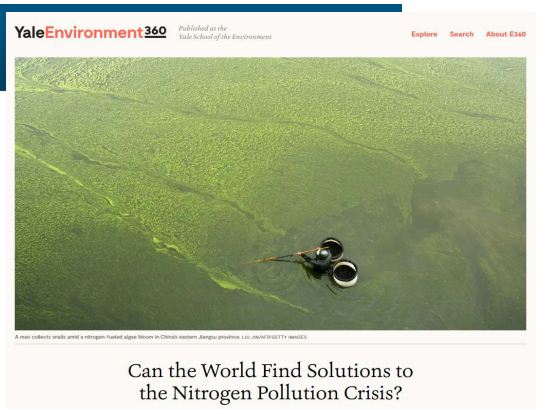
The Road to Maximum Milk Nitrogen Efficiency: Progress, Potential and Practical Feasibility

Jan Dijkstra - Wageningen University & Research (NL)

Fodringsdag September 1, 2026 – Herning (DK)

Nitrogen – hot topic



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Presentation today

- Where have we come from and where are we today?
  - lessons from Dutch experiences
- What is biologically achievable?
  - defining biological limit of milk N efficiency
- How can nutrition move us closer to biological limit?
  - nutritional strategies at rumen and post-rumen levels
- Can low-protein feeding be sustained long term?
  - effects on production and health long term

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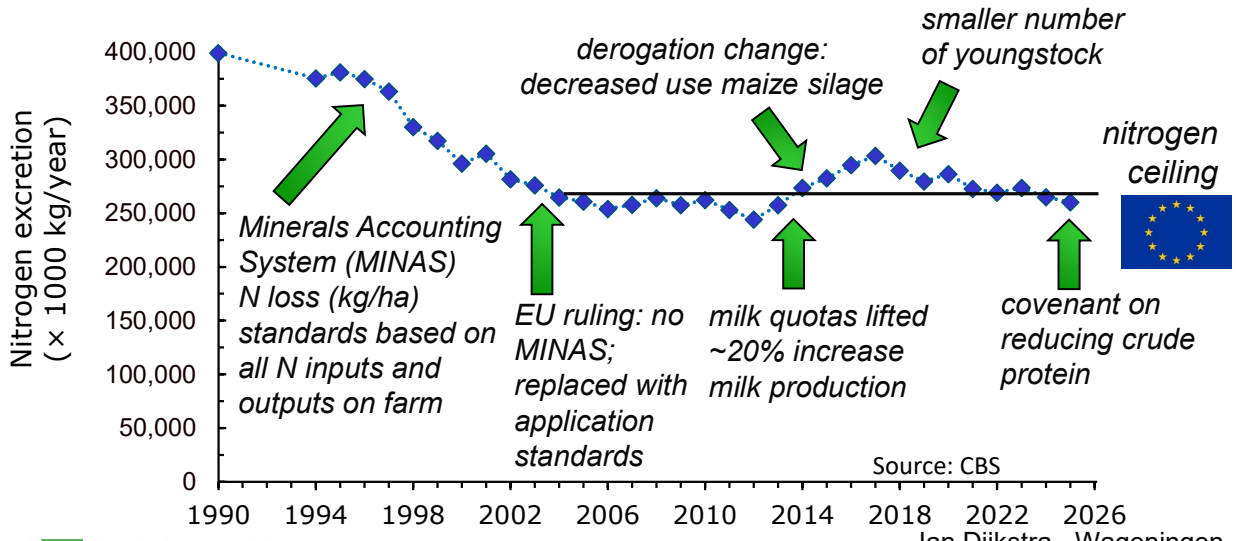
Nitrogen excretion dairy cattle and youngstock



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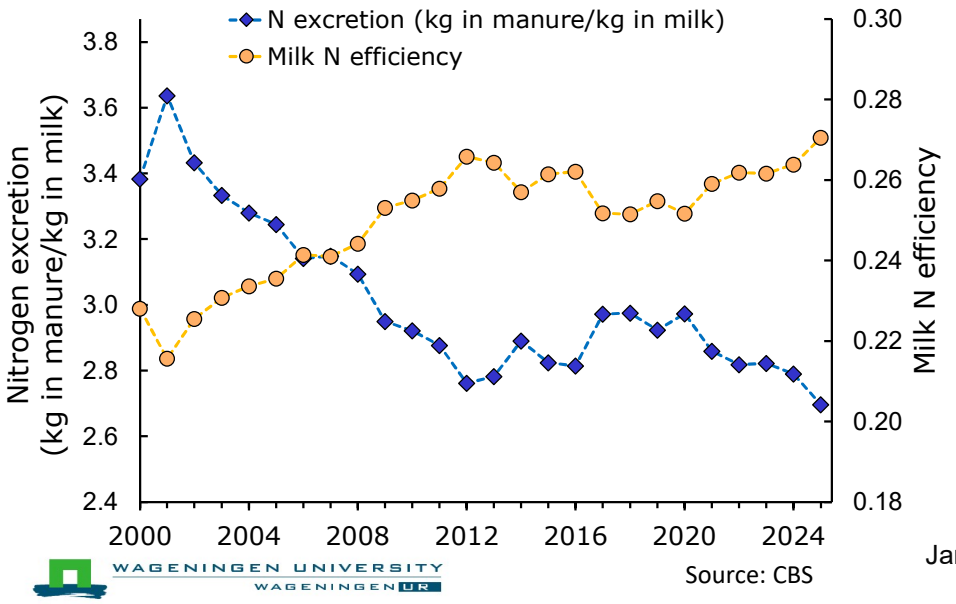
More N in milk, less N with manure



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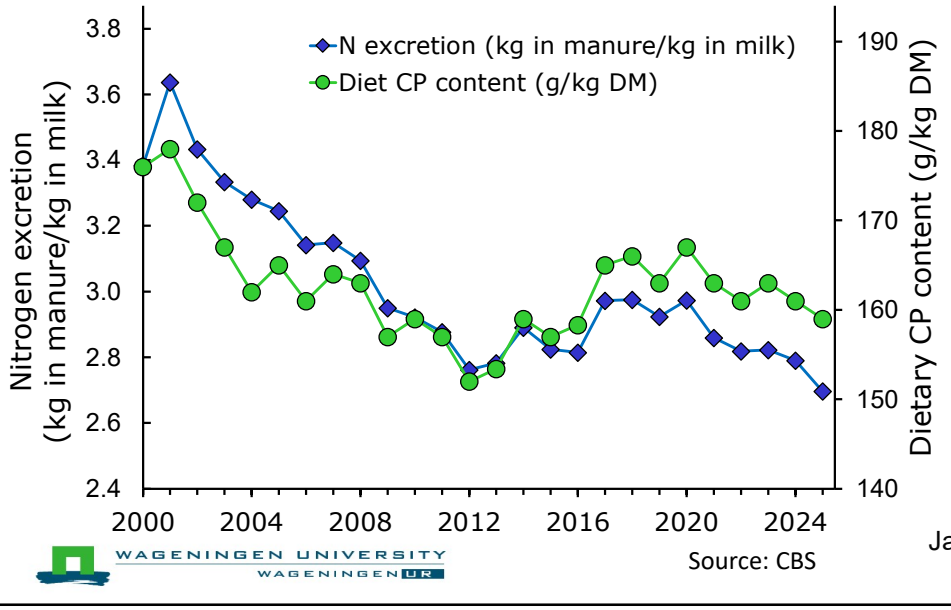
N excretion depends on more than dietary CP



