Viable future dairy farming systems: a comprehensive nutritional approach to minimize methane emission and phosphorus and nitrogen excretion

Jan Dijkstra - Wageningen University & Research

Thomas Schonewille — Utrecht University

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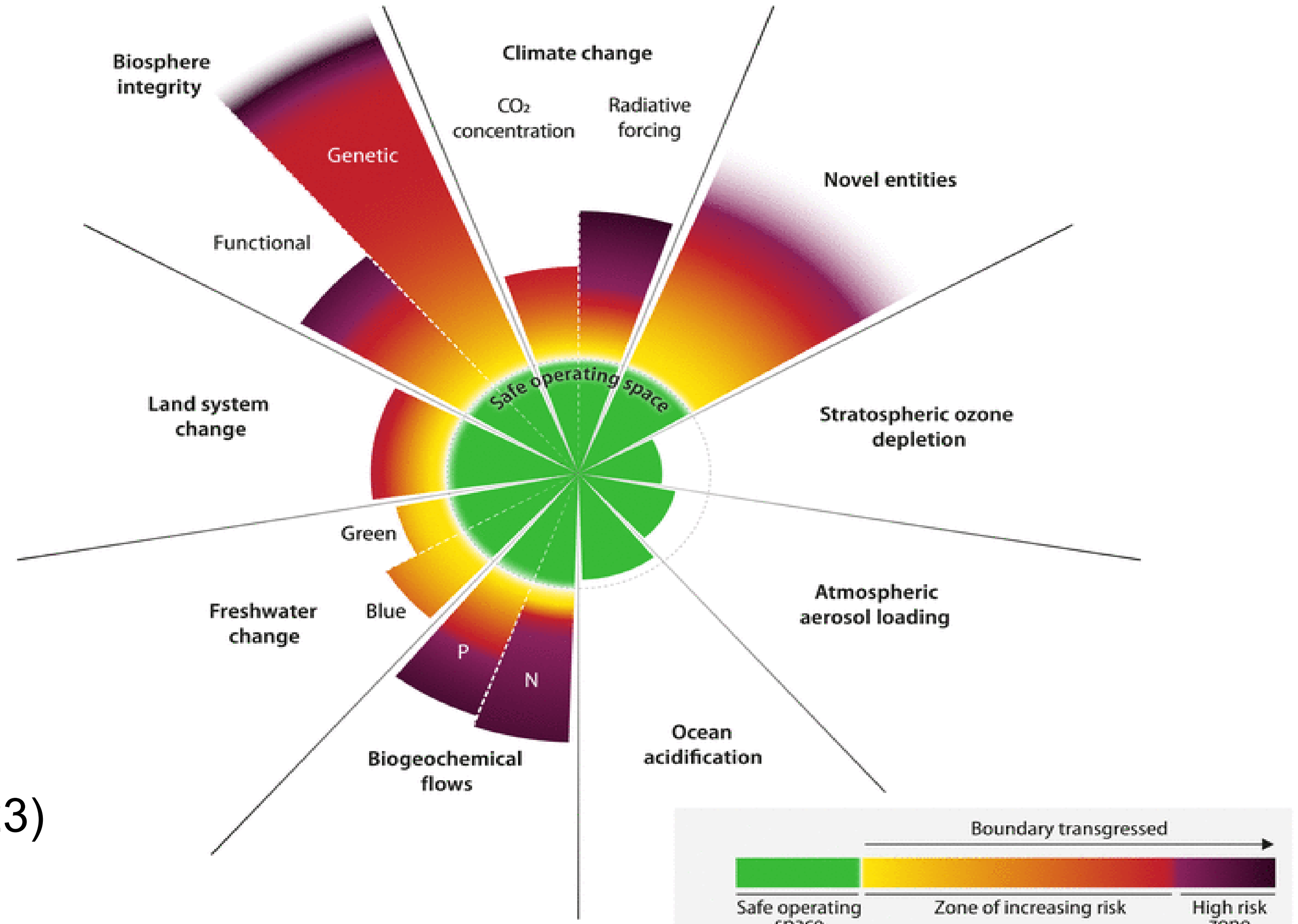
Kelly Nichols — UC Davis, University of California

André Bannink — Wageningen University & Research

Wageningen University — Wageningen UR

75th EAAP Annual Meeting 2024

Earth beyond six of nine planetary boundaries



Richardson et al. (2023)

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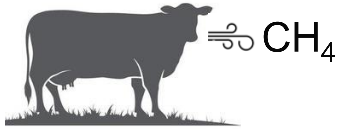
Reducing environmental impact dairy farming

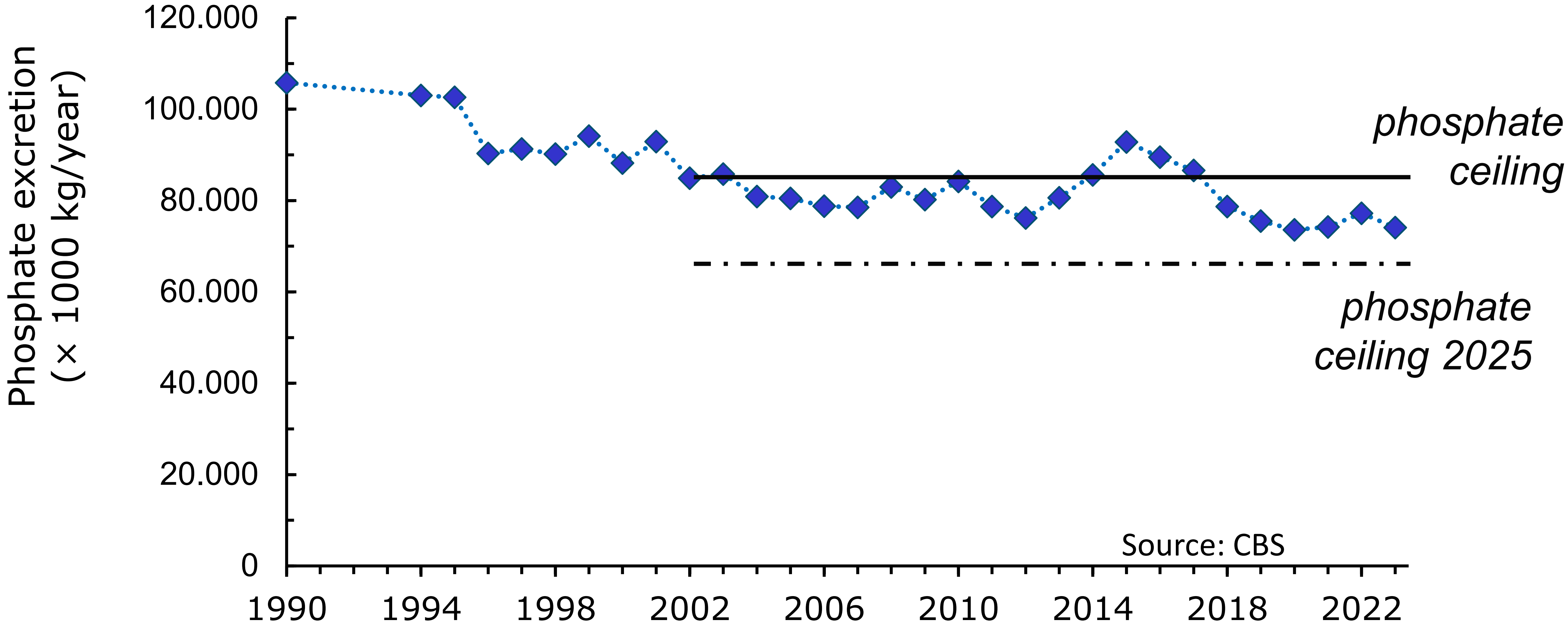
Nutritional approaches to ↓

- phosphorus excretion
- nitrogen excretion
- enteric methane emission



with focus on Dutch dairy sector as a case

Phosphate excretion dairy cattle and youngstock



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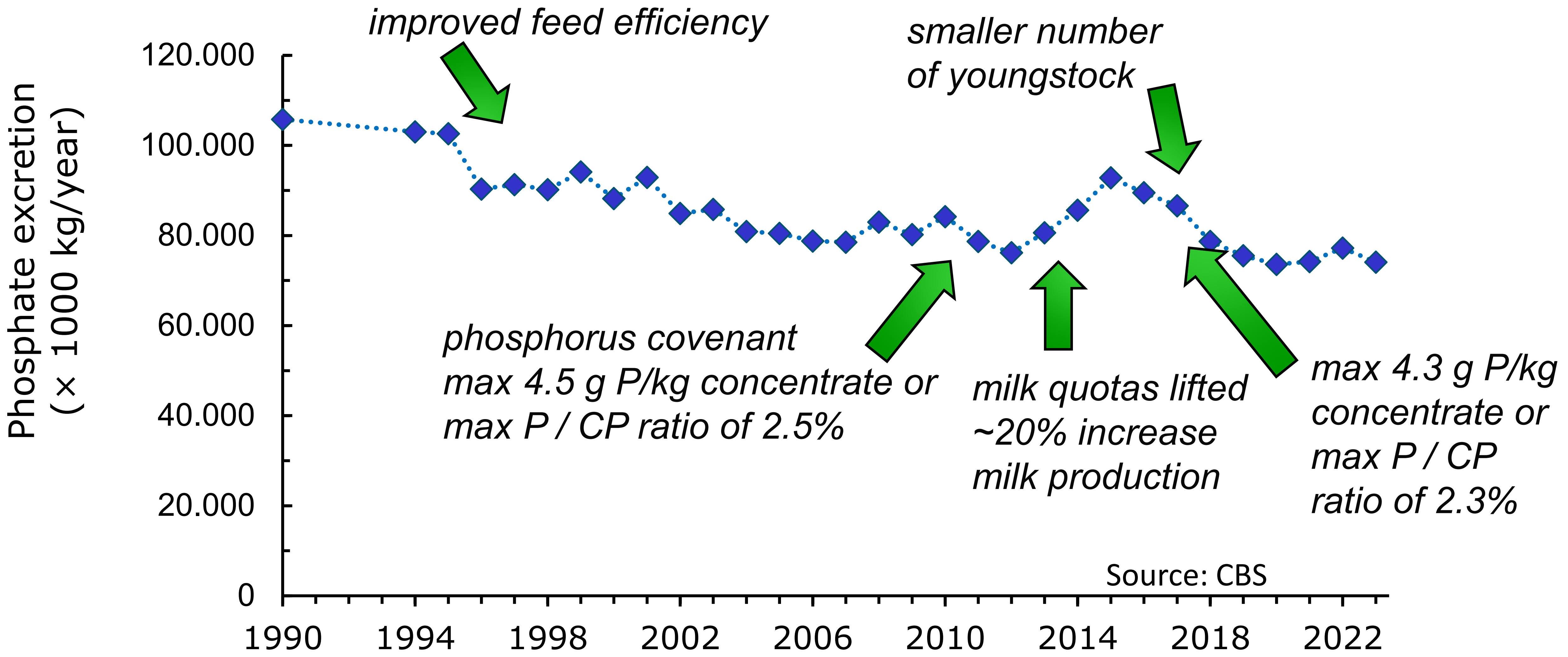

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Considerations to reduce P in practice

- Grass herbage / grass silage high P content
- Concentrates / byproducts with low P but adequate protein at a premium
- Concerns about lower dietary P affecting production, transition health, and fertility
- Experiment dairy cattle (n = 60)

(Keanthao et al., 2021)

