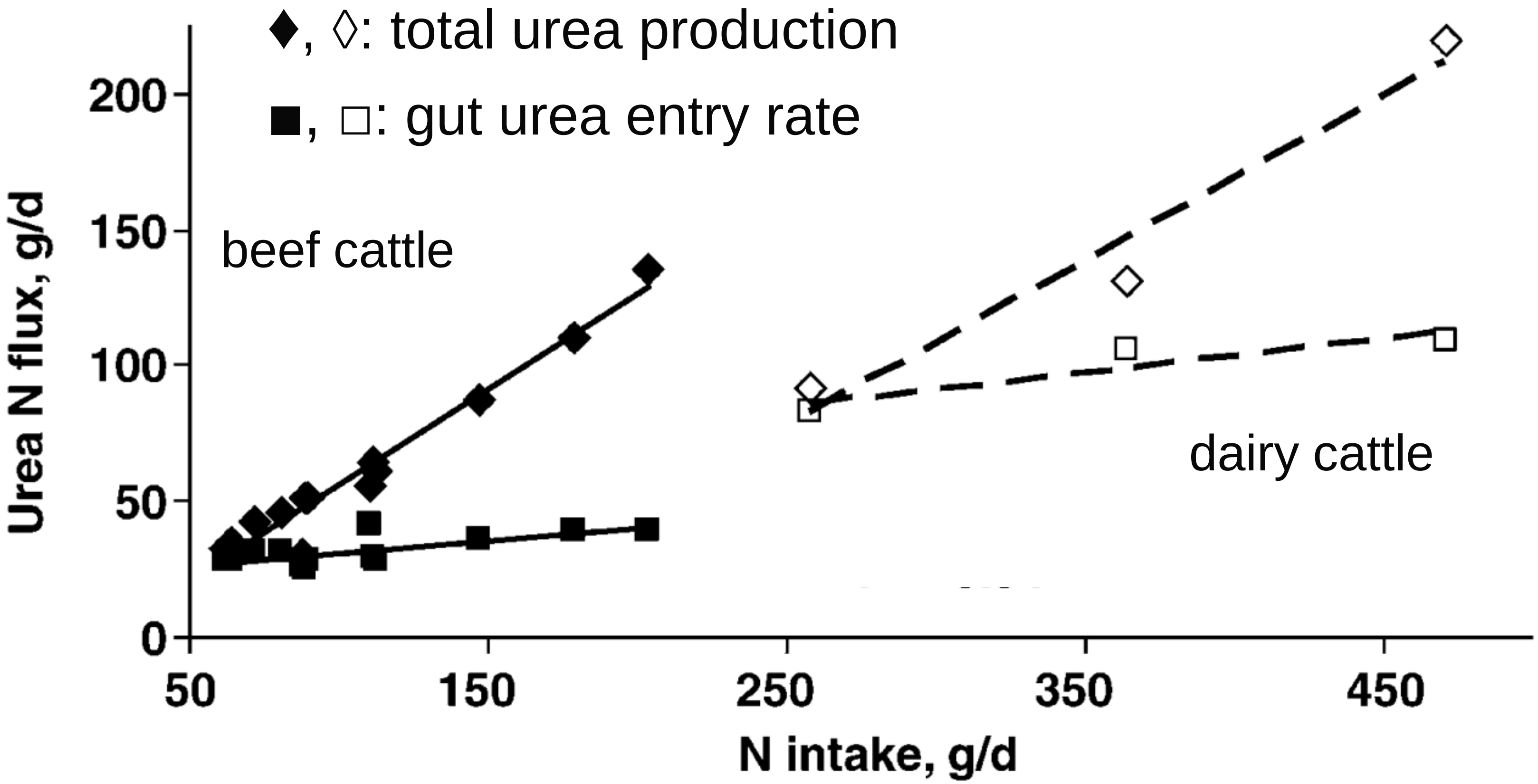
Fraction of urea production (UER) recycled to gut



Reynolds and Kristensen (2008)

Urea N fluxes

urea-N entry gut = 54.2 + 0.124 N intake



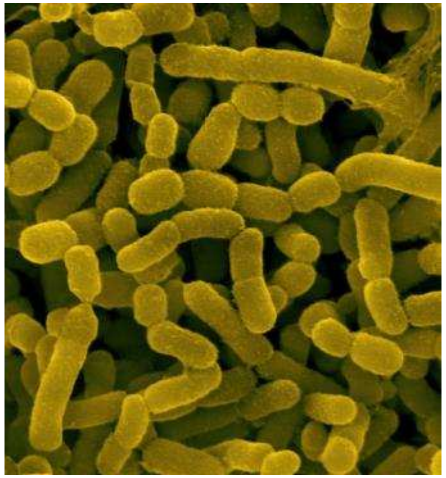
Reynolds and Kristensen (2008)

Inevitable N losses

- Digestion
  - Fermentation **35 g N/d**
  - Microbial composition
  - Undigested protein
  - Endogenous protein
- Maintenance
- Milk production

Microbial biomass composition

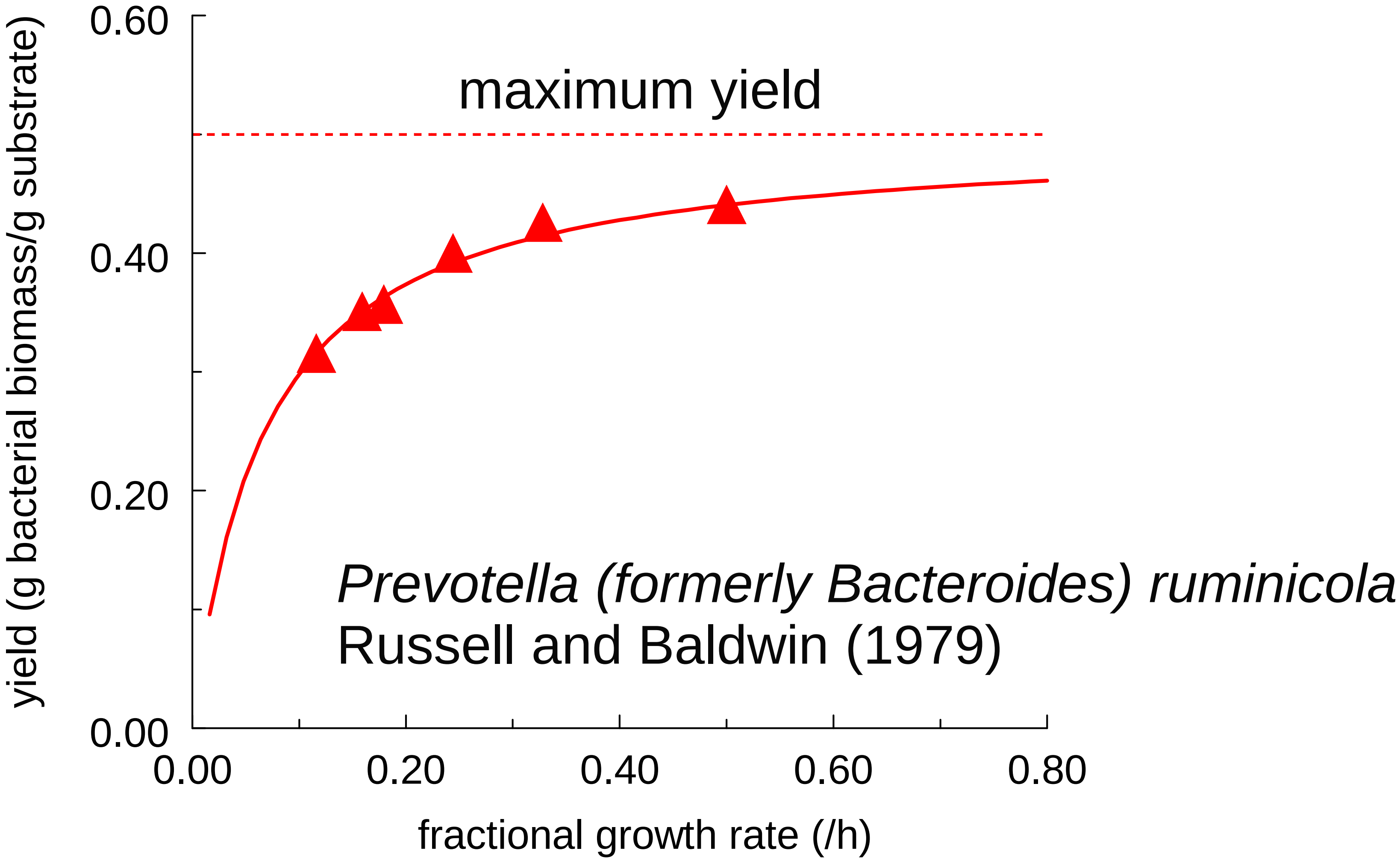
- Microbial crude protein ≠ amino acids
- N in microbial biomass (% of total N)
  - protein 72.2
  - DNA 5.5
  - RNA 18.4
  - cell wall components 3.9