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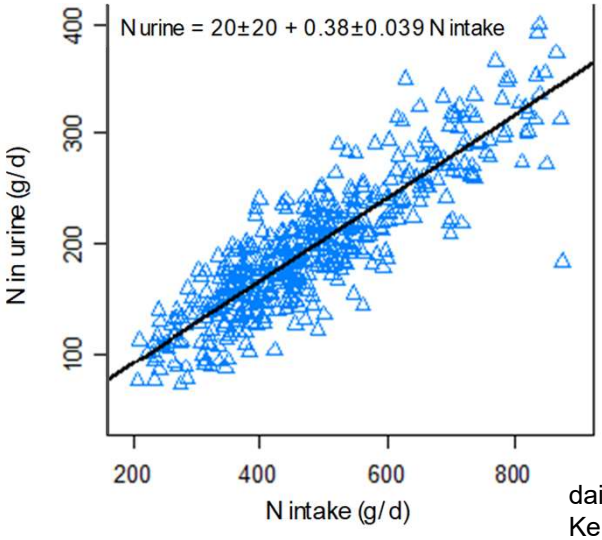
N intake is principal driver of N excretion, but...



Urine N (g/d):
$20_{(20.0)} + 0.38_{(0.039)}$ N-intake

Prediction significantly better with energy intake included

Urine N (g/d):
$48_{(20.1)} + 0.56_{(0.030)}$ N-intake
$- 71.4_{(12.20)}$ ME-intake

N-intake, g/d
Metabolizable Energy (ME) intake, MJ/(kg$^{0.75}$ d)

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

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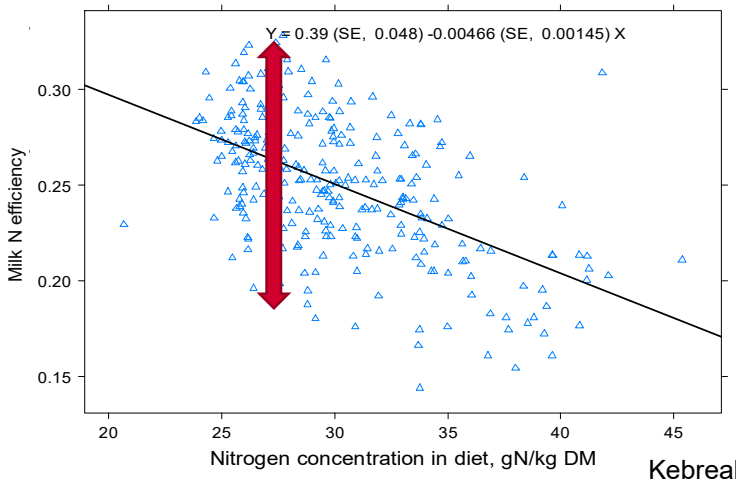
Large variation in milk N efficiency



Kebreab et al. (2010)

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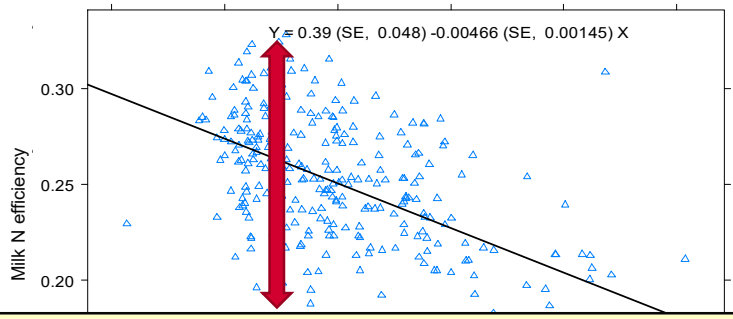

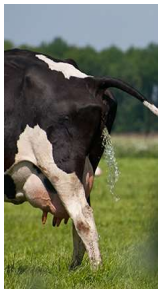

Two herds with the same N intake can have very different N excretion because they differ in milk N efficiency

Kebreab et al. (2010)

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Key messages from Dutch perspective

- policies based on mineral accounting system central to reducing N excretion
- differences in milk N efficiency explain substantial variation in N excretion beyond N intake alone

► How high can milk N efficiency become?

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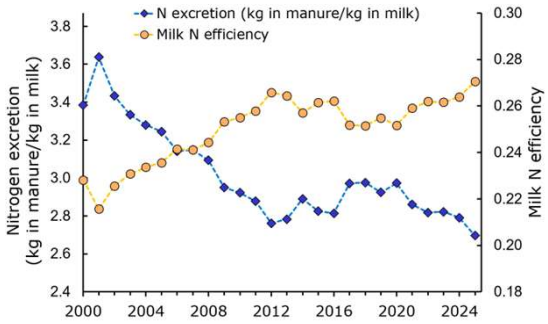
How much N is inevitably lost?

- Currently NL: milk N efficiency ~26% ► **N loss ~2.8 × milk N**



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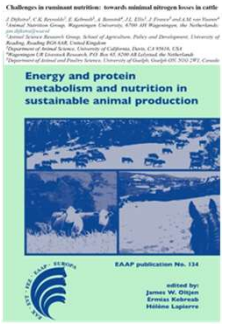
How much N is inevitably lost?

- Currently NL: milk N efficiency ~26% ► **N loss ~2.8 × milk N**
- Theoretical maximum: milk N efficiency ~43% ► **N loss ~1.3 × milk N**

Full details: Dijkstra et al. (Int Symp Protein Energy Metabolism 2013)



potential reduction in N excretion is enormous

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Zero N excretion is impossible in dairy cattle

Source unavoidable N loss	N faeces	N urine	N milk
Fermentation rumen		35	
Microbial nucleic acids	13	71	
Undigested protein	37		
Endogenous protein	39	19	
Maintenance cow		13	
Milk production		36	198
Total	89	174	198
Maximum N efficiency			***43%***
Diet CP content: 120 g/kg DM			

Reference cow: 40 kg milk/d, milk true protein content 32 g/kg

Dijkstra et al. (2013)

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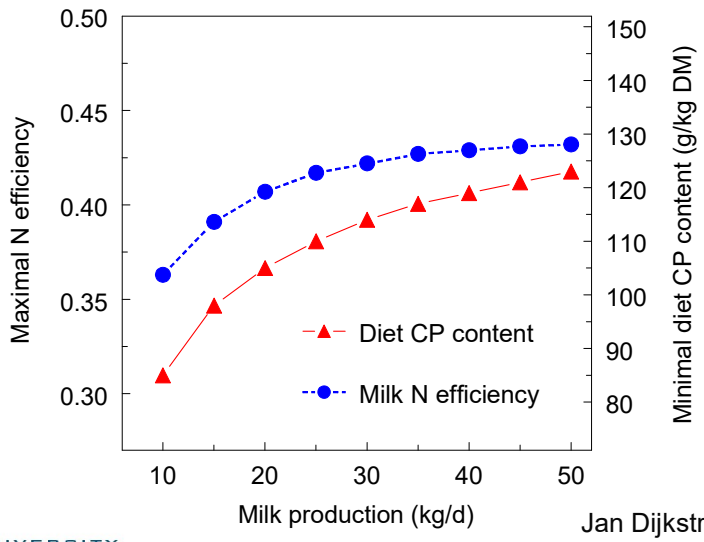
ONTARIO AGRICULTURAL COLLEGE DEPARTMENT OF ANIMAL BIOSCIENCES