  - 6 wks antepartum to 8 wks postpartum
  - 2 × 2 factorial design
    - dry period: 2.2 (recommended) or 3.6 (practice) g P/kg DM
    - lactating period: 2.9 (low) or 3.8 (recommended) g P/kg DM

J. Dairy Sci. 104:11646–11659
https://doi.org/10.3168/jds.2021-20488

Effects of dietary phosphorus concentration during the transition period on plasma calcium concentrations, feed intake, and milk production in dairy cows

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Effects of P level dry period and early lactation period

- No effect of P level on DM intake, milk production, milk composition

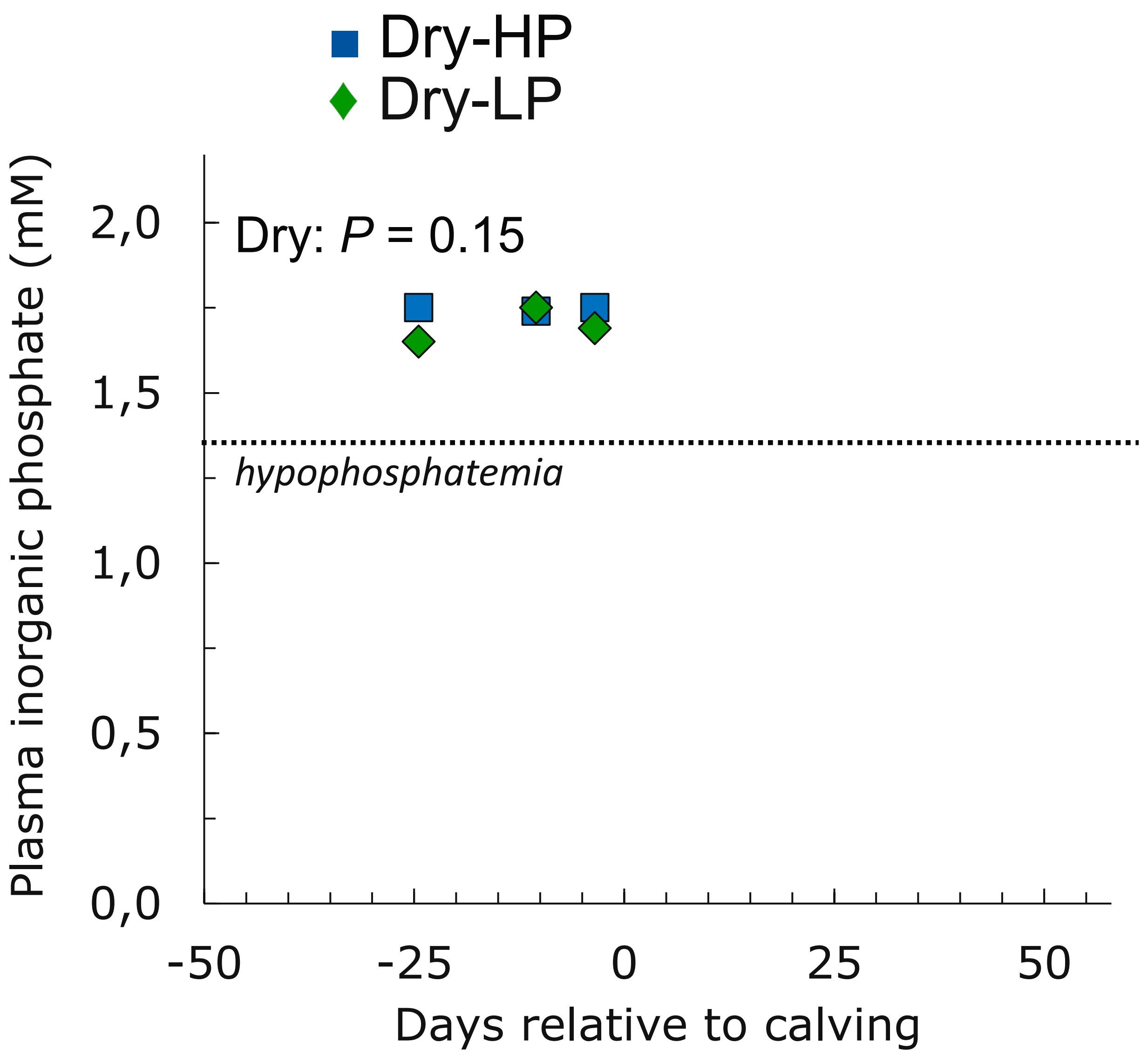
Keanthao et al. (2021)

- In line with other findings on absence of effect at / somewhat below recommended P levels

  Valk and Šebek (1999)
  Wu et al. (2001)
  Peterson et al. (2005)
  Puggaard et al. (2014)
  Wächter et al. (2022)

AGREE ✓

Effect of P level on plasma Pi and Ca concentration



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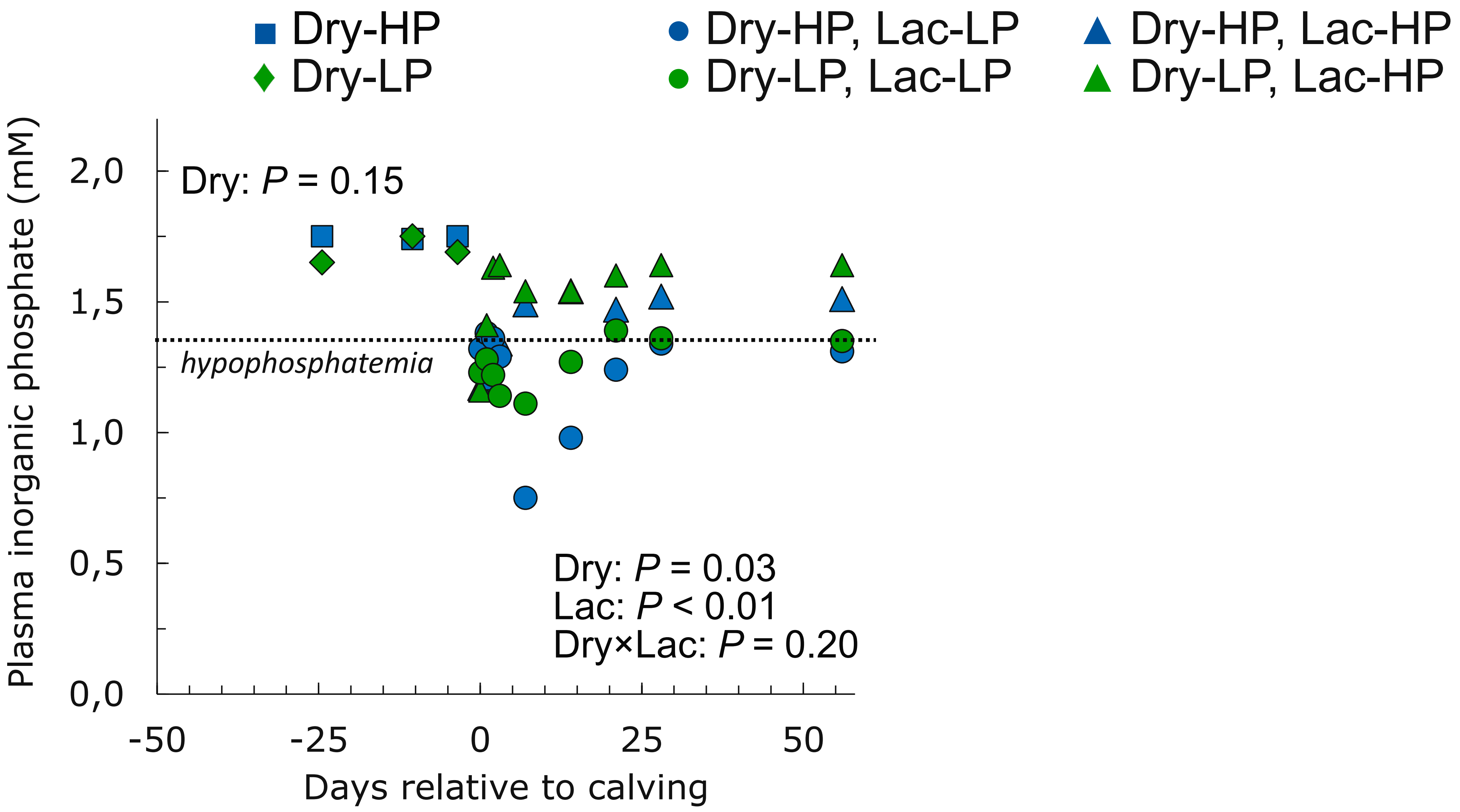
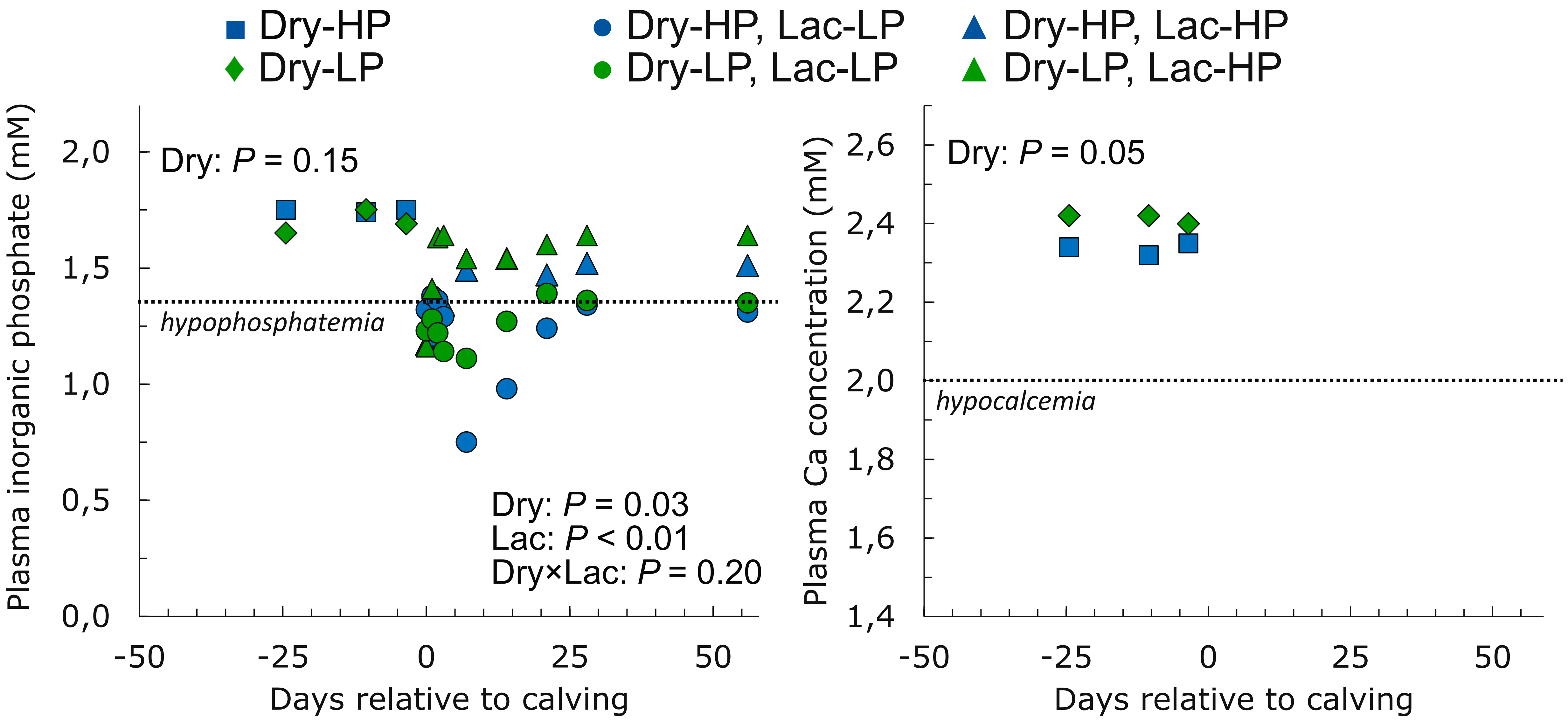
Keanthao et al. (2021)