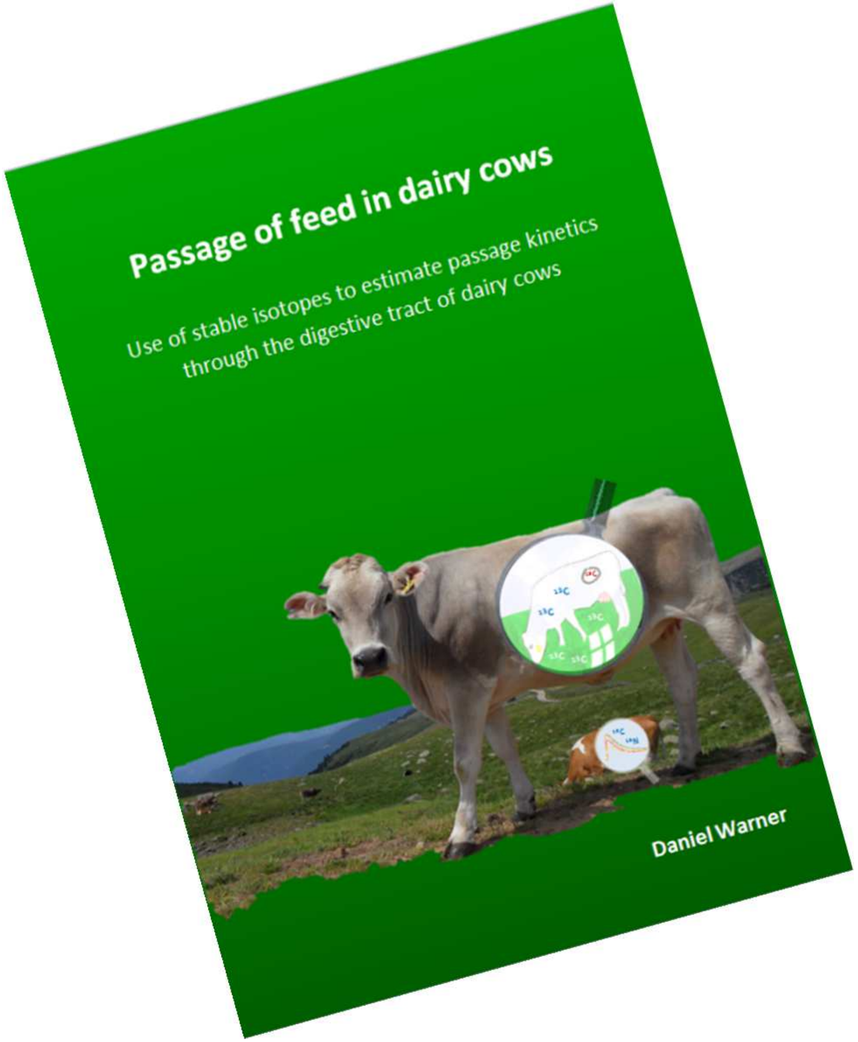
Dijkstra et al. (1992)

- Nucleic acid content ↑ with fractional growth rate
- Microbial efficiency ↑ with fractional growth rate
  - Pirt (1965) relationship

Microbial efficiency



Fractional passage rate



Daniel Warner

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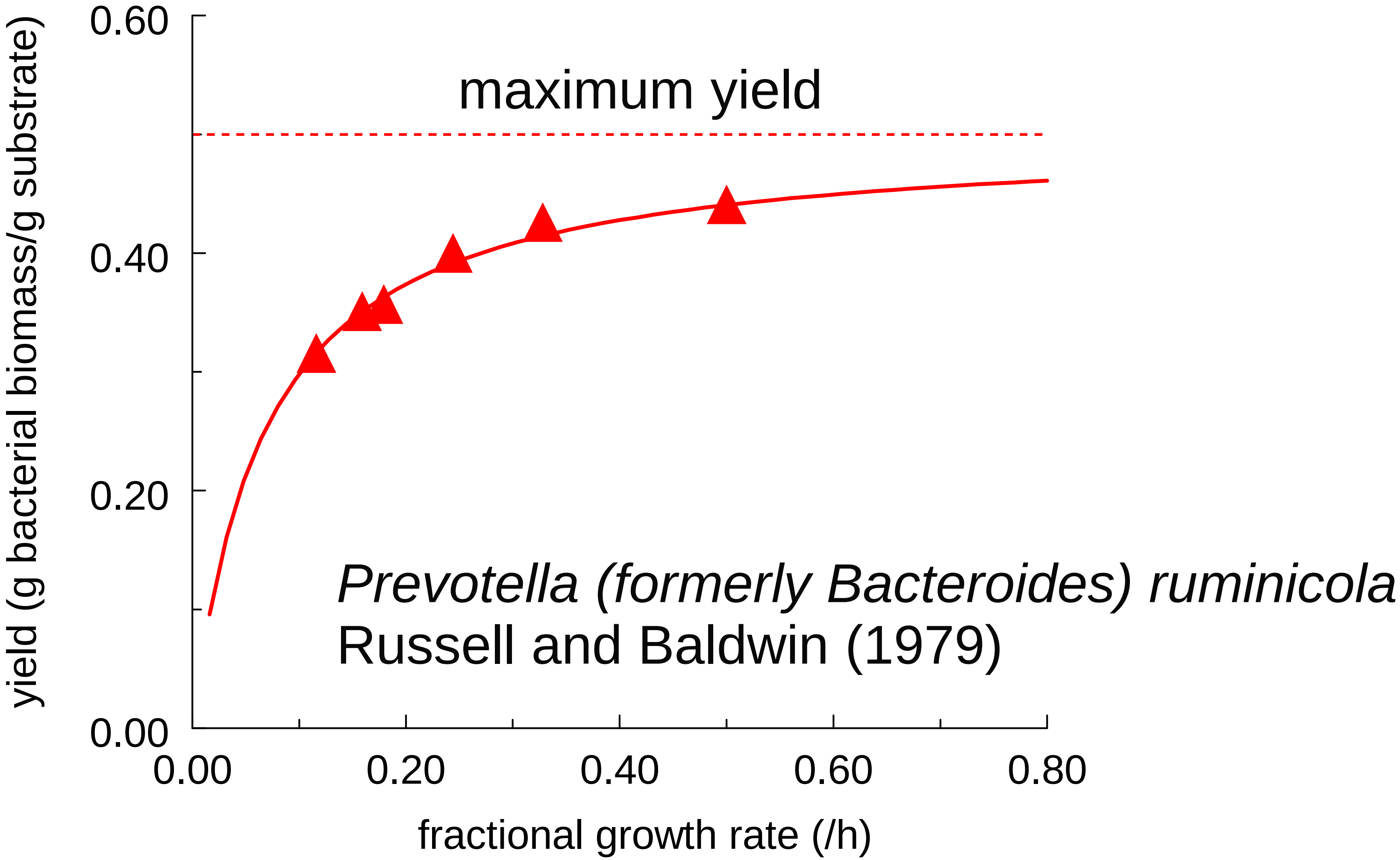
Microbial efficiency