Milk production level and maximal N efficiency



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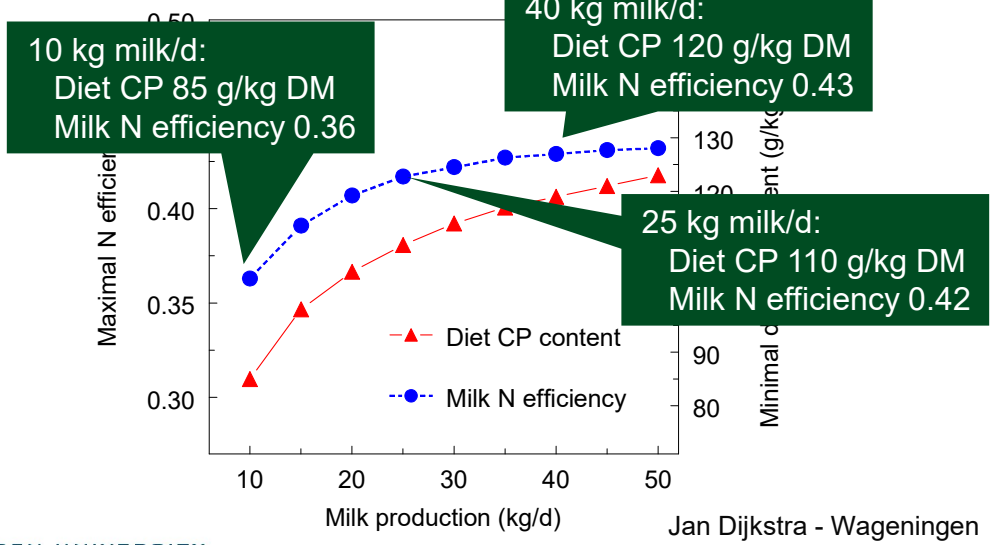

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Key messages on maximal milk N efficiency

- maximum milk N efficiency depends on production level
  - 36% at 10 kg FPCM/d
  - 43% at 40 kg FPCM/d
- ~60% inevitable N losses related to rumen microbial activity
- current milk N efficiency well below this biological maximum

► How can nutrition close this gap?

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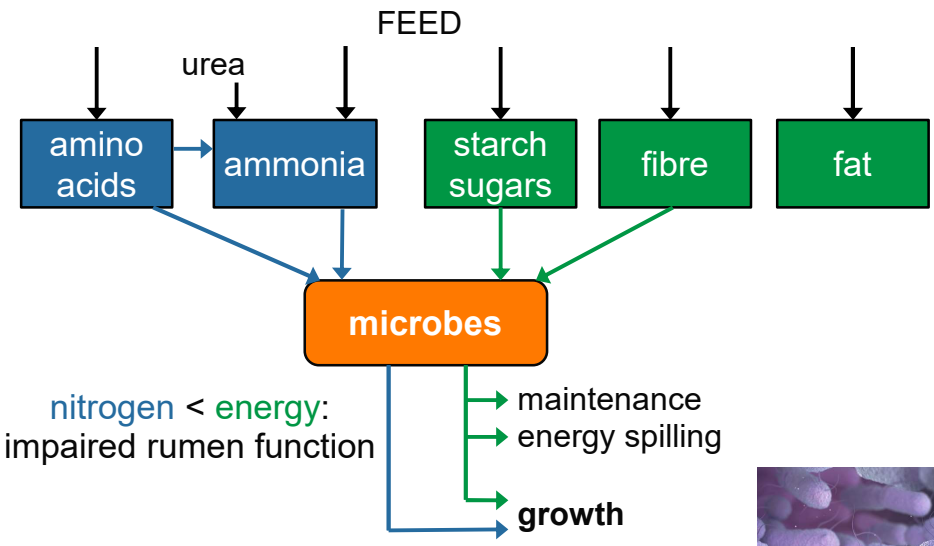
Balanced rumen N and energy supply



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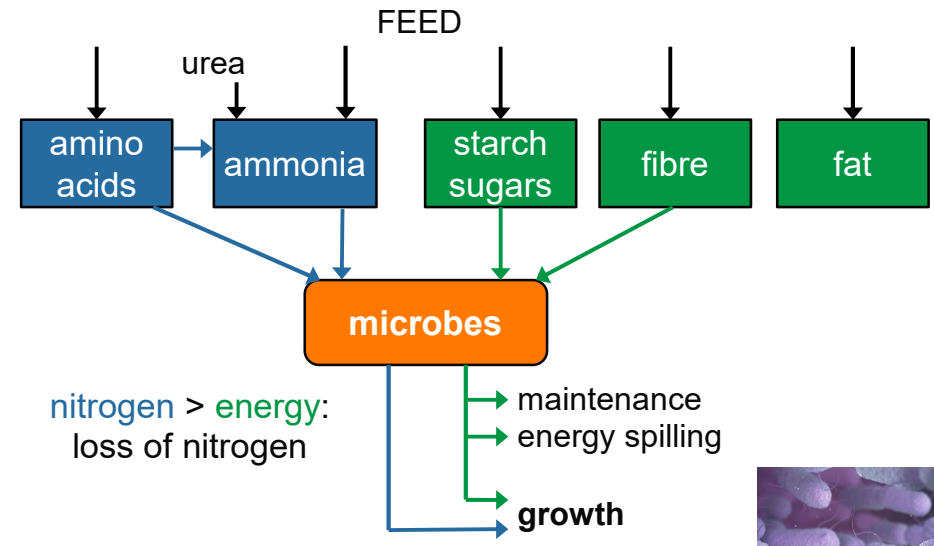

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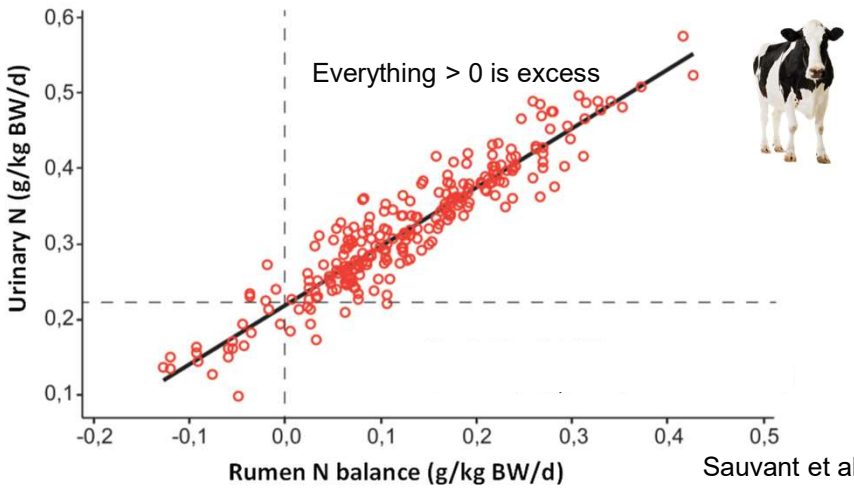
Most excess rumen N is lost via urine



Sauvant et al. (2015)