Effect of P level on plasma Pi and Ca concentration



Keanthao et al. (2021)

Effect of P level on plasma Pi and Ca concentration



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Keanthao et al. (2021)

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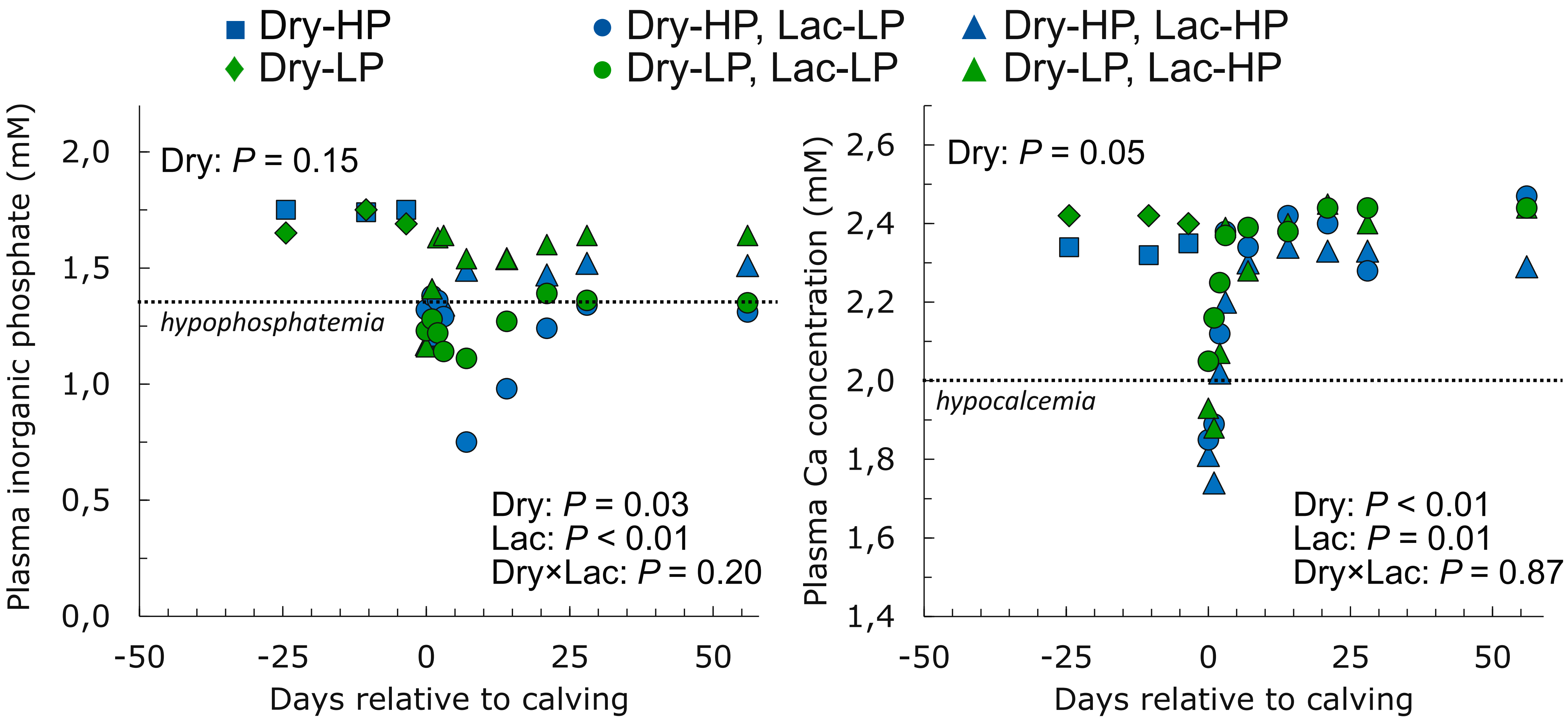

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Keanthao et al. (2021)

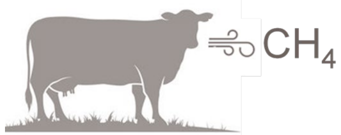
Conclusions on phosphorus (P) excretion

- Reduced P excretion without decreased production volume requires lowering dietary P
- Covenant on lower P levels concentrate effective
- Recommended dietary P levels may be excessive
  - low P levels during dry period/start of lactation aid smoother transition

Reducing environmental impact dairy farming

Nutritional approaches to ⇩

- phosphorus excretion
- nitrogen excretion
- enteric methane emission



with focus on Dutch dairy sector as a case

Nitrogen – hot topic

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ENVIRONMENT

Dutch farmers angry about nitrogen restrictions

The Netherlands is under pressure to reduce its nitrogen emissions — gases proven to be 300 times worse for global warming than CO2. That means the country's agriculture has to change. But the restrictions the government is proposing aren't going down well with Dutch farmers.

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Dutch tractor protest sparks 'worst rush hour'

1 October 2019

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Climate change

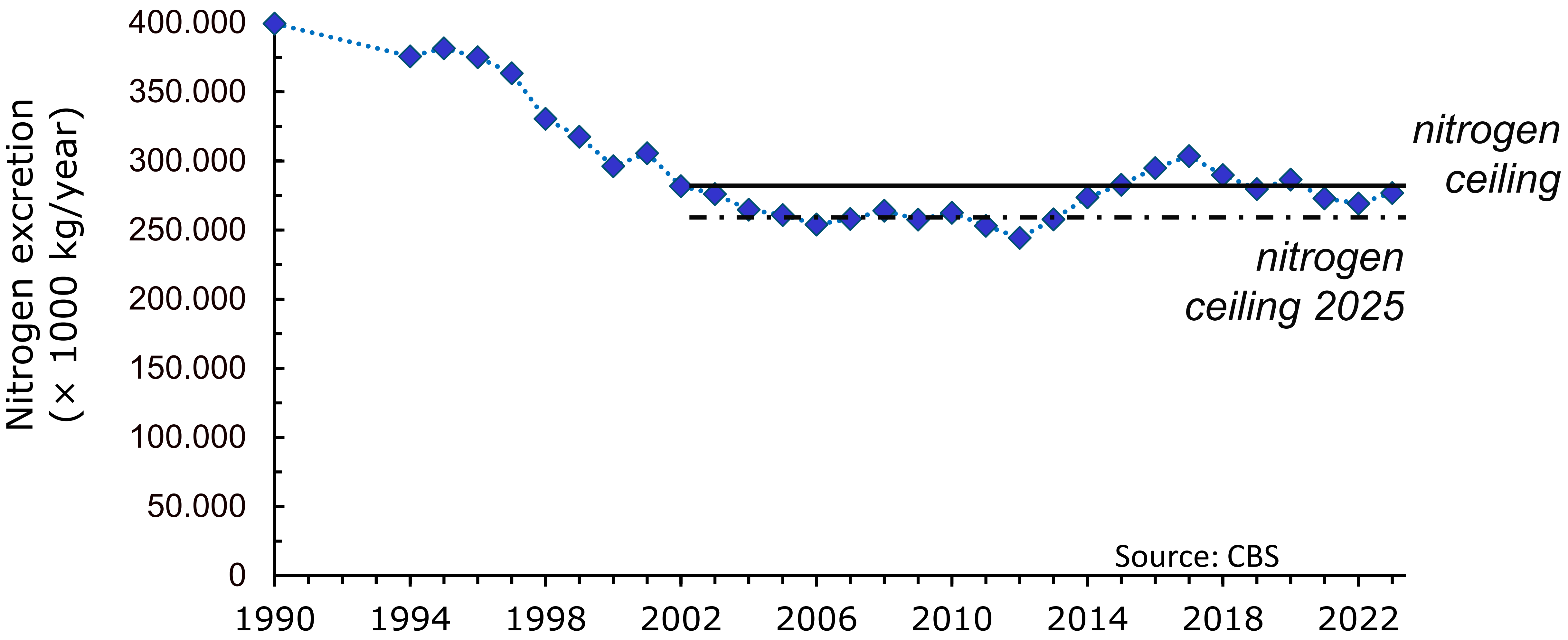
Dutch farmers clogged up more than 1,000km of roads with their tractors

Tractor-driving farmers taking to the streets to demand greater recognition caused the worst ever Dutch morning rush hour on Tuesday, according to motoring organisation ANWB.

There were 1,136km (700 miles) of jams at the morning peak, it said.

Farmers reacted angrily to claims that they were largely responsible for a nitrogen oxide emissions problem.

Nitrogen excretion dairy cattle and youngstock



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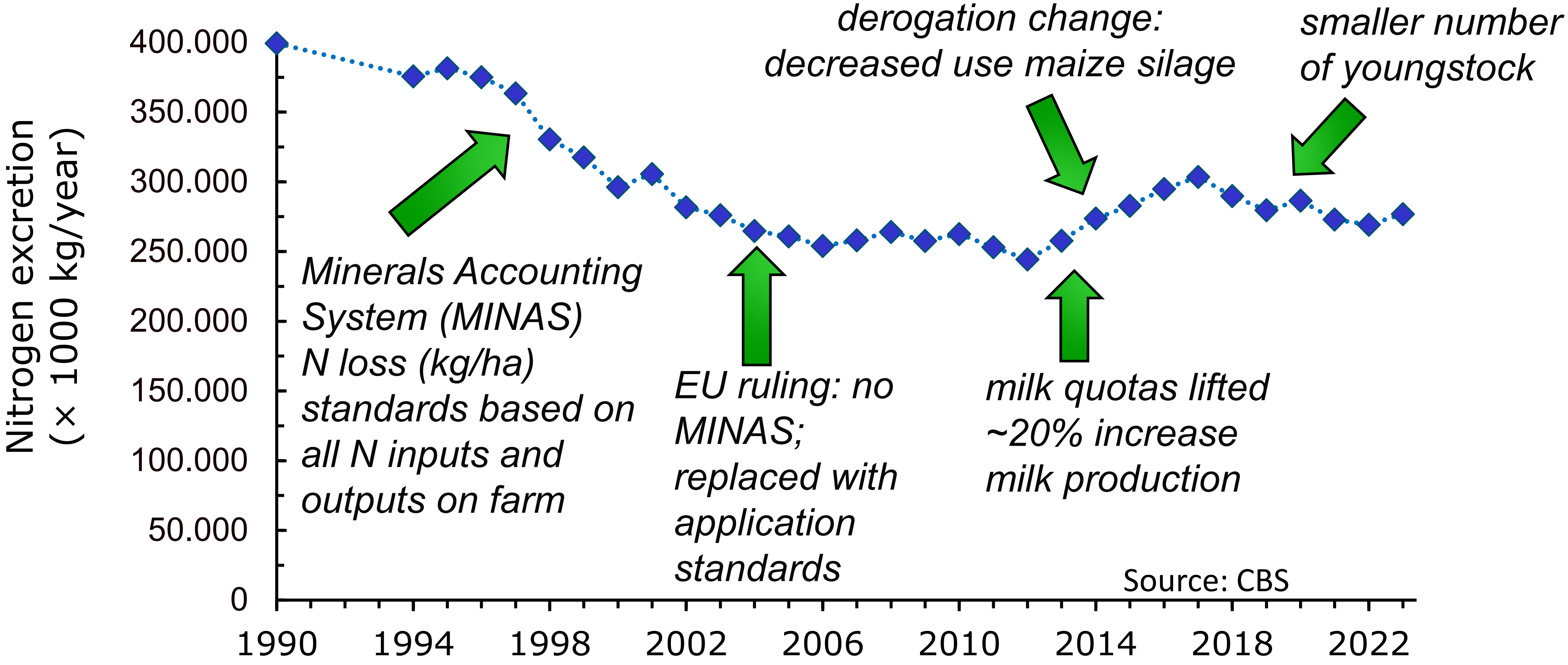
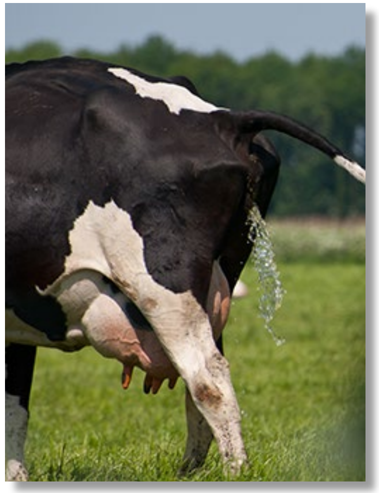
Nitrogen excretion dairy cattle and youngstock