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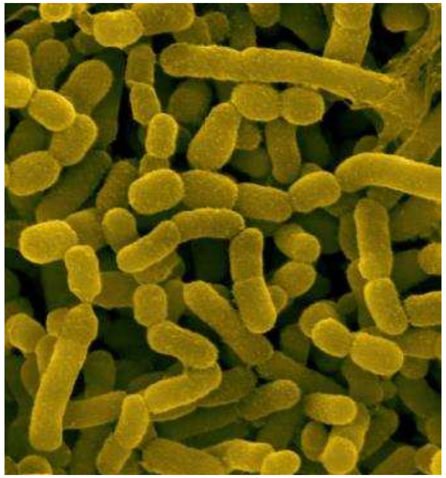
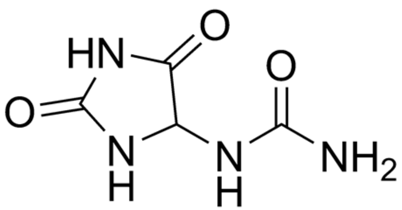


Dijkstra et al. (1992)

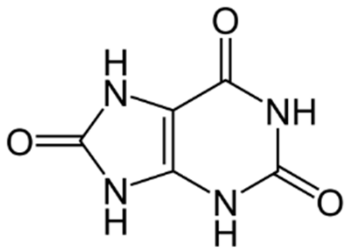
- Nucleic acid content ↑ with fractional growth rate
- Microbial efficiency ↑ with fractional growth rate
  - Pirt (1965) relationship
- True protein content microbial crude protein ~75%

Inevitable loss of nucleic acid N

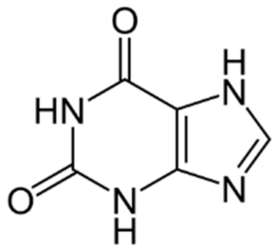
- Pyrimidine bases catabolised to β-amino acids, ammonia and CO_2
- Purine bases catabolised to purine derivatives



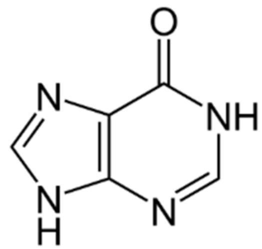
allantoin



uric acid



xanthine



hypoxanthine

Inevitable loss of nucleic acid N

- True ileal digestibility of nucleic acids 81 - 87%

  Storm et al. (1983)

- 83 - 88% of abomasally infused purines excreted in urine
  - ~1% purines excreted in milk
  - < 0.1% recycled to rumen via saliva

  Fujihara and Shem (2011)

- Inevitable N loss reference cow **84 g N/d**
  - nucleic acid N in faeces: 13 g/d
  - urea and purine derivative N in urine: 71 g/d

Inevitable N losses

- Digestion
  - Fermentation 35 g N/d
  - Microbial protein
    loss nucleic acid N **84 g N/d**
  - Undigested protein
  - Endogenous protein
- Maintenance
- Milk production

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Small intestinal protein digestion

- True digestibility microbial true protein 80-85%
  - used in various protein evaluation systems
  - largely based on sheep data
  - digestibility in dairy cattle lower (75-77%)?

Larsen et al. (2001)

- True digestibility escape feed protein up to ~100%
- Inevitable N loss reference cow **37 g N/d**
  - excreted in faeces



Inevitable N losses

- Digestion
  - Fermentation 35 g N/d
  - Microbial protein 84 g N/d
  - Undigested protein **37 g N/d**
  - Endogenous protein
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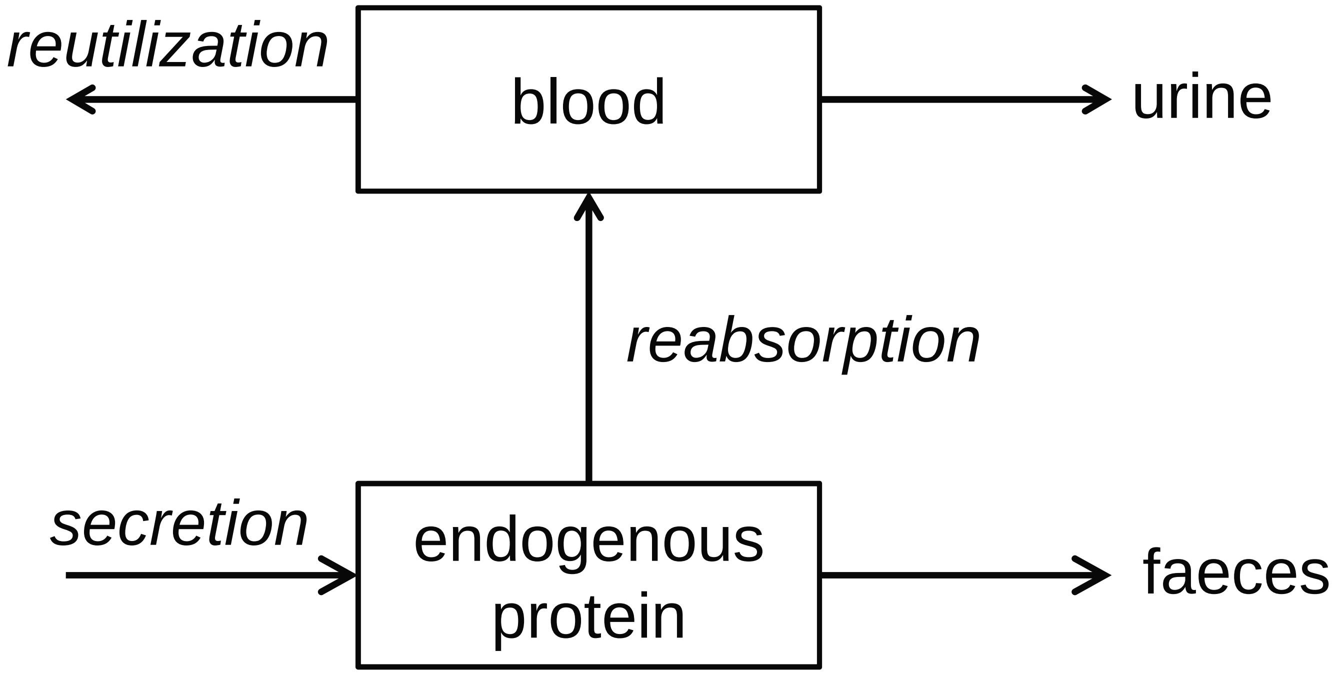
Endogenous protein losses