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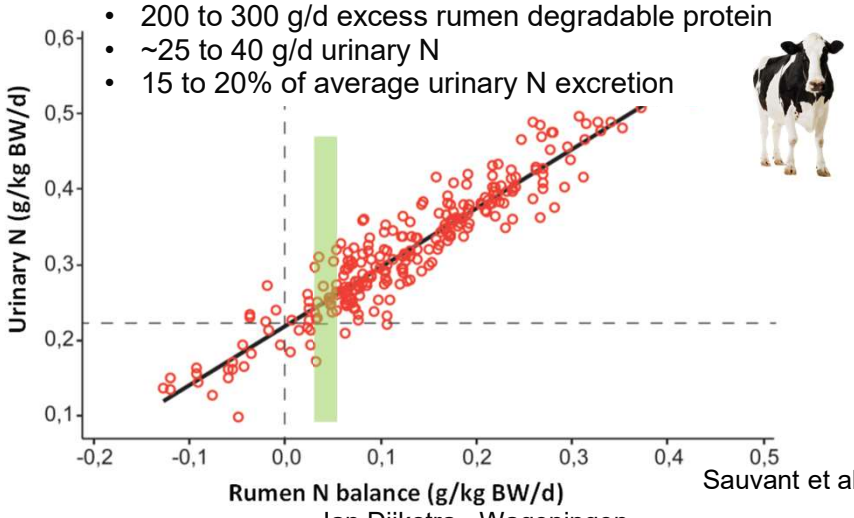
Uncertainty creates a costly safety margin

Typical NL safety margin:

- 200 to 300 g/d excess rumen degradable protein
- ~25 to 40 g/d urinary N
- 15 to 20% of average urinary N excretion



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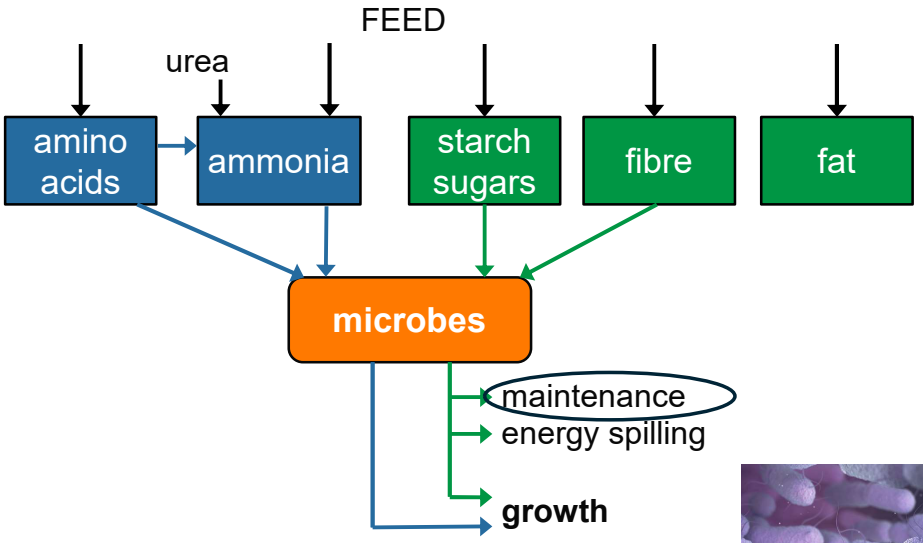

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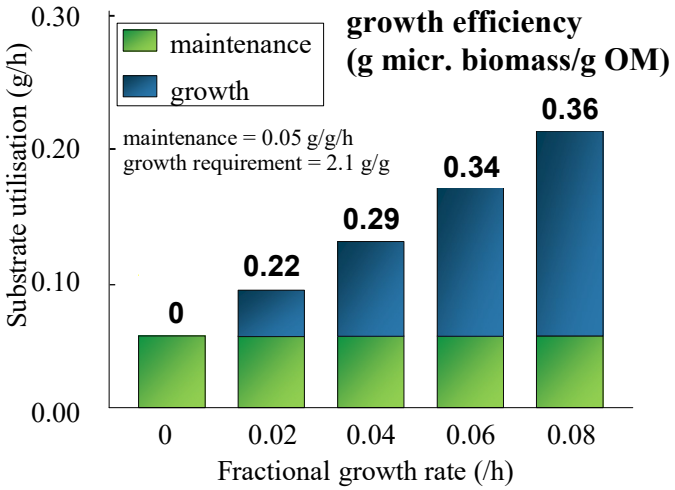
Rumen N requirements are not fixed



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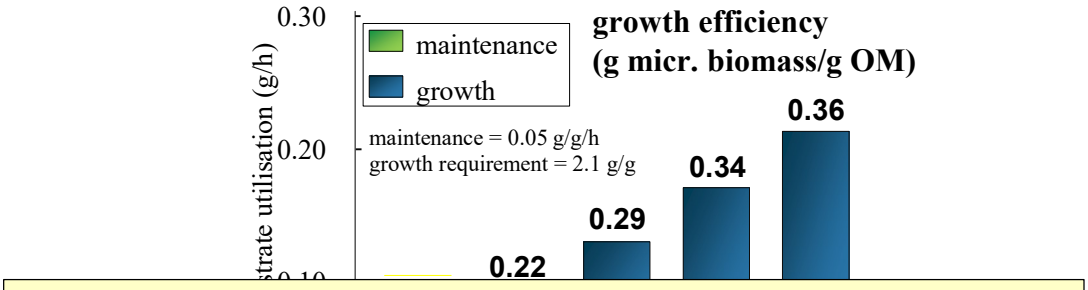

- optimal rumen N : energy supply ratio varies with fractional growth rate
- ↑ passage rate → ↑ microbial growth rate

High feed intake cows require more RDN per unit FOM

FOM: rumen fermentable organic matter
RDN: rumen degradable N

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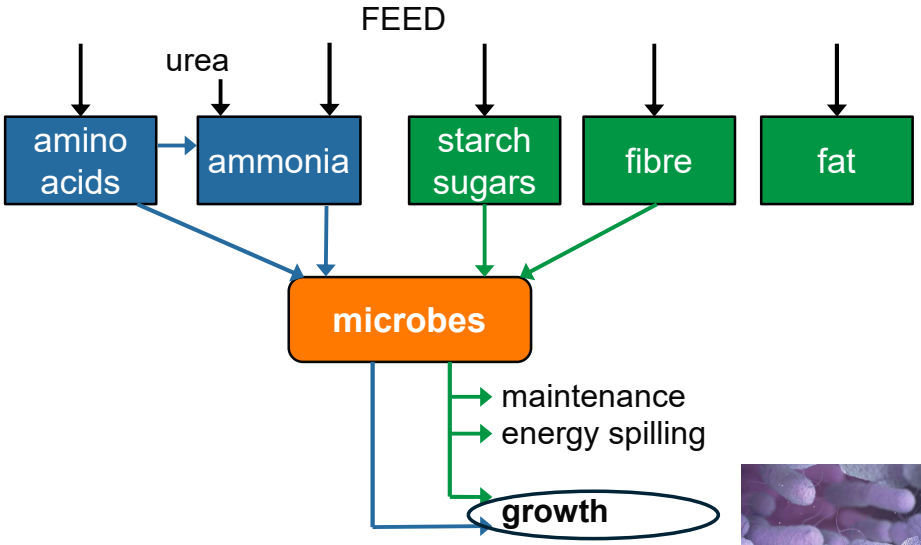
Balanced rumen N and energy supply