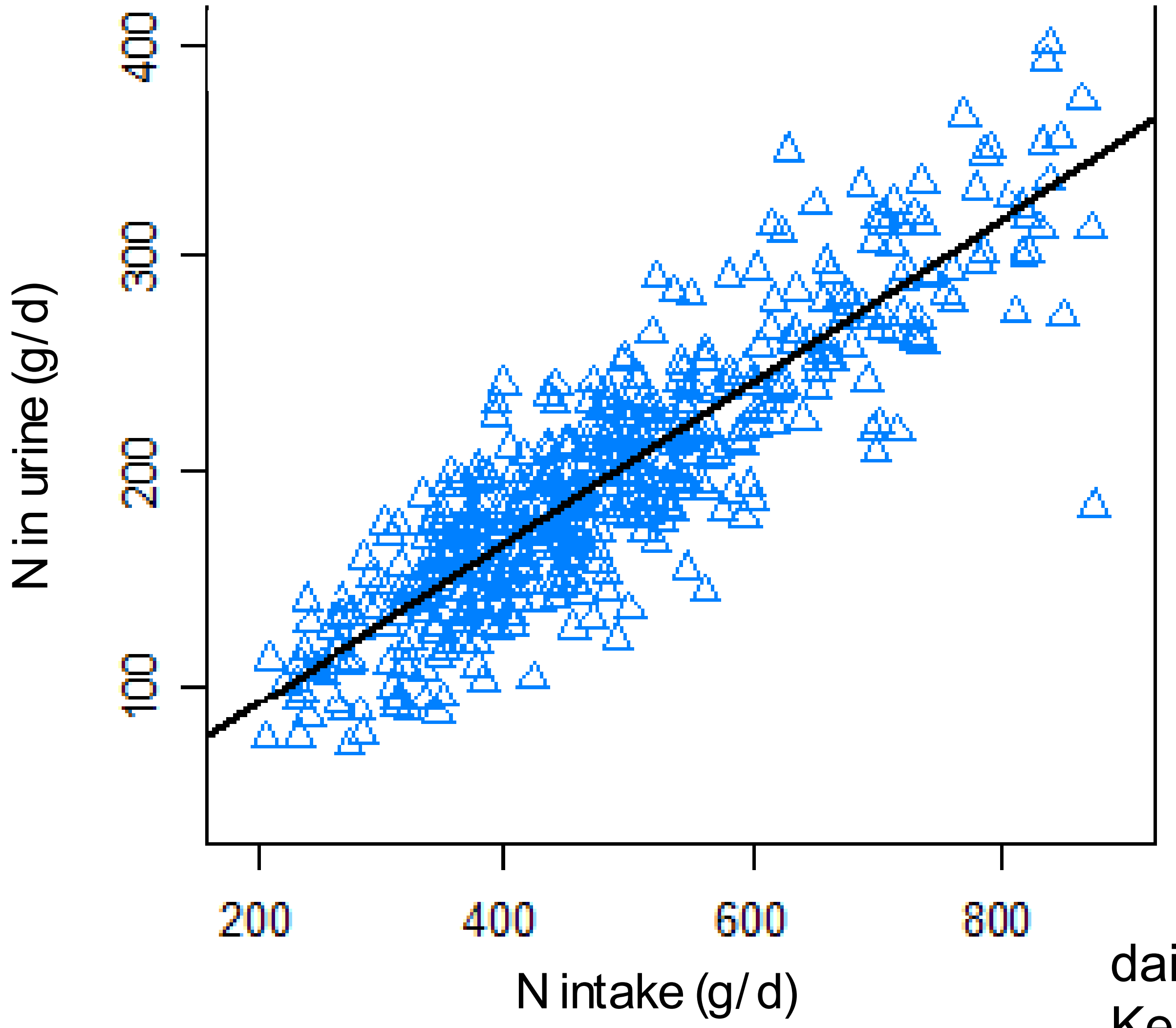


The 🔑 is protein supply....

- Potential negative impact of lower N diet on production
- Focus on decreasing urinary N excretion
  - ↑ absorbed amino acid-N to milk



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)

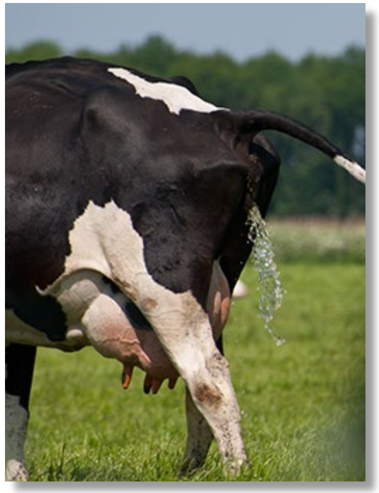
dairy cattle (*n* = 470)

Kebreab et al. (2010)

The  is protein supply....
..... but relative to energy supply

- Potential negative impact of lower N diet on production
- Focus on decreasing urinary N excretion
  - ↑ absorbed amino acid-N to milk
- Balanced rumen N and energy supply

➡ Post-absorptive balance energy (*NE_L*) and protein (*MP*) is complex



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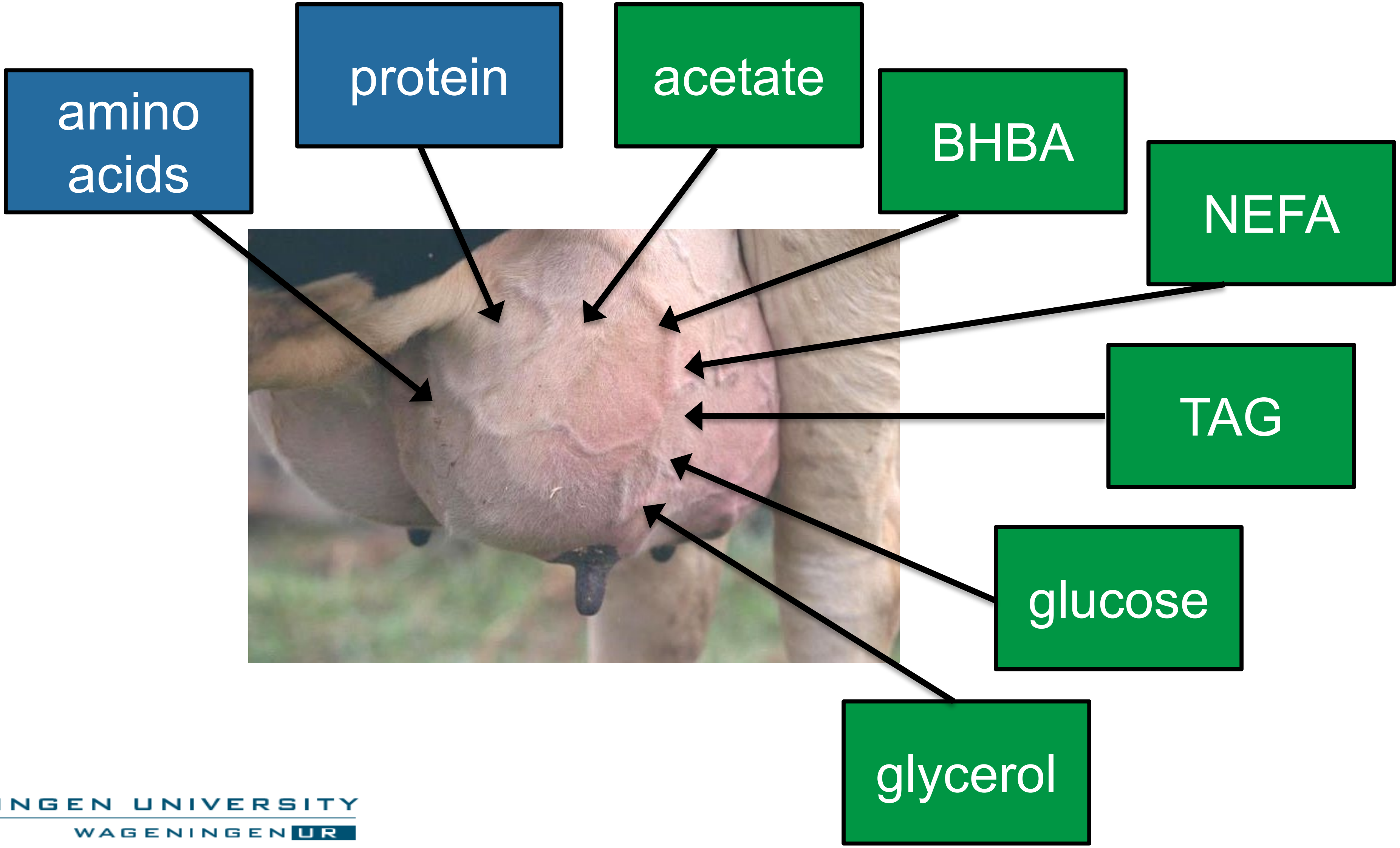
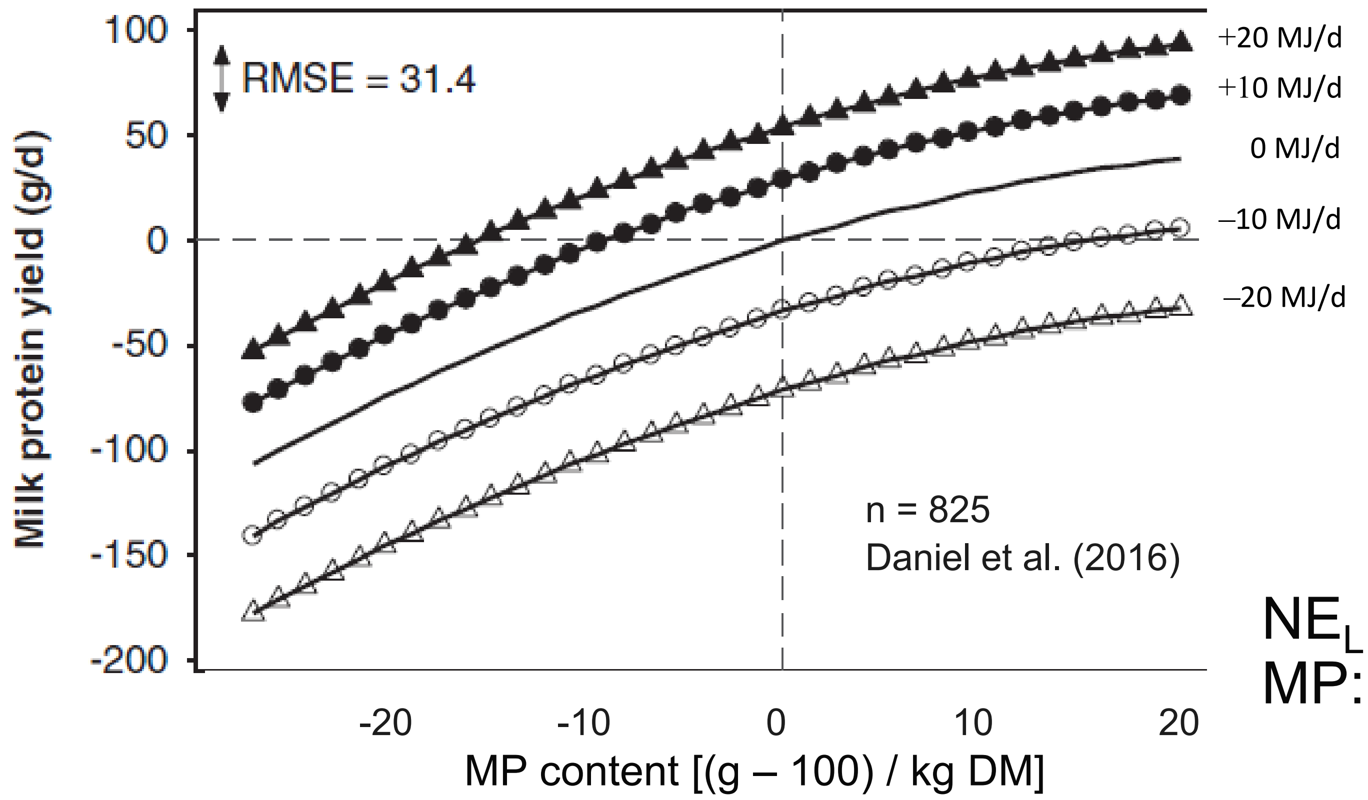
Balanced protein and energy supply udder