- Endogenous N lost in digestive process
  - digestive enzymes, bile, mucus, cells
- Endogenous protein at terminal ileum 6 - 20% of ingested protein Tamminga et al. (1995)
- Losses related to quantity of DM passing through intestinal tract
  - endogenous losses ↓ with ↑ in DM digestibility

Swanson (1982)
- Loss is net result of secretion, re-absorption and re-utilization

Endogenous protein losses



Inevitable loss of endogenous protein-N

- Endogenous loss ~ 12 g N/kg faecal DM (~75 g CP/kg faecal DM)
- Resynthesis efficiency 67%

Van Duinkerken et al. (2011)

- Inevitable N loss reference cow **58 g N/d**
  - endogenous protein N in faeces: 39 g/d
  - urea N in urine: 19 g/d

Inevitable N losses

- Digestion
  - Fermentation 35 g N/d
  - Microbial protein 84 g N/d
  - Undigested protein 37 g N/d
  - Endogenous protein **58 g N/d**
- Maintenance
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Maintenance requirement protein

- Maintenance requirements
  - endogenous N losses in urine
  - scurf N losses (skin, hair)
  - (endogenous N losses in faeces)
- Endogenous N urine 2.75 $W^{0.50}$ g N/d
- Endogenous N scurf 0.2 $W^{0.60}$ g N/d

Swanson (1977)

- Efficiency: 67%
- Inevitable N loss reference cow **13 g N/d**
  - ~90% as urine-N

Inevitable N losses

• Digestion	
• Fermentation	35 g N/d
• Microbial protein	84 g N/d
• Undigested protein	37 g N/d
• Endogenous protein	58 g N/d
• Maintenance	**13 g N/d**
• Milk production	

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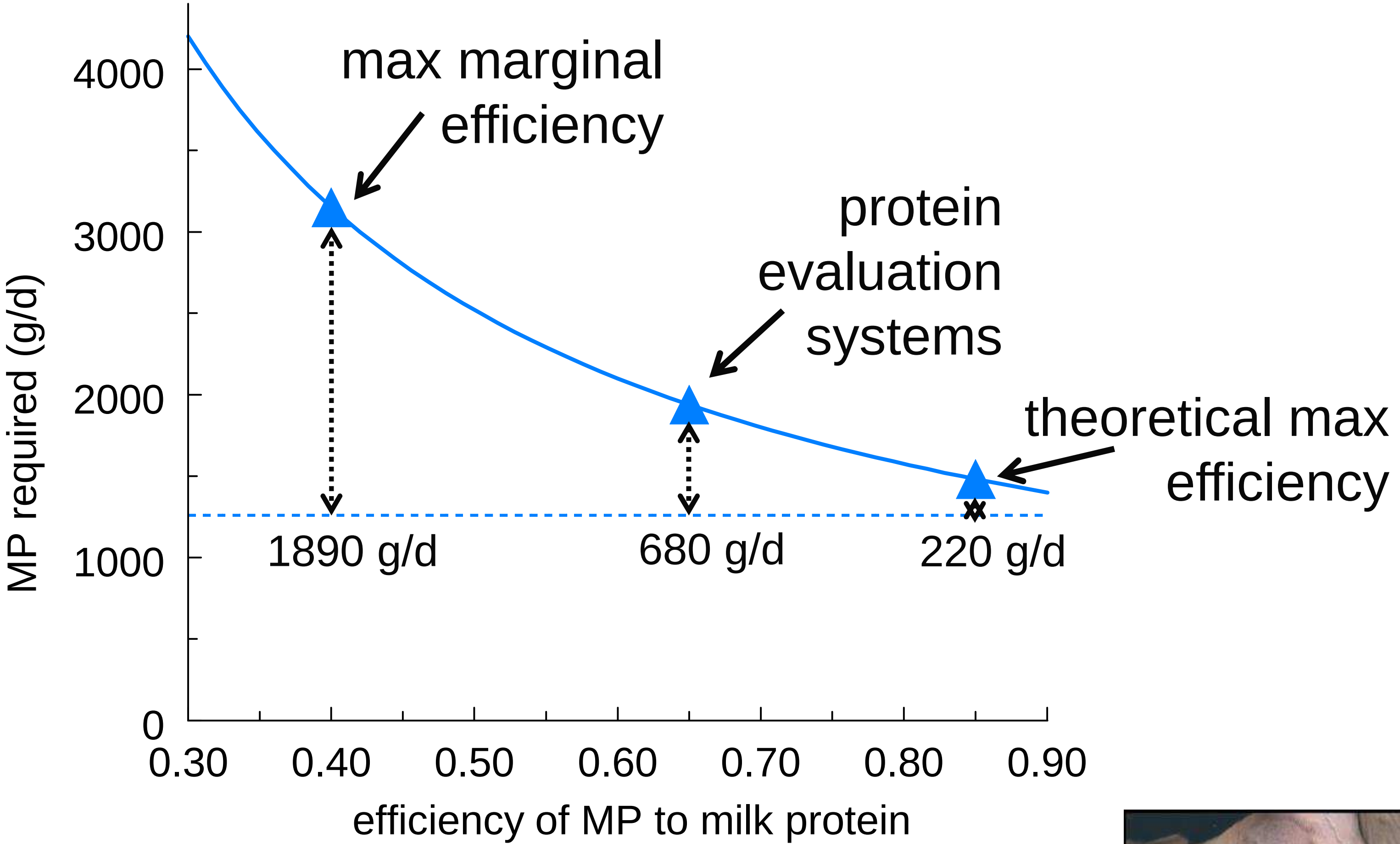
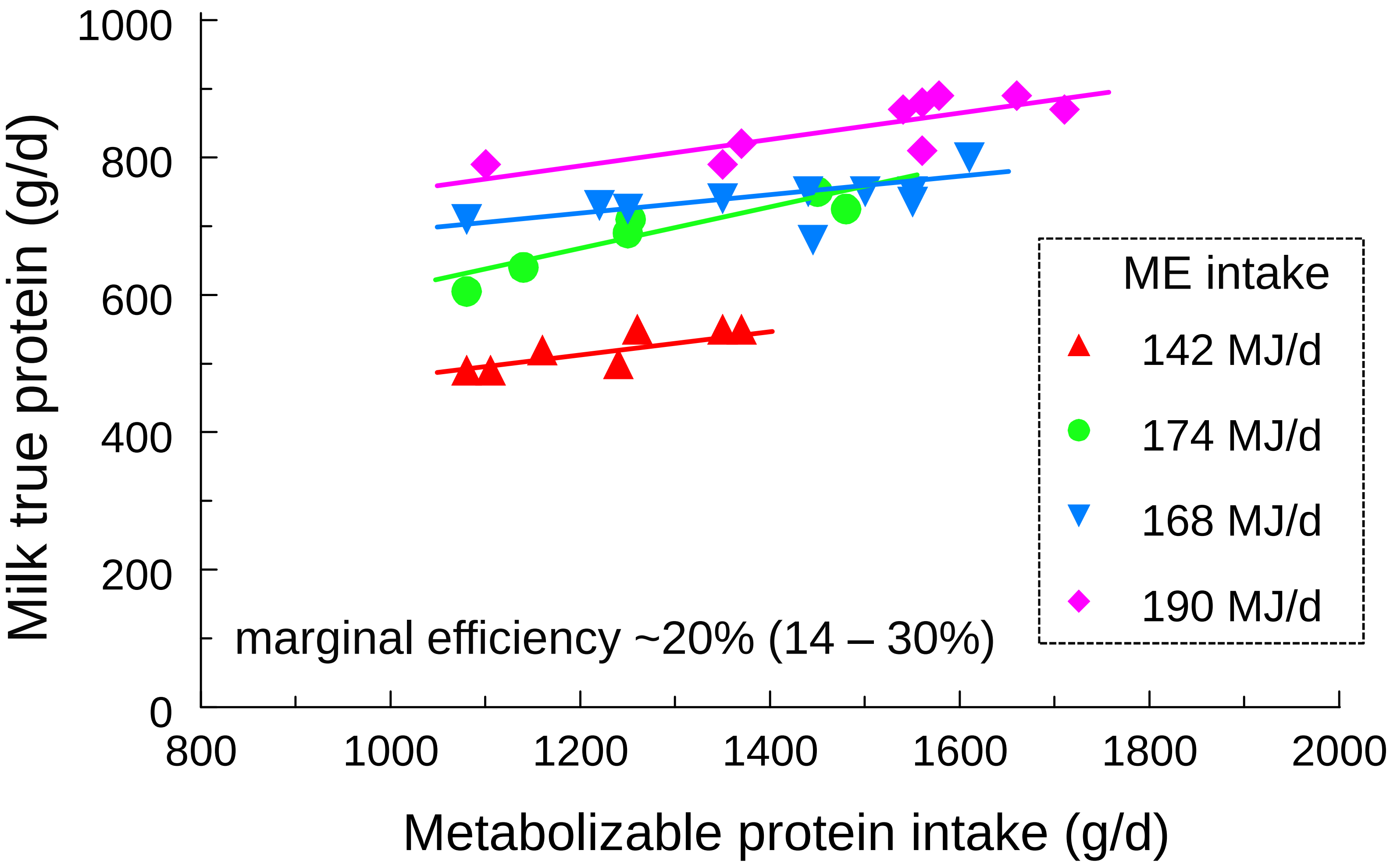
Milk protein synthesis