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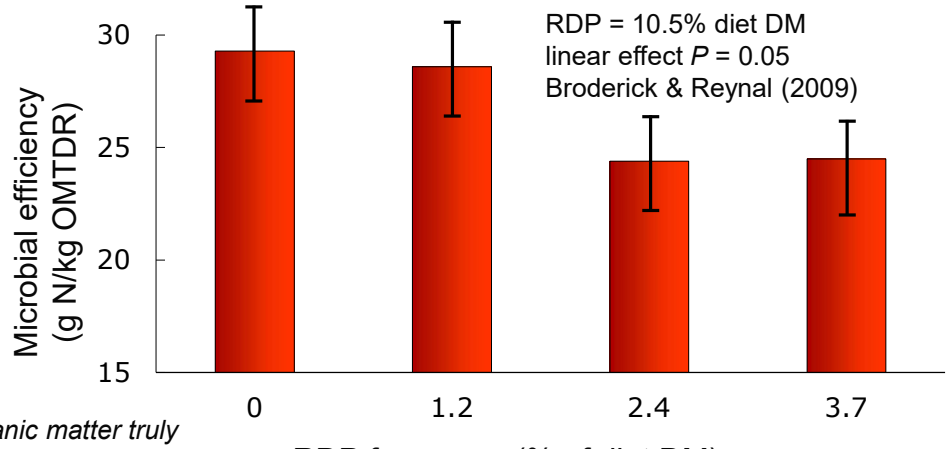
Nitrogen source affects optimal rumen N:energy balance



OMTDR: organic matter truly digested in rumen

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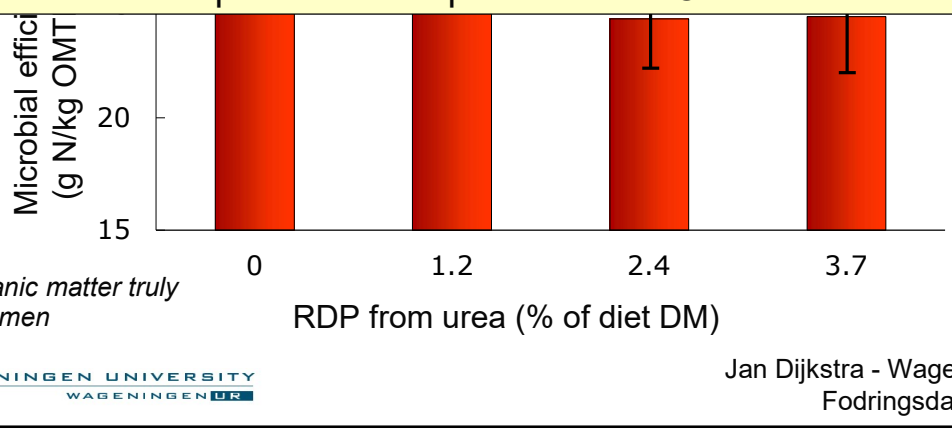
Nitrogen source affects optimal rumen N:energy balance

- ammonia-based microbial growth requires more energy than amino acid-based growth
- low-protein diets require a lower optimal RDN:FOM ratio



OMTDR: organic matter truly digested in rumen

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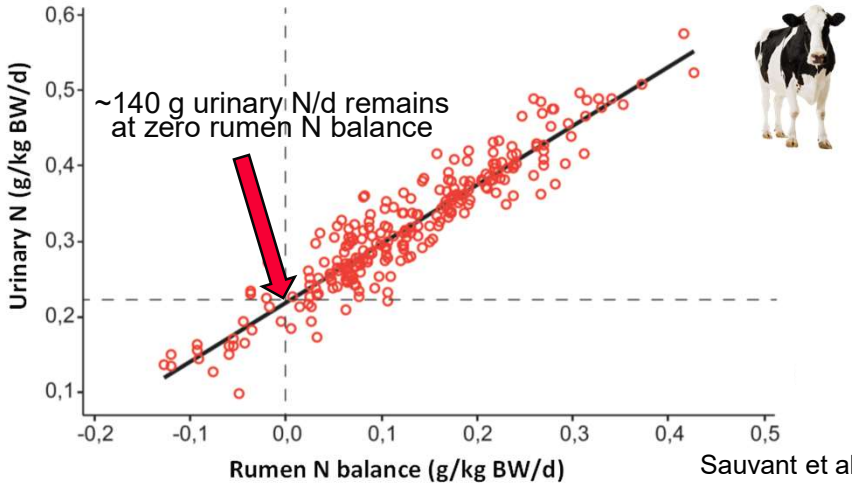
Considerable N loss even at zero rumen N balance



Sauvant et al. (2015)

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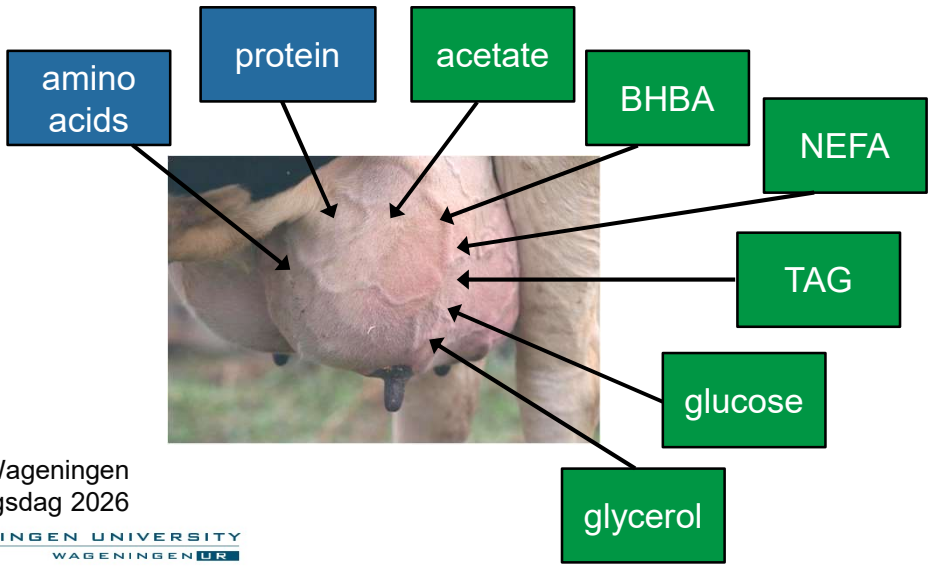
Balanced protein and energy supply udder



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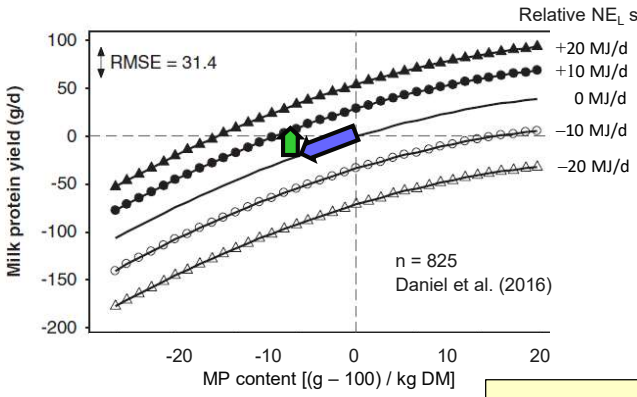
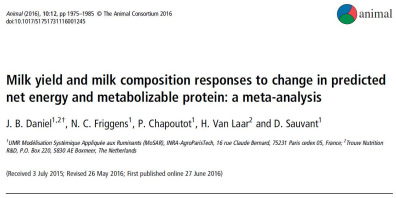
Metabolizable protein efficiency depends on energy supply




Animal (2016), 10:12, pp 1975–1985 © The Animal Consortium 2016
doi:10.1017/S1751731116001245

animal

Milk yield and milk composition responses to change in predicted net energy and metabolizable protein: a meta-analysis