Response to change in NE_L and MP



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)

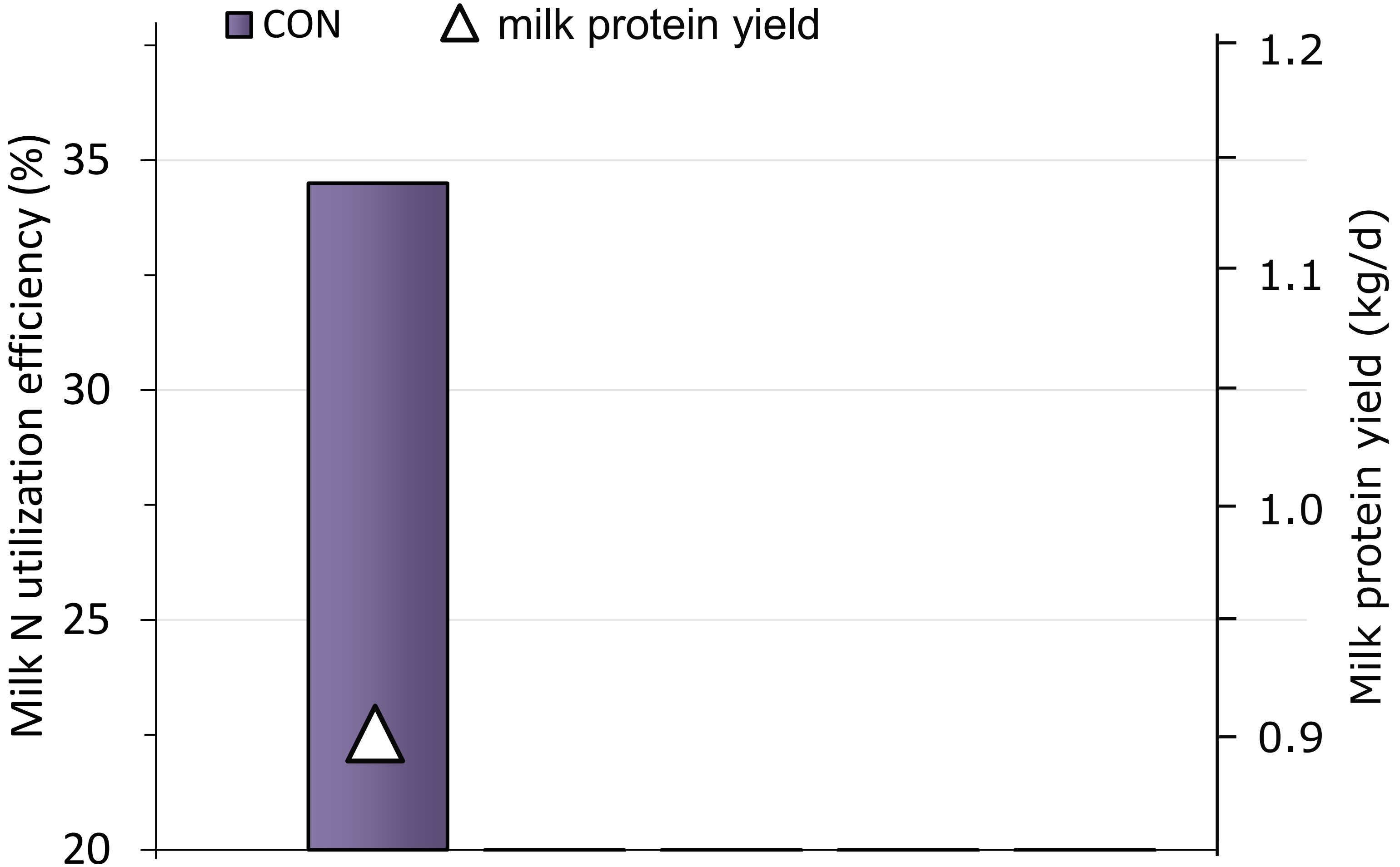
NE_L: net energy for lactation
MP: metabolizable protein

Response to dietary MP content depends on dietary NE_L content
- increase in NE_L content may balance impact of decrease in MP content and reduce urinary N excretion

Importance of amino acid profile for milk N efficiency

Milk protein yield limited by single amino acid?

Importance of amino acid profile for milk N efficiency



Diet CP 13% of DM
Abomasal infusion
562 g MP/d:
CON: none (0 g MP/d)

SEM = 0.89

Nichols et al. (2019)

J. Dairy Sci. 102:8963–8976
https://doi.org/10.3168/jds.2019-16400

Energy and nitrogen balance of dairy cattle as affected by provision of different essential amino acid profiles at the same metabolizable protein supply

K. Nichols,[1,2]* A. Bannink,[2] and J. Dijkstra[1]
[1]Animal Nutrition Group, Wageningen University and Research, PO Box 338, 6700 AH Wageningen, the Netherlands
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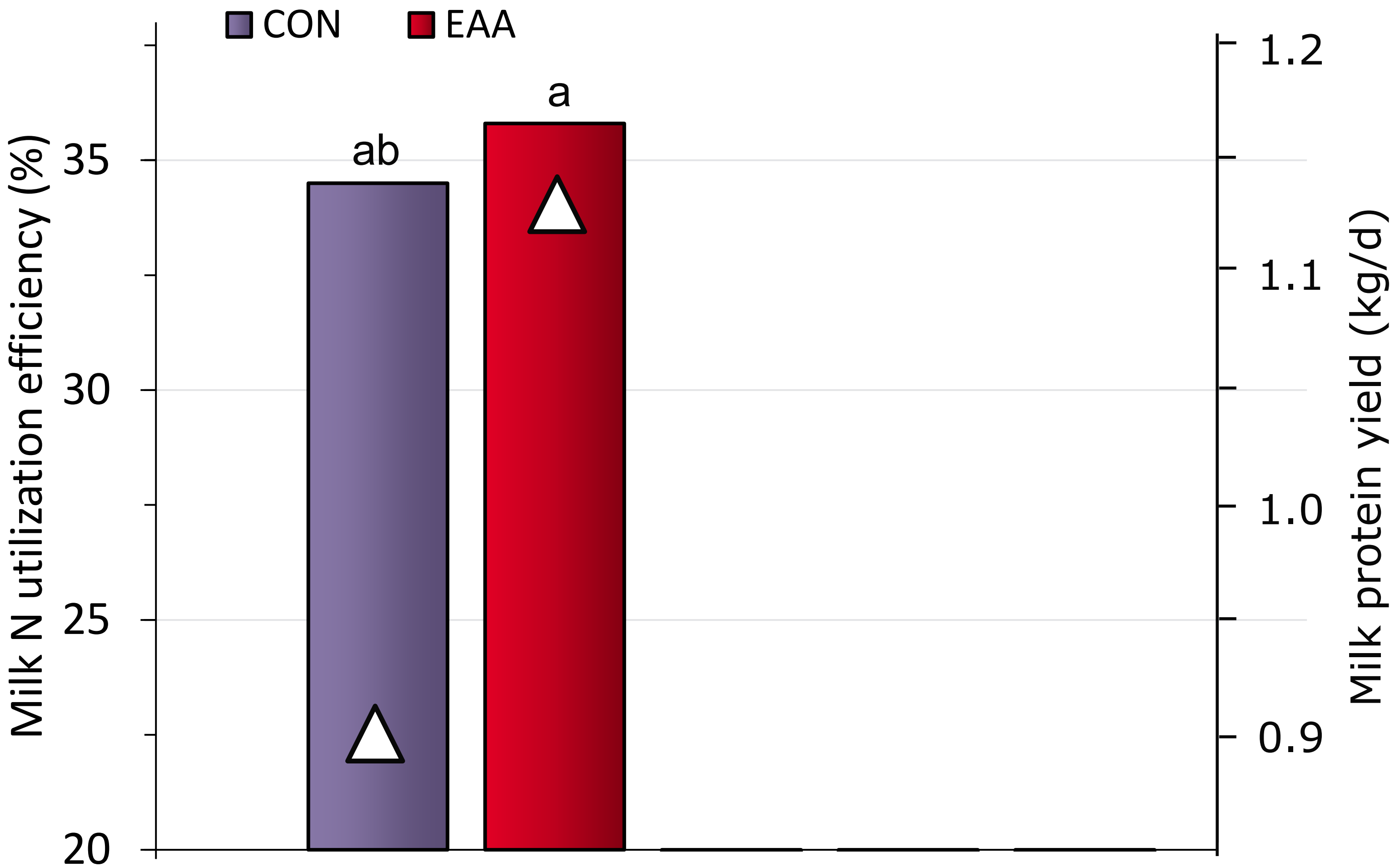