- Theoretical maximal efficiency of absorbed AA for milk protein 85% ARC (1980)
- AA efficiency in protein evaluation systems 64 to 70%
- Maximal marginal AA efficiency 38%

Efficiency large impact on requirements



Marginal and overall protein efficiency



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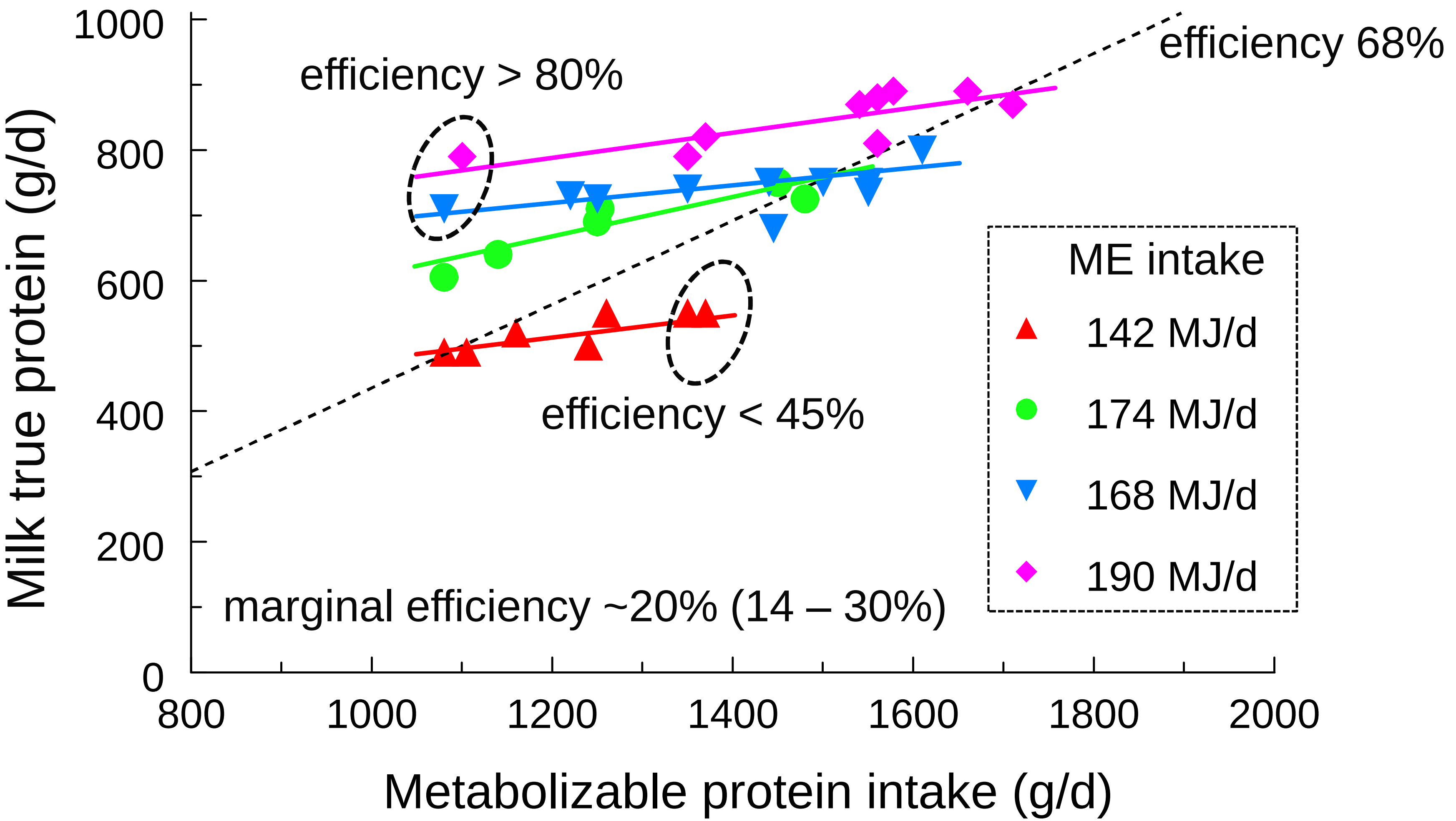
4 experimental farms
AFRC (1992)

Marginal and overall protein efficiency



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Milk protein synthesis

- Theoretical maximal efficiency of absorbed AA for milk protein 85% ARC (1980)
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- Inevitable loss reference cow: **36 g N/d** at optimal AA efficiency
  - excreted as urea in urine