J. B. Daniel[1,2†], N. C. Friggens[1], P. Chapoutot[1], H. Van Laar[2] and D. Sauvant[1]

[1]UMR Modélisation Systémique Appliquée aux Ruminants (MoSAR), INRA-AgroParisTech, 16 rue Claude Bernard, 75231 Paris cedex 05, France; [2]Trouw Nutrition R&D, P.O. Box 220, 5830 AE Boxmeer, The Netherlands

(Received 3 July 2015; Revised 26 May 2016; First published online 27 June 2016)

MP response depends on NE$_L$ content
- higher NE$_L$ can offset lower MP, improving milk N efficiency

MP: metabolizable protein
NE$_L$: net energy for lactation

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Energy source affects milk N efficiency

GLUCOGENIC
- Starch-rich feedstuffs
- Ruminal propionate

LIPOGENIC
- Fibre-rich feedstuffs
- Fat supplements
  calcium soaps; rapeseed

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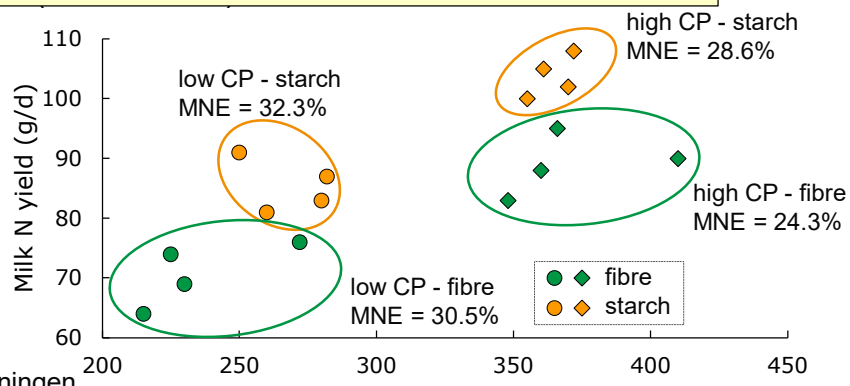
Energy source affects milk N efficiency

starch-rich (glucogenic) diets improve milk N efficiency



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REDNEX

MNE: milk N efficiency
Cantalapiedra-Hijar et al. (2014)

Practical example from Dutch dairy farming

	North West	South East
Diet ingredients (% DM)		
Grass herbage	13	8
Grass silage	44	33
Maize silage	11	28
Concentrate	32	31
N intake (kg/yr)	197.4	191.4
N in milk (kg/yr)	49.8	52.0
Milk N efficiency (%)	25.2	27.2

2024; source: CBS

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Mammary flexibility in using individual amino acids

Milk protein yield limited by single amino acid?

Unlikely, because:

- ✔ mTOR pathway in ribosomal protein synthesis responds independently and additively to essential AA and energy compounds
- ✔ milk protein yield stimulated by mutually exclusive sets of essential AA
- ✔ equal losses in milk protein yield when individual AA are removed from duodenal essential AA supply

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Cant et al. (2018)

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- ✔ mTOR pathway in ribosomal protein synthesis responds independently and additively to essential AA and energy compounds
- ✔ milk protein yield stimulated by mutually exclusive sets of essential AA

example: equal stimulation with Arg+His and Lys+Met

supply

example: omitting His, Met, or Phe decreased milk protein yield to a similar extent

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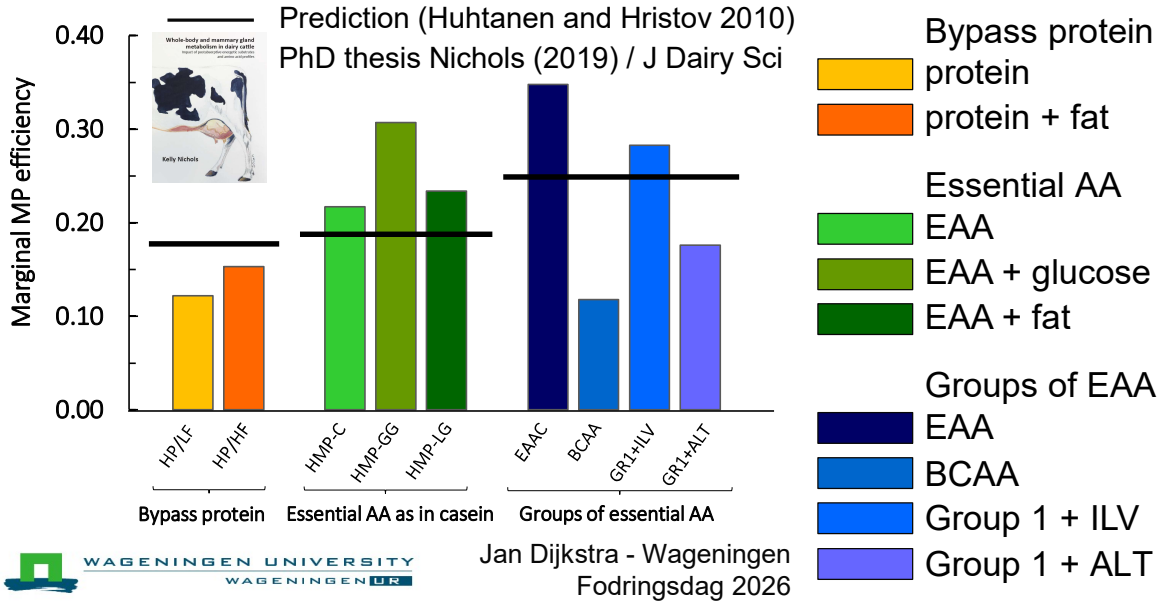
Response to nutrient supplementation



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Mammary flexibility in using individual amino acids

Milk protein yield limited by single amino acid?

Additive and independent responses to nutrients

- size of leak depends on mix of nutrients
- plugging any crack may help: several amino acids offer opportunity for improvement

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Key messages on nutritional strategies

Improving milk N efficiency requires more than reducing dietary protein

- balance N and energy supply in the rumen and after absorption
- the optimal balance is dynamic and depends on
  - rumen microbial growth rate
  - N source in rumen
  - energy type and supply post-absorptively
- focus on nutrient balance rather than individual nutrients
  - no unique first-limiting amino acid

► But can low-protein diets be sustained long term?

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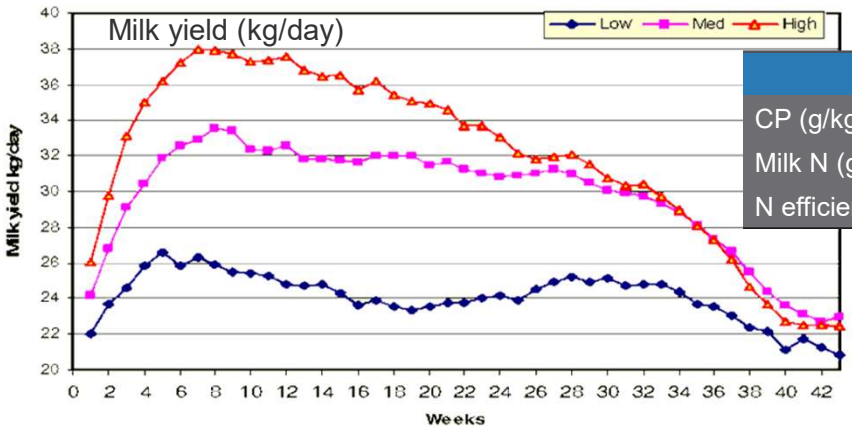
Impact of dietary protein level: full lactation