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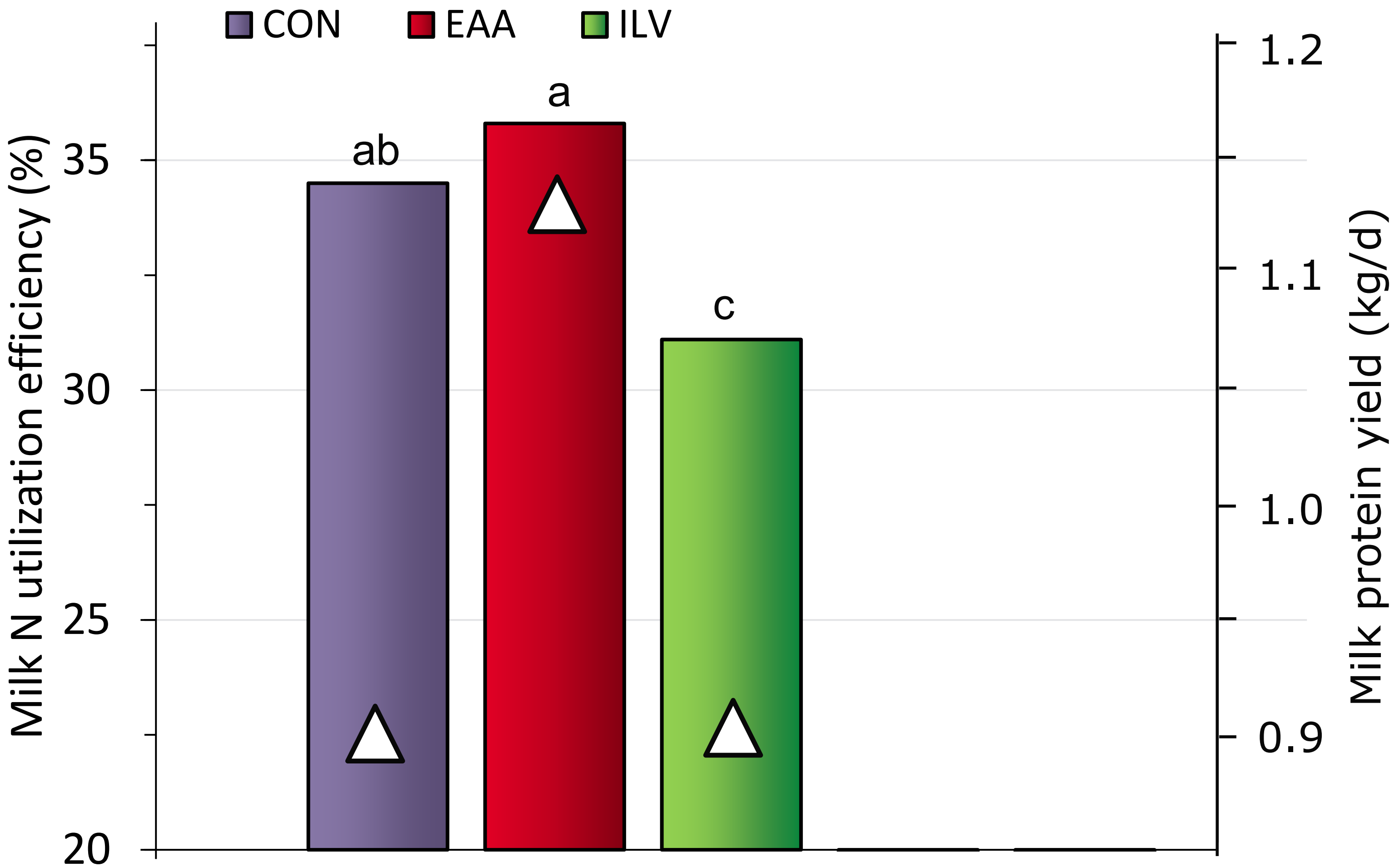

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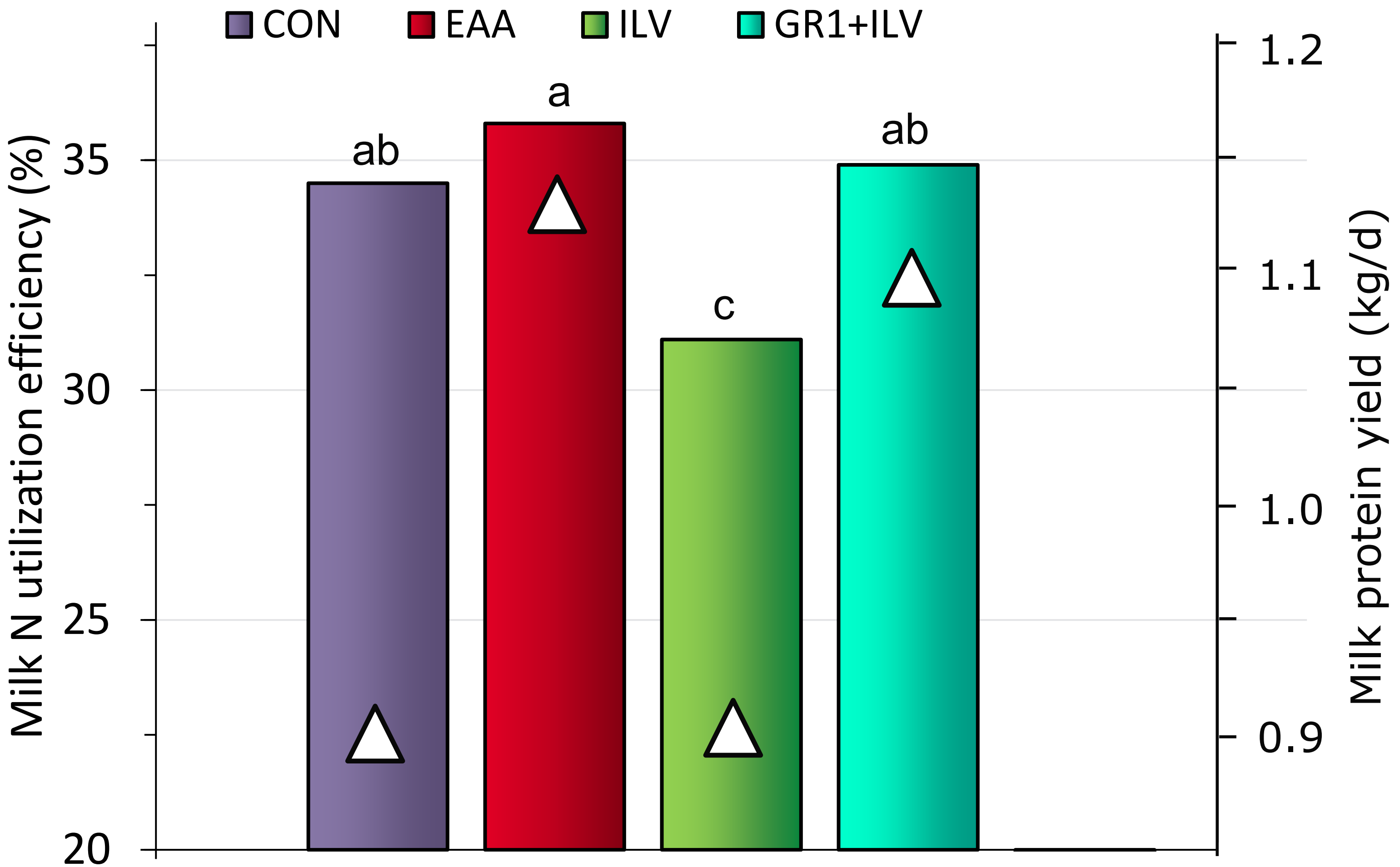

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ILV: Ile, Leu, Val

GR1+ILV: His, Ile, Leu, Met, Phe, Trp, Val

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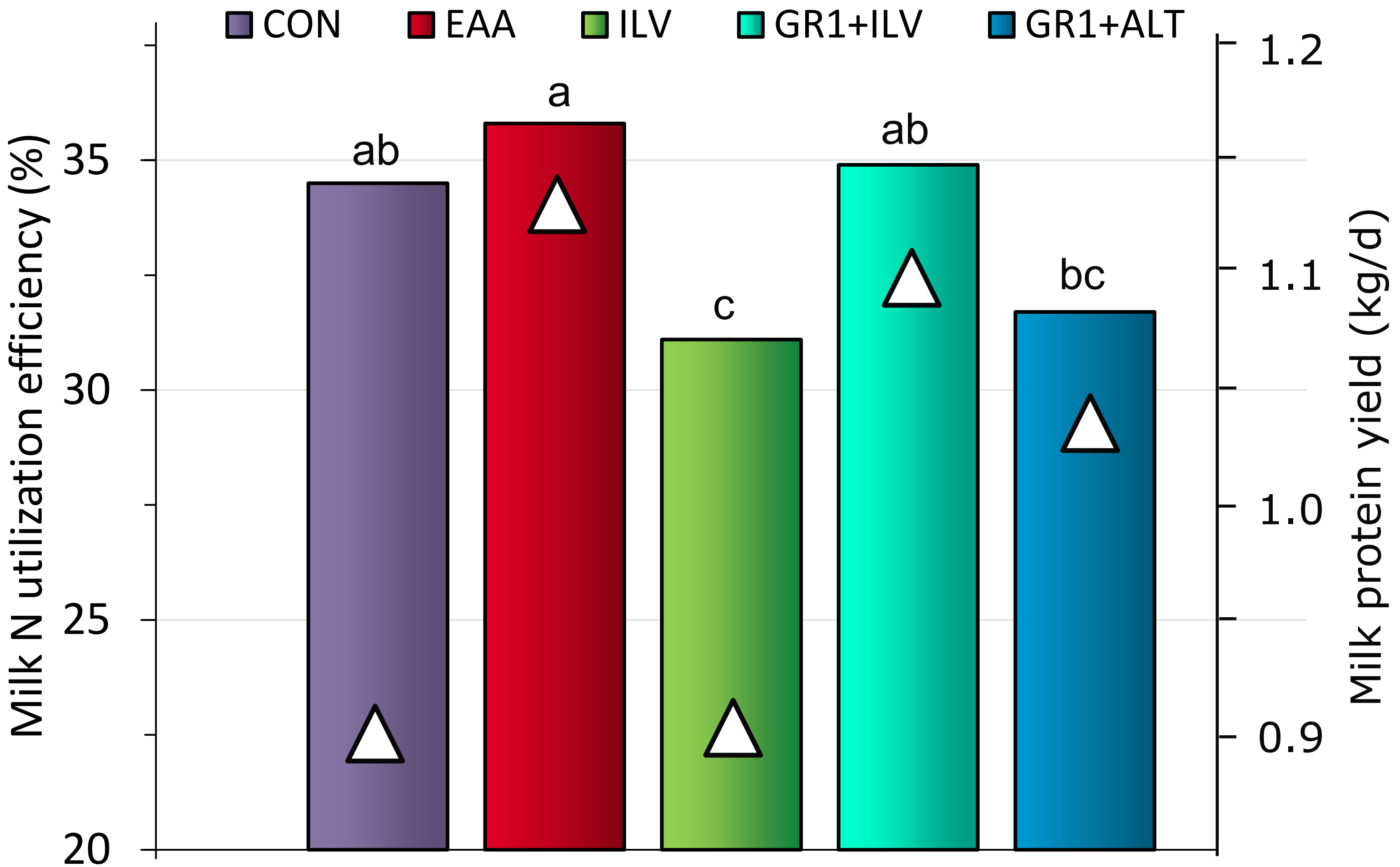

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- ILV: Ile, Leu, Val
- GR1+ILV: His, Ile, Leu, Met, Phe, Trp, Val
- GR1+ALT: Arg, His, Lys, Met, Phe, Thr, Trp

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Conclusions on nitrogen (N) excretion

- N accounting system (inputs & outputs N) key to reducing N excretion
- Decreasing dietary protein level *per se* is not major goal
  - proper balance between dietary protein and level / type of energy at rumen / post absorptive level
- Efficiency of post-absorptive utilization amino acids is not fixed
  - focus quantitatively and qualitatively: as <u>groups</u>, not individual

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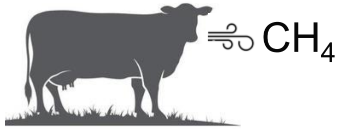
Reducing environmental impact dairy farming