Inevitable N losses

• Digestion	
• Fermentation	35 g N/d
• Microbial protein	84 g N/d
• Undigested protein	37 g N/d
• Endogenous protein	58 g N/d
• Maintenance	13 g N/d
• Milk production	**36 g N/d**

Inevitable N losses and milk N output (g/d)

Source	N faeces	N urine	N milk
Fermentation		35	
Microbial nucleic acids	13	71	
Undigested protein	37		
Endogenous protein	39	19	
Maintenance		13	
Milk production		36	198
Total	89	174	198
Maximum N efficiency			***0.43***

Reference cow: 40 kg milk/d, milk true protein content 31.5 g/kg

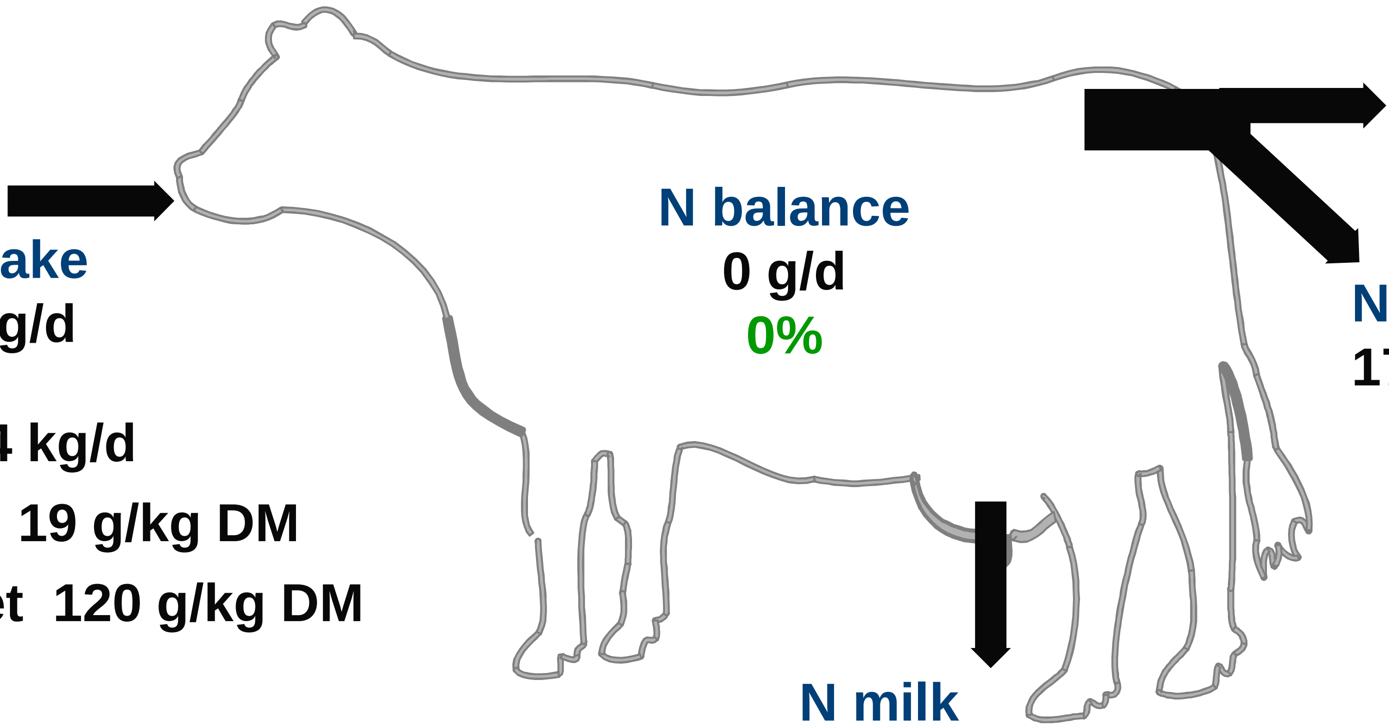
Average N flows reference cow

N intake
461 g/d

DMI 24 kg/d

N diet 19 g/kg DM

CP diet 120 g/kg DM



N balance
0 g/d
0%

N faeces
89 g/d
20%

N urine
174 g/d
38%

N milk
198 g/d
43%

Challenges and opportunities to achieve maximal N efficiency

Inevitable N losses and milk N output (g/d)

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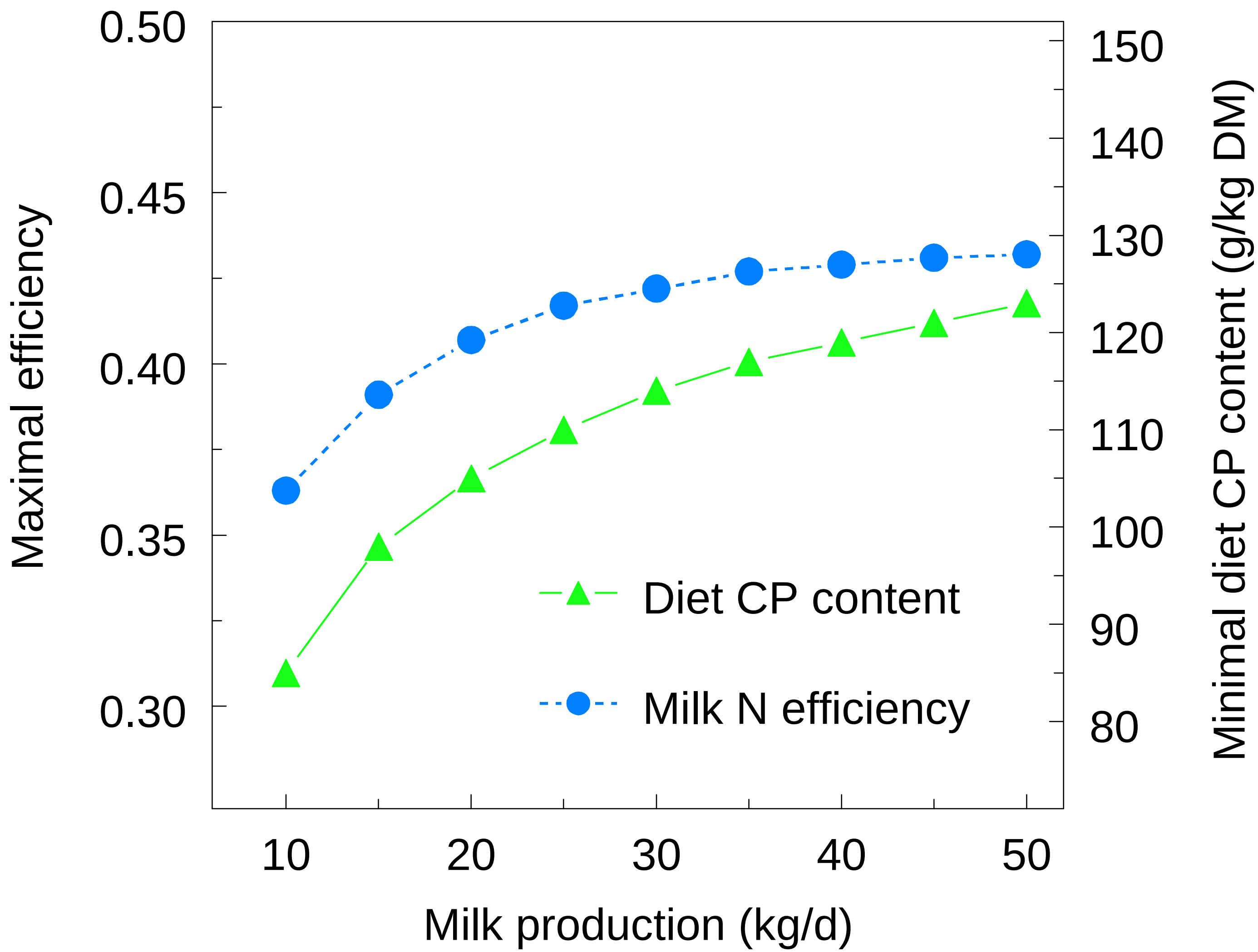
Minimize N excretion: production level