	L	M	H
CP (g/kg DM)	114	144	173
Milk N (g/d)	123	155	170
N efficiency	0.406	0.379	0.325

Law et al. (2009)
Source: Prof CK Reynolds

305 day yield

High 9653 kg **Medium** 9089 kg **Low** 7435 kg

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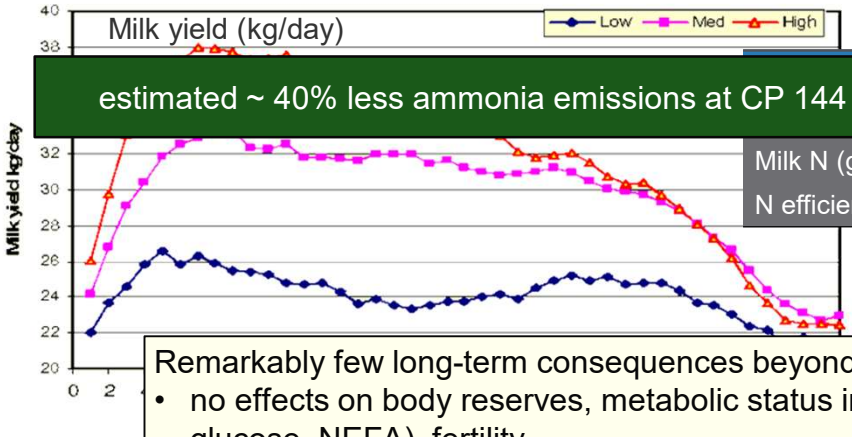

estimated ~ 40% less ammonia emissions at CP 144 vs 173 g/kg DM

			H
			173
Milk N (g/d)	123	155	170
N efficiency	0.406	0.379	0.325

Remarkably few long-term consequences beyond lower milk yield
- no effects on body reserves, metabolic status indicators (IGF-1, leptin, glucose, NEFA), fertility
- higher incidence of metritis at lowest CP level

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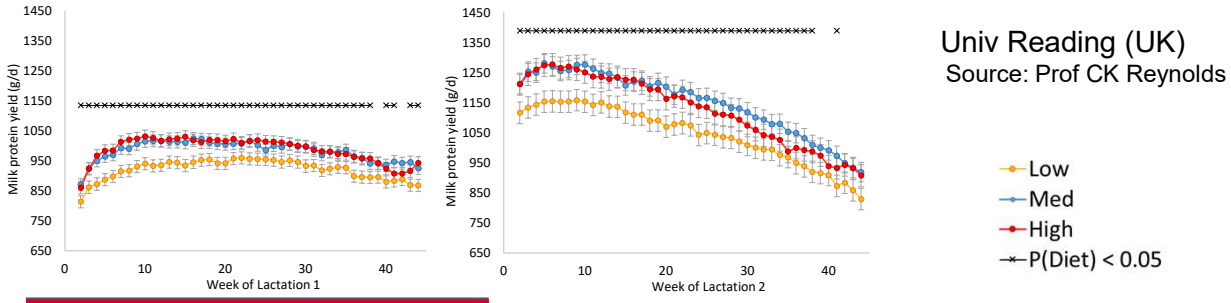
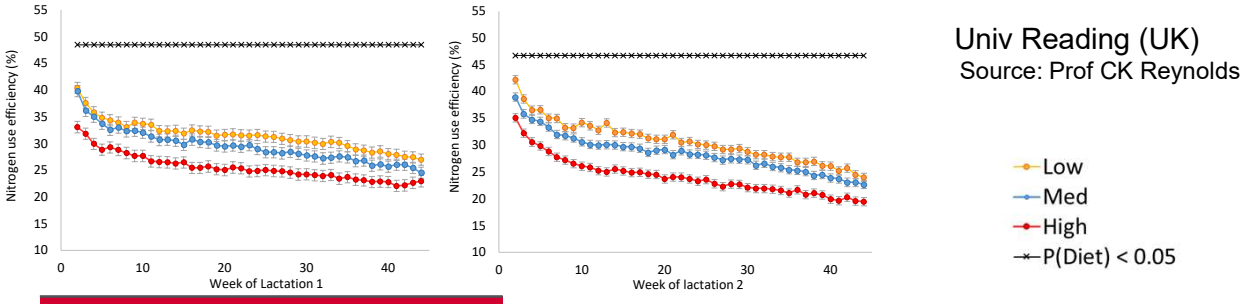
Impact of dietary protein level: 3 full lactations



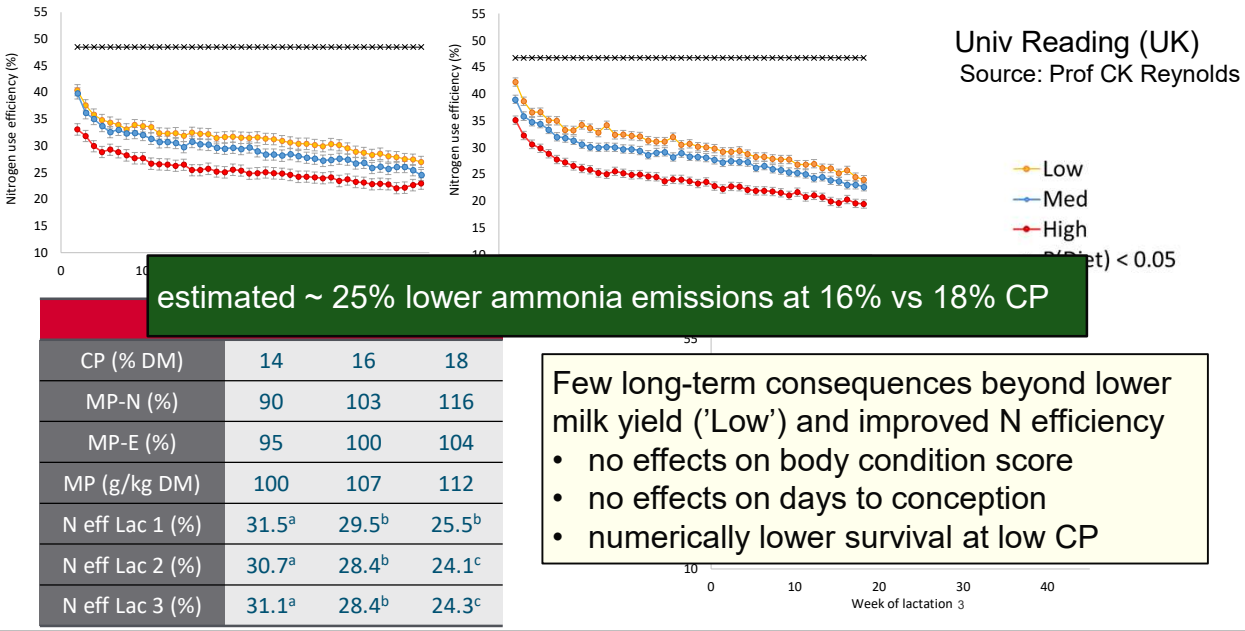
	Low	Med	High
CP (% DM)	14	16	18
MP-N (%)	90	103	116
MP-E (%)	95	100	104
MP (g/kg DM)	100	107	112

Impact of dietary protein level: 3 full lactations



	Low	Med	High
CP (% DM)	14	16	18
MP-N (%)	90	103	116
MP-E (%)	95	100	104
MP (g/kg DM)	100	107	112
N eff Lac 1 (%)	31.5[a]	29.5[b]	25.5[b]
N eff Lac 2 (%)	30.7[a]	28.4[b]	24.1[c]
N eff Lac 3 (%)	31.1[a]	28.4[b]	24.3[c]