Nutritional approaches to

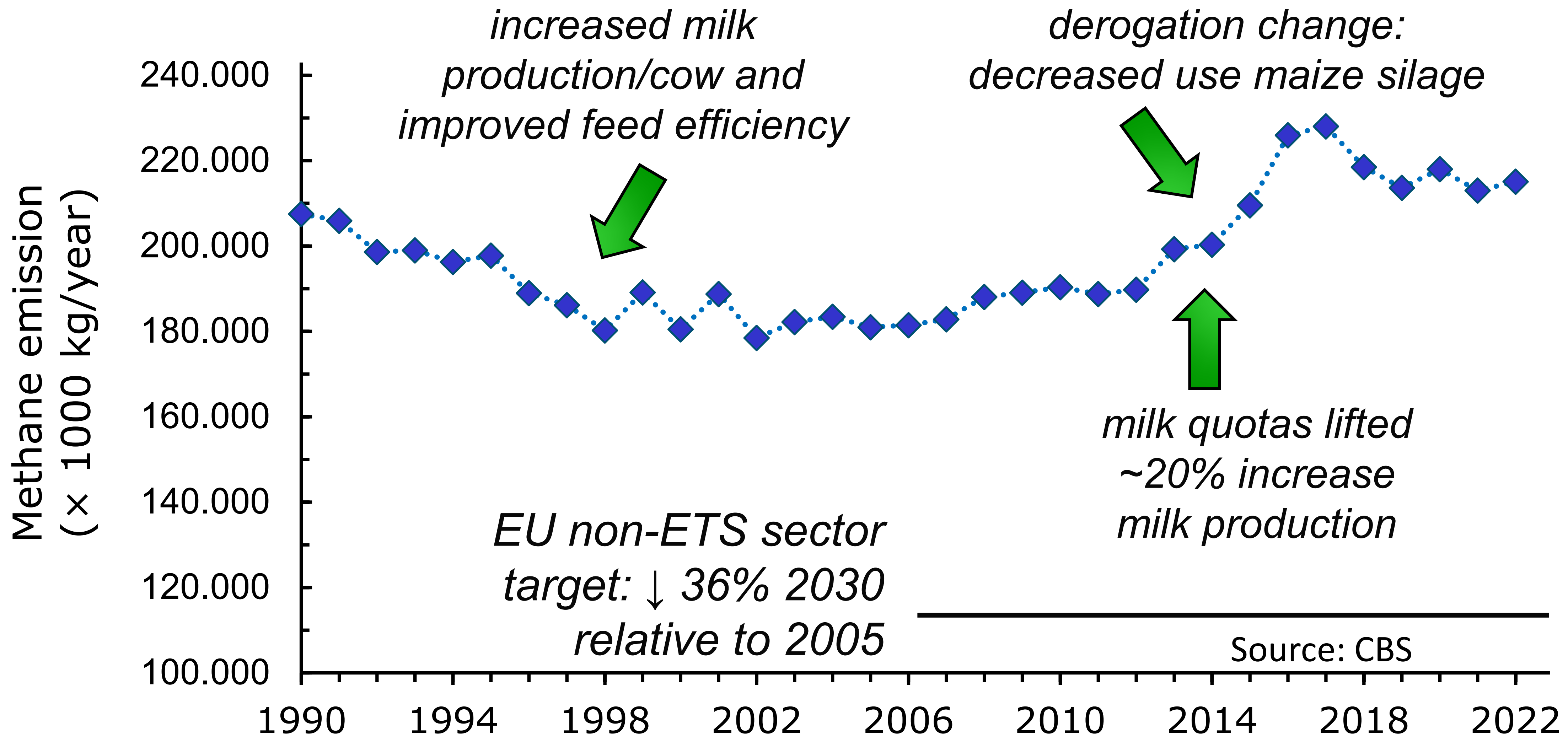
- phosphorus excretion 

- nitrogen excretion 

- enteric methane emission 

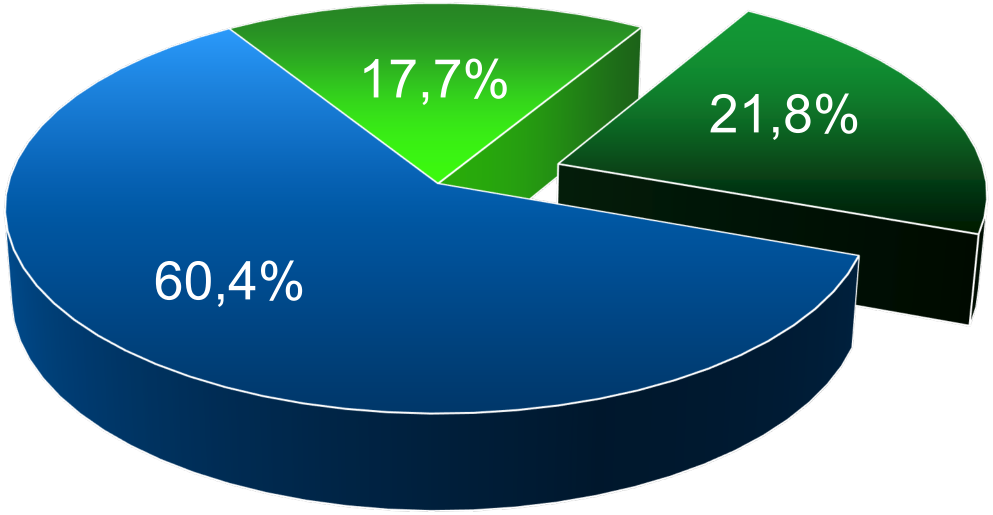
with focus on Dutch dairy sector as a case

Enteric methane emission dairy cattle



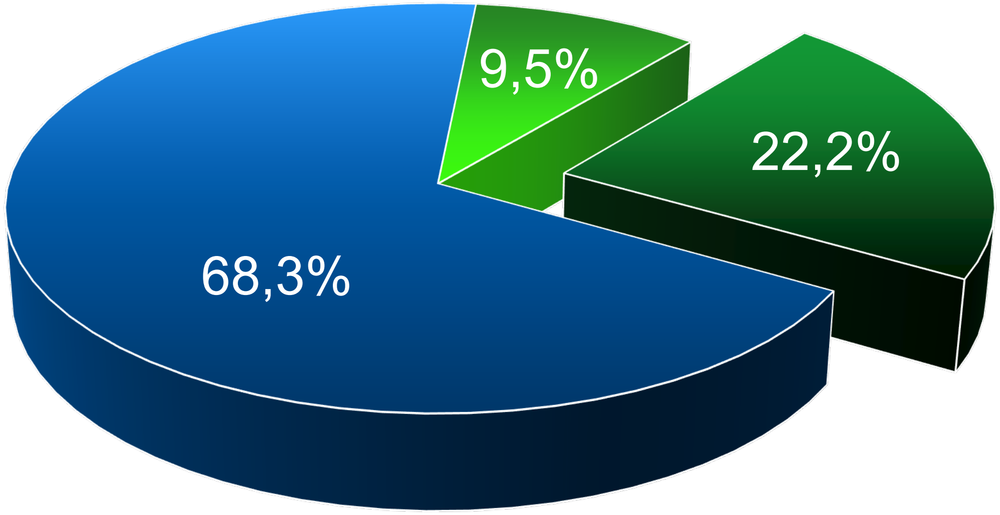
Many methane mitigation strategies not effective

Methane yield (g/kg feed DM)
(n = 96)



strategies (% of total)
■ No effect ■ Effect < 10% ■ Effect > 10%

Methane intensity (g/kg FPC milk)
(n = 63)



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PNAS RESEARCH ARTICLE | SUSTAINABILITY SCIENCE OPEN ACCESS

Full adoption of the most effective strategies to mitigate methane emissions by ruminants can help meet the 1.5 °C target by 2030 but not 2050

Claudia Arndt[a,1], Alexander N. Hristov[b], William J. Price[c], Shelby C. McClelland[d], Amalia M. Pelaez[b,e], Sergio F. Cueva[b], Joonpyo Oh[b], Jan Dijkstra[e], André Bannink[e], Ali R. Bayat[f], Les A. Crompton[g], Maguy A. Eugène[h], Dolapo Enahoro[a], Ermias Kebreab[i], Michael Kreuzer[j], Mark McGee[k], Cécile Martin[h], Charles J. Newbold[l], Christopher K. Reynolds[g], Angela Schwarm[m], Kevin J. Shingfield[f,2], Jolien B. Veneman[n], David R. Yáñez-Ruiz[o], and Zhongtang Yu[p]

430 studies
meta-analysis
Arndt et al. (2022)

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Effective methane mitigation strategies

Product based reductions

1. Increasing feeding level
2. Decreasing grass maturity
3. Decreasing forage to concentrate ratio

↑ performance whilst ↓ methane intensity

Absolute reductions

4. CH_4 inhibitors (3NOP)
5. Tanniferous forages
6. Electron sinks (nitrate)
7. Oils and fats
8. Oilseeds

↓ methane emissions whilst not ↓ performance

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Edited by Akkihebbal Ravishankara, Colorado State University, Fort Collins, CO; received June 25, 2021; accepted February 8, 2022

Arndt et al. (2022)

Effective methane mitigation strategies

Product based reductions

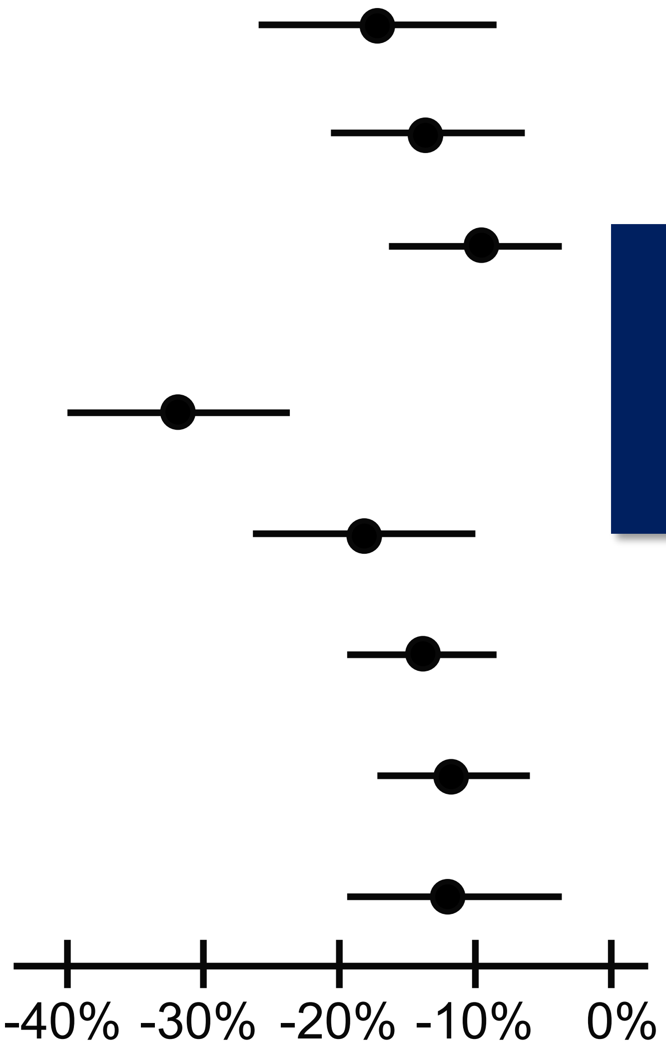
1. Increasing feeding level
2. Decreasing grass maturity
3. Decreasing forage to concentrate ratio