Hypothetical diet: no fermentable OM

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Inevitable N losses and milk N output (g/d)

Source	N faeces	N urine	N milk
Fermentation		35	
Microbial nucleic acids	[illegible]	71	
[illegible]			
[illegible]		19	
[illegible]		13	
[illegible]		36	198
Total	89	174	198
Maximum N efficiency			***0.43***

- little scope to improve N recycling to rumen
- optimal rumen fermentable energy to RDN supply

Reference cow: 40 kg milk/d, milk true protein content 31.5 g/kg

Inevitable N losses and milk N output (g/d)

Source	N faeces	N urine	N milk
Fermentation		35	
Microbial nucleic acids	13	71	
Undigested protein	[illegible]		
[illegible]	[illegible]	19	
[illegible]		13	
[illegible]		36	198
[illegible]	[illegible]	174	198
[illegible]			***0.43***

- always nucleic acid N loss with microbial fermentation
- shift from rumen fermentation (*fibre)* to intestinal digestion (*starch, fat)*

Reference cow: 40 kg milk/d, milk true protein content 31.5 g/kg

Inevitable N losses and milk N output (g/d)

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Fermentation		35	
Microbial nucleic acids	13	71	
Undigested protein	37		
Endogenous protein	39	19	
Maintenance		13	
		36	198
	89	174	198
			0.43

- little variation in microbial protein digestion
- use high digestible feed resources (*starch vs fibre*)

Reference cow: 40 kg milk/d, milk true protein content 31.5 g/kg

Inevitable N losses and milk N output (g/d)

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Fermentation		35	
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Maximum N efficiency			***0.43***

- little scope to reduce loss

Reference cow: 40 kg milk/d, milk true protein content 31.5 g/kg

Inevitable N losses and milk N output (g/d)

- efficiency of absorbed protein to milk protein often lower than maximum
- feed high energy, low protein diets
- avoid imbalance of amino acids

	…ces	N urine	N milk
		35	
		71	
		19	
		13	
Milk production		36	198
Total	89	174	198
Maximum N efficiency			***0.43***

Reference cow: 40 kg milk/d, milk true protein content 31.5 g/kg

Energy supply key to maximal N efficiency

- Improve energy supply to capture more N in product
  - reduction urine N excretion in particular
  - reduction urea-N as fraction of total urine N

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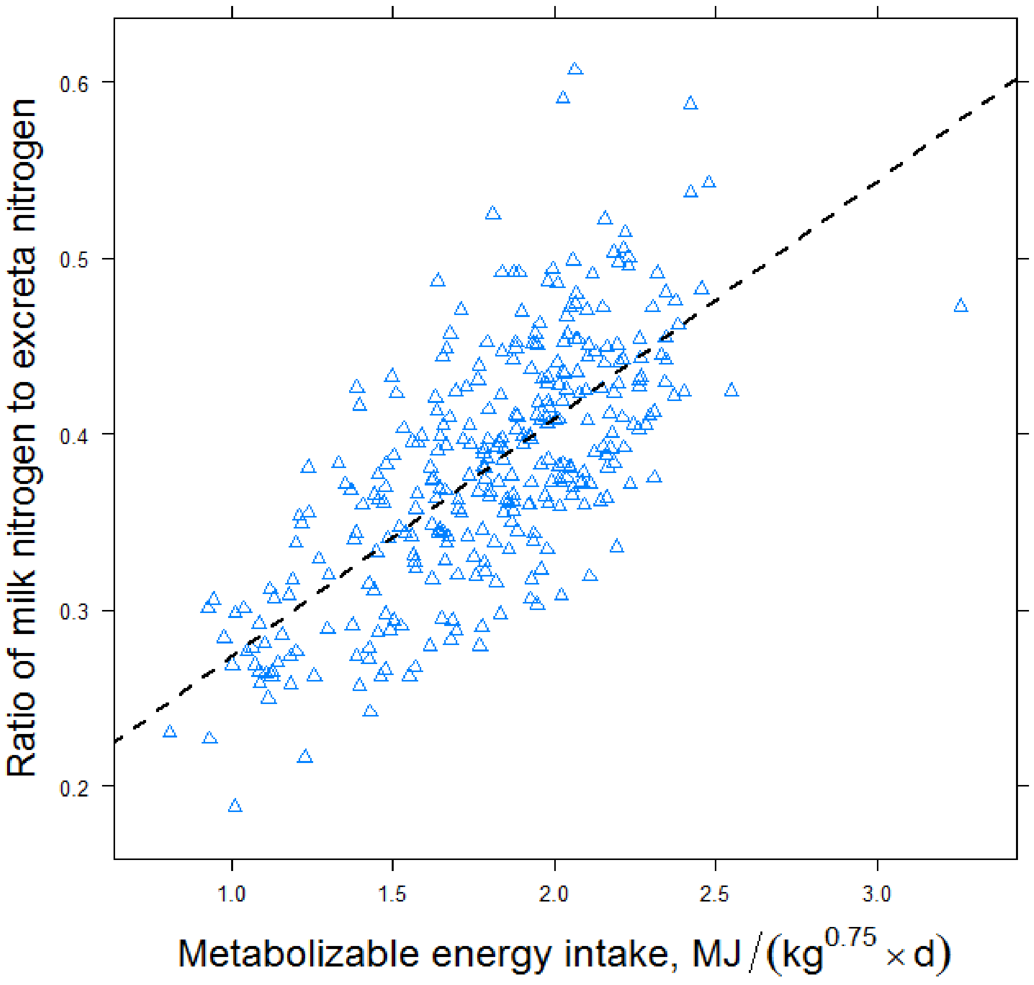
Energy supply reduces urinary N losses



Faecal N excretion: no effect of ME intake

Urine N (g/d):