Impact of dietary protein level: 3 full lactations

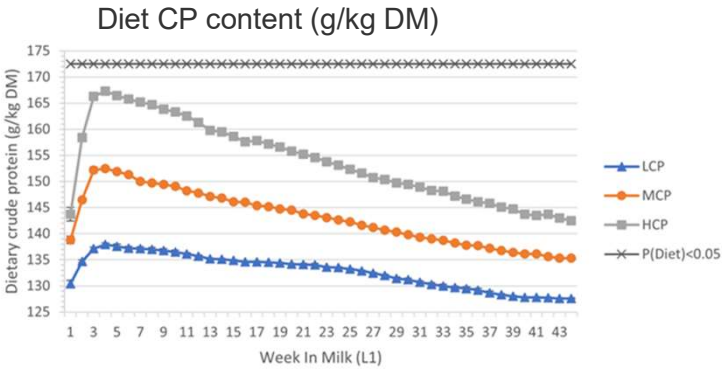


estimated ~ 25% lower ammonia emissions at 16% vs 18% CP

CP (% DM)	14	16	18
MP-N (%)	90	103	116
MP-E (%)	95	100	104
MP (g/kg DM)	100	107	112
N eff Lac 1 (%)	31.5^{a}	29.5^{b}	25.5^{b}
N eff Lac 2 (%)	30.7^{a}	28.4^{b}	24.1^{c}
N eff Lac 3 (%)	31.1^{a}	28.4^{b}	24.3^{c}

Few long-term consequences beyond lower milk yield ('Low') and improved N efficiency
- no effects on body condition score
- no effects on days to conception
- numerically lower survival at low CP

Stage specific protein supply: 1 full lactation



	LCP	MCP	HCP
CP (g/kg DM)	133^{c}	143^{b}	154^{a}

- Identical basal diet
- CP differences achieved through low or high CP concentrate

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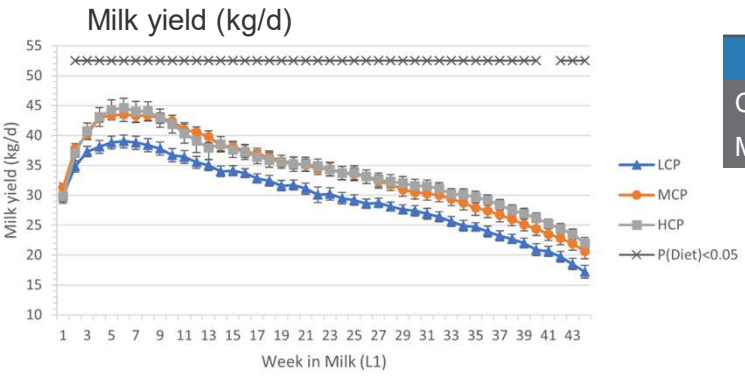
Van Ruitenbeek et al. (unpublished)

Stage specific protein supply: 1 full lactation



	LCP	MCP	HCP
CP (g/kg DM)	133^{c}	143^{b}	154^{a}
Milk (kg/d)	29.9^{b}	33.8^{a}	34.2^{a}

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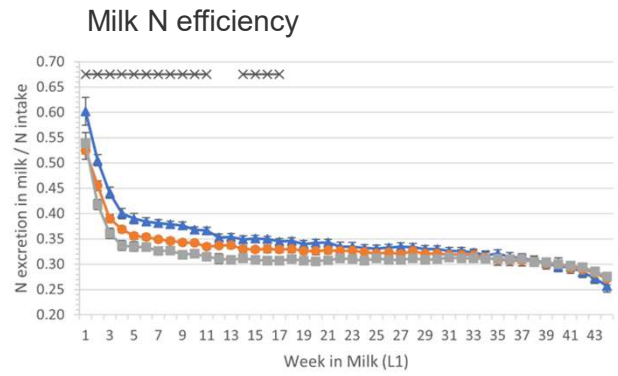
Stage specific protein supply: 1 full lactation



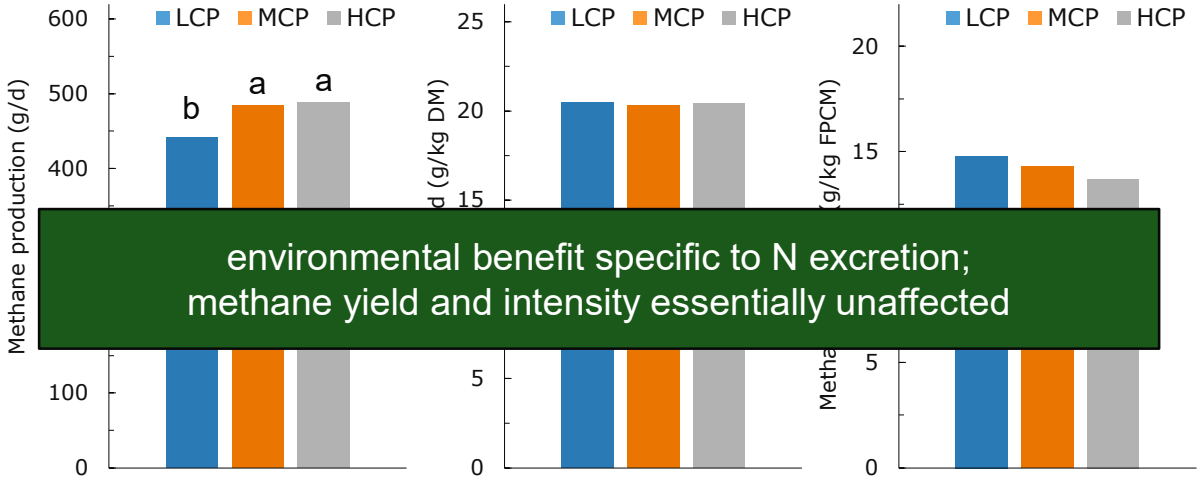
	LCP	MCP	HCP
CP (g/kg DM)	133^{c}	143^{b}	154^{a}
Milk (kg/d)	29.9^{b}	33.8^{a}	34.2^{a}
N efficiency (%)	34.8^{a}	33.2^{b}	31.9^{c}

Health, fertility and 2nd full lactation responses currently under analysis

measured ~ 20% lower urinary N excretion at 143 vs 154 g CP/kg DM

Van Ruitenbeek et al. (unpublished)

Stage specific protein supply: 1 full lactation



environmental benefit specific to N excretion;
methane yield and intensity essentially unaffected

Van Ruitenbeek et al. (unpublished)

Key messages from long-term low-protein studies

- Low-protein diets can be sustained over full lactation/lactations
- Very low CP supply may increase health and fertility risks
- Milk production is more sensitive to protein restriction than health or fertility
- Small or moderate reductions in dietary CP can substantially reduce N losses
  - lower urinary N excretion and likely lower ammonia emissions

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The road ahead

scan for my personal page

- Consistent policy and farm-level monitoring are essential for reducing N excretion
- Milk N efficiency matters as much as N intake
- Current milk N efficiency remains well below its biological potential
- Improving N efficiency requires a dynamic balance between N and energy supply
- Move beyond the dogma of a unique first-limiting amino acid
- Moderate dietary protein reductions can be sustained over extended periods while substantially reducing N losses

➡ **Feed the right amount of protein, not the least amount of protein**

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thank you *jan.dijkstra@wur.nl*