↓ methane intensity 12% (9 to 17%)

Absolute reductions

4. CH_4 inhibitors (3NOP)
5. Tanniferous forages
6. Electron sinks (nitrate)
7. Oils and fats
8. Oilseeds

↓ methane intensity 17% (12 to 32%)



Variation in response to be included in mitigation policies


PNAS RESEARCH ARTICLE | SUSTAINABILITY SCIENCE OPEN ACCESS

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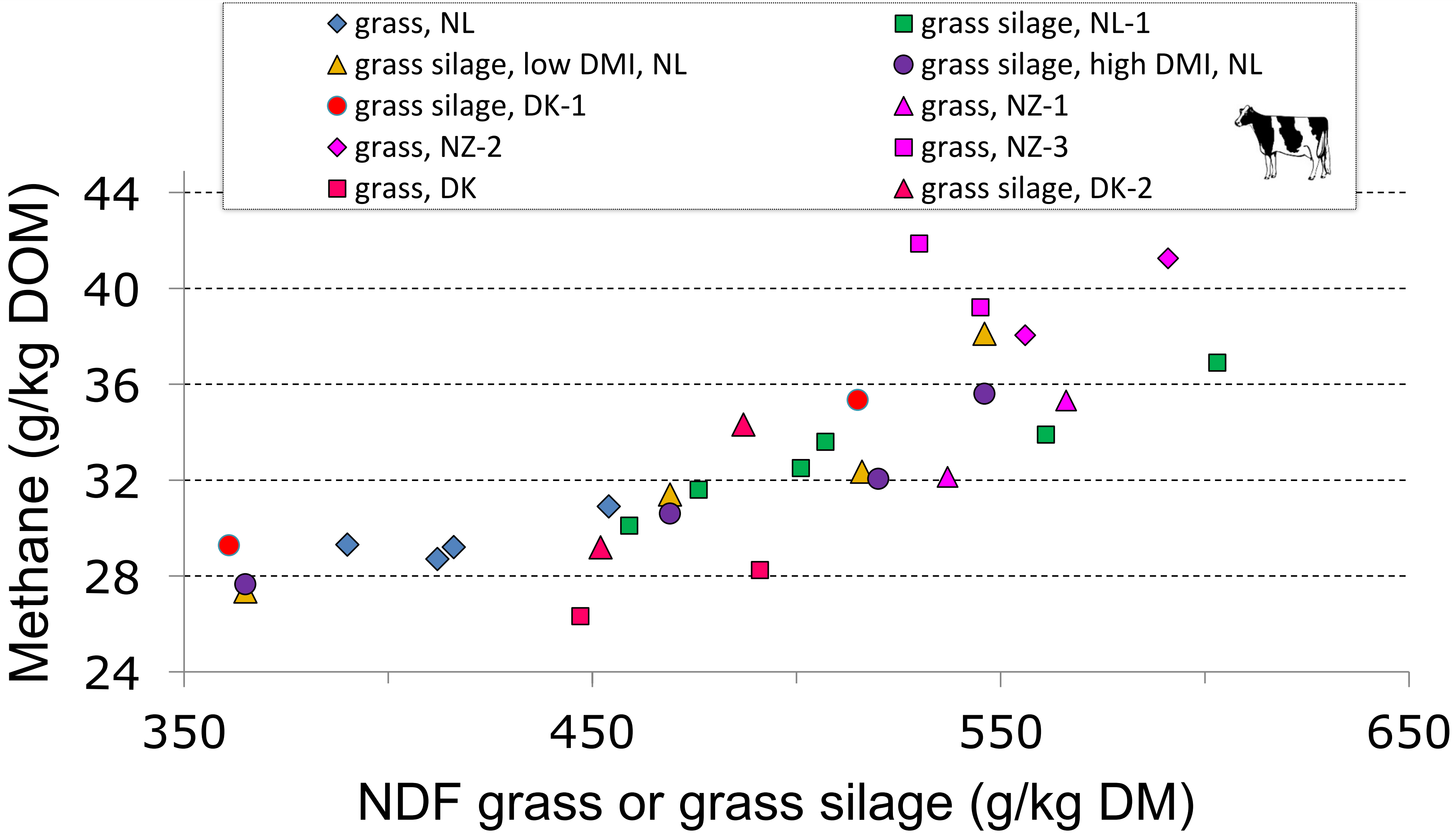
Arndt et al. (2022)

The is high quality forage



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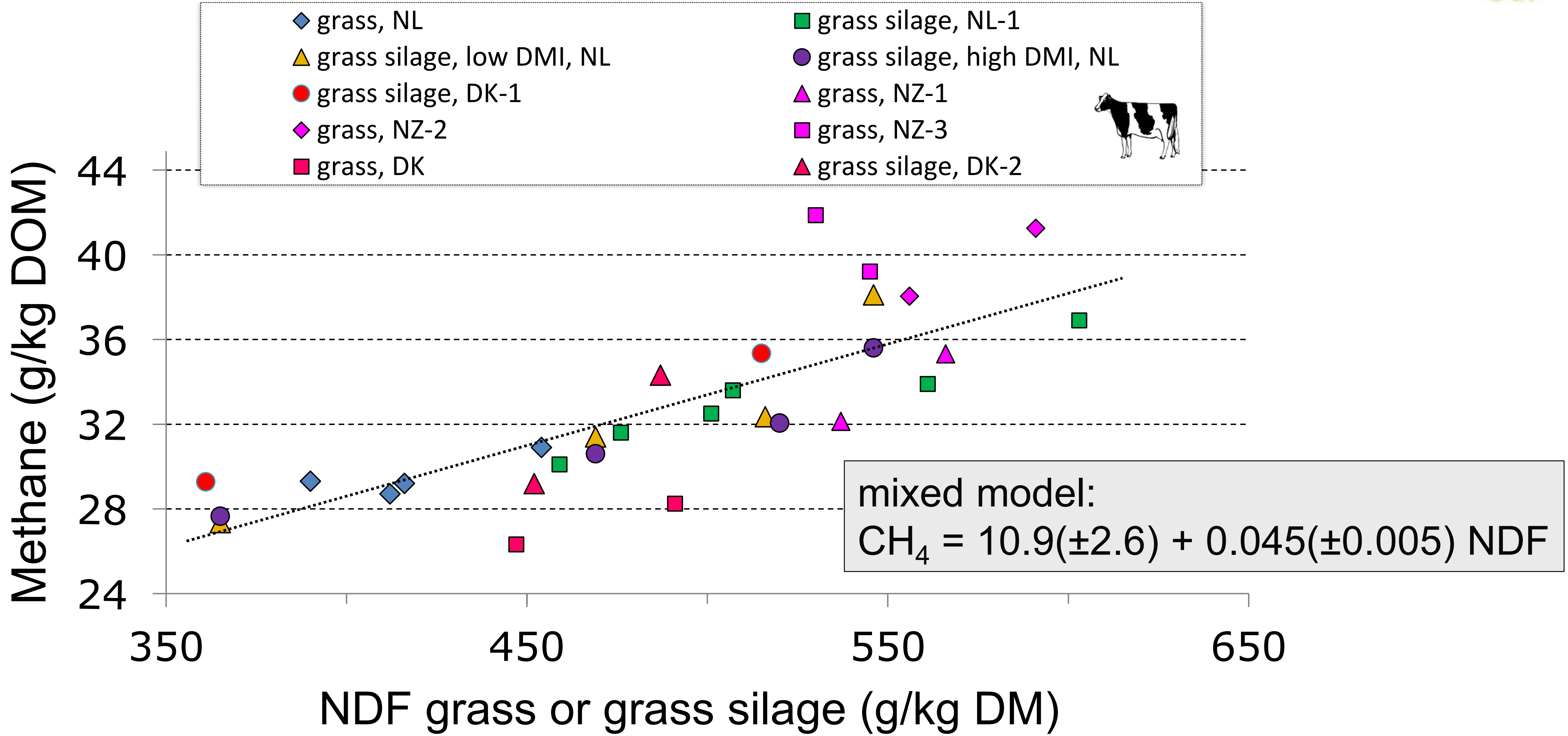
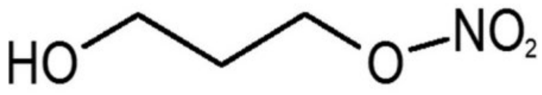


Meta-analysis CH_4 production: 3-NOP supplementation

	Mean	Effect	SE	*P*-value
Mixed effect model		Mean difference (% of control)		
Overall effect size		−32.4	1.3	<0.01

Heterogeneity > 90%



3-Nitrooxypropanol

Kebreab et al. (2023)

J. Dairy Sci. 106:927–936
https://doi.org/10.3168/jds.2022-22211

A meta-analysis of effects of 3-nitrooxypropanol on methane production, yield, and intensity in dairy cattle

Ermias Kebreab,[1]* André Bannink,[2] Eleanor May Pressman,[1] Nicola Walker,[3] Alexios Karagiannis,[3] Sanne van Gastelen,[2] and Jan Dijkstra[4]
[1]Department of Animal Science, University of California, Davis 95616
[2]Wageningen Livestock Research, Wageningen University & Research, PO Box 338, 6700 AH, Wageningen, the Netherlands
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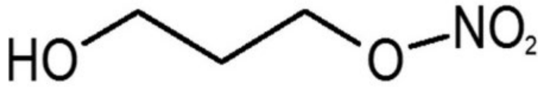
Meta-analysis CH_4 production: 3-NOP supplementation

	Mean	Effect	SE	*P*-value
Mixed effect model		Mean difference (% of control)		
Overall effect size		−32.4	1.3	<0.01
		Change in mean difference*		
3-NOP (mg/kg DM)	71	−0.28	0.07	<0.01
NDF (g/kg DM)	329	0.[illegible]92	0.034	0.02
Crude fat (g/kg DM)	42[illegible]	[illegible].31	0.13	0.04



3-Nitrooxypropanol

*centered on their means

dose-dependent

106:927–936
/10.3168/jds.2022-22211

of effects of 3-nitrooxypropanol on methane production, yield, and intensity in dairy cattle

Ermias Kebreab,[1]* André Bannink,[2] Eleanor May Pressman,[1] Nicola Walker,[3] Alexios Karagiannis,[3] Sanne van Gastelen,[2] and Jan Dijkstra[4]
[1]Department of Animal Science, University of California, Davis 95616
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Kebreab et al. (2023)

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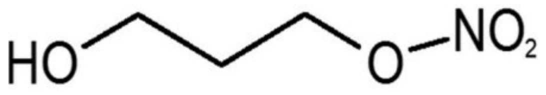

3-Nitrooxypropanol

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lower efficacy when fibre content increases

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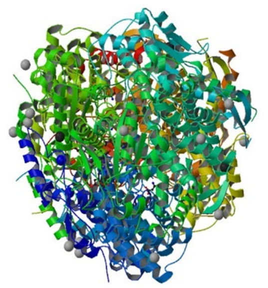

Kebreab et al. (2023)

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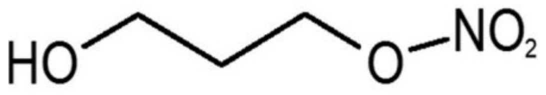

3-Nitrooxypropanol

*centered on their means

lower efficacy when fat content increases

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Kebreab et al. (2023)

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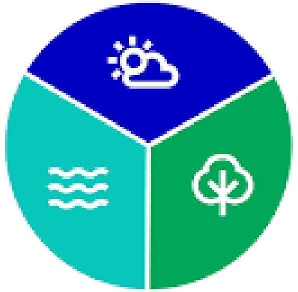