- ❑ 20 + 0.38 N-intake
- ❑ 48 + 0.56 N-intake -71.4 ME-intake

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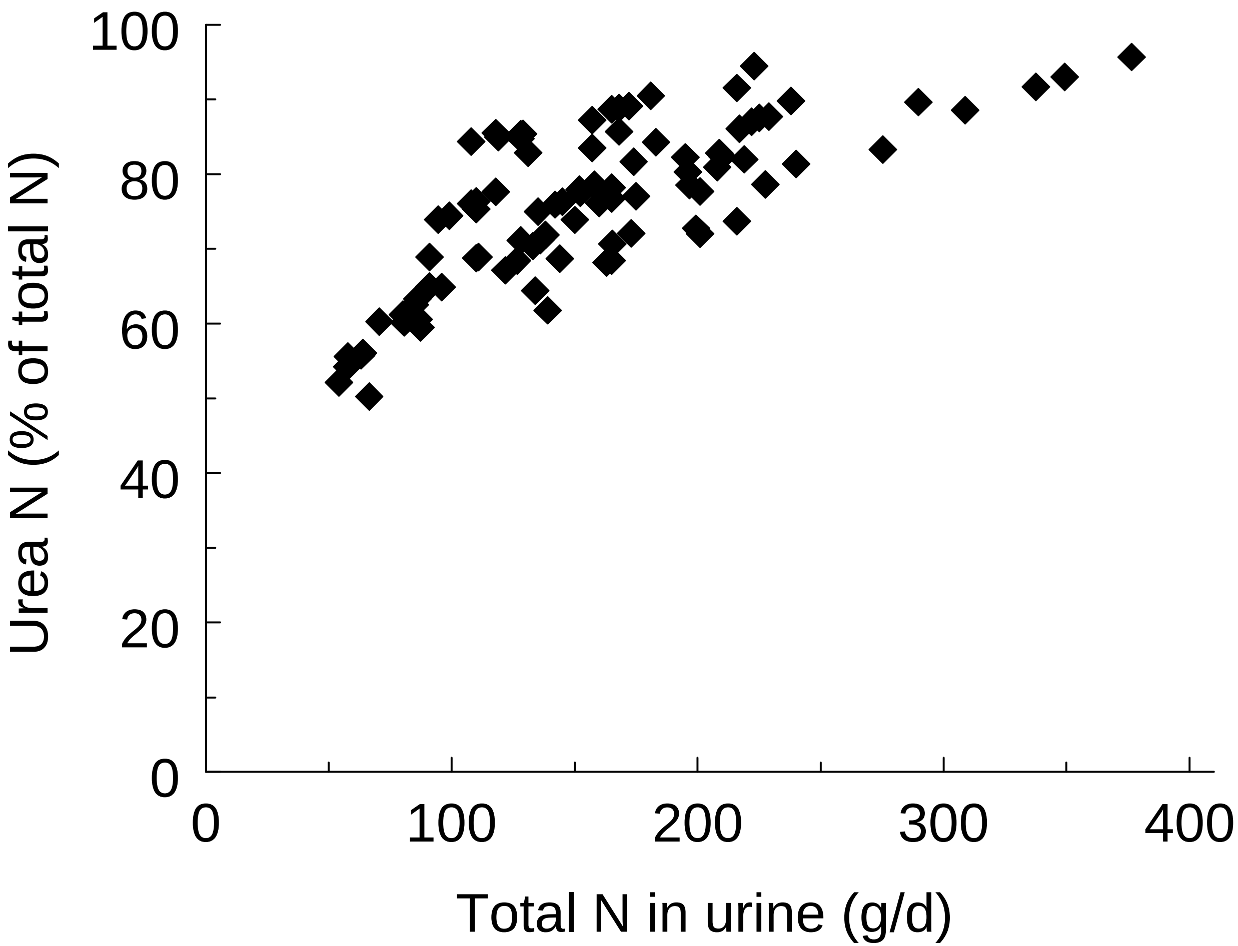
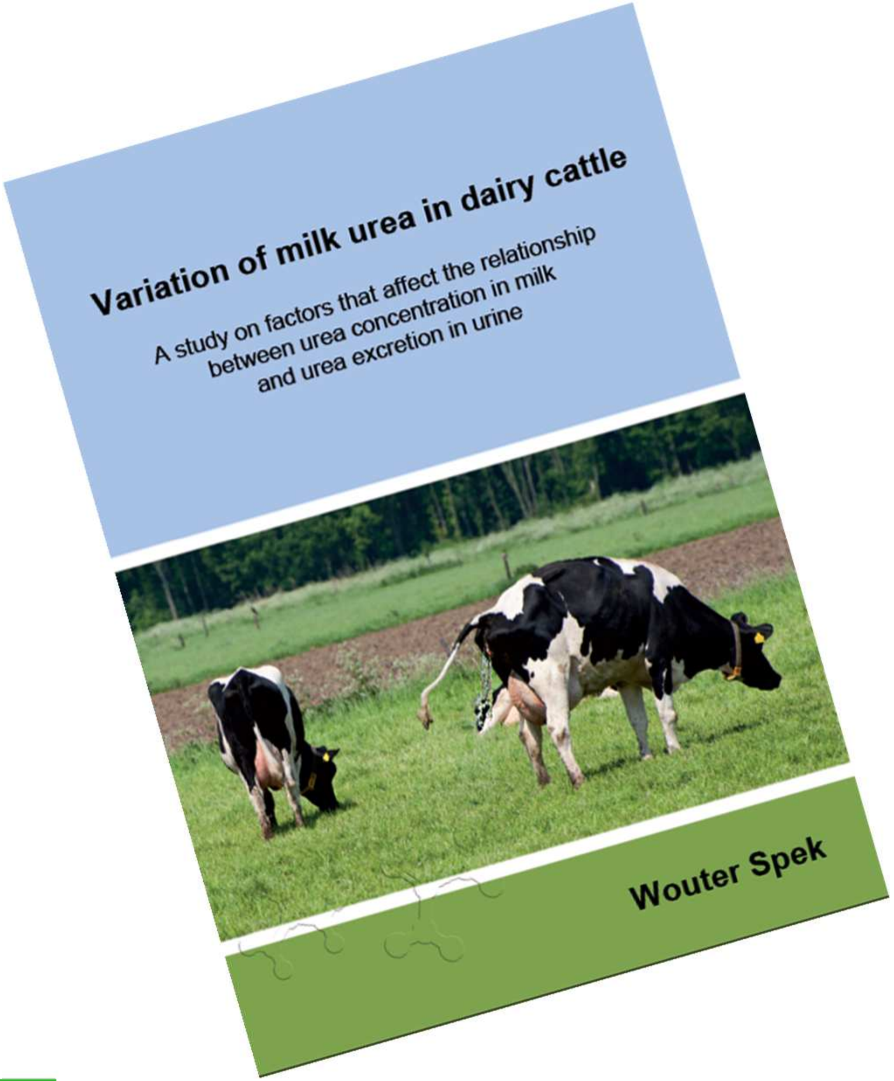
dairy cattle (*n* = 470) Kebreab et al. (2010)

Urea major N component urine



84 observations in 20 experiments
Spek et al. (2013)

Milk urea and N excretion



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Energy supply key to maximal N efficiency

- Improve energy supply to capture more N in product
  - reduction urine N excretion in particular
  - reduction urea-N as fraction of total urine N
- Higher N efficiency with intestinal digestible than rumen fermentable energy sources
  - shift from fibre to non-fibre carbohydrates
  - may contrast with role of ruminants in global food security

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Conclusions

- Key role ruminants in global food security
  - convert cell wall material into food
- Unavoidable losses of N in faeces and urine
- High proportion unavoidable N losses related to microbial metabolism
- Improving N efficiency critical to reduce N losses
  - in particular losses N in urine

Conclusions

- Maximal milk N efficiency ~0.43
  - N efficiency on farm much lower
- Strategies to improve N efficiency to focus on optimal supply of rumen degradable N and optimal post-absorptive amino acid utilization
  - energy supply key to maximal N efficiency
- Integrated approach to energy and protein metabolism is essential

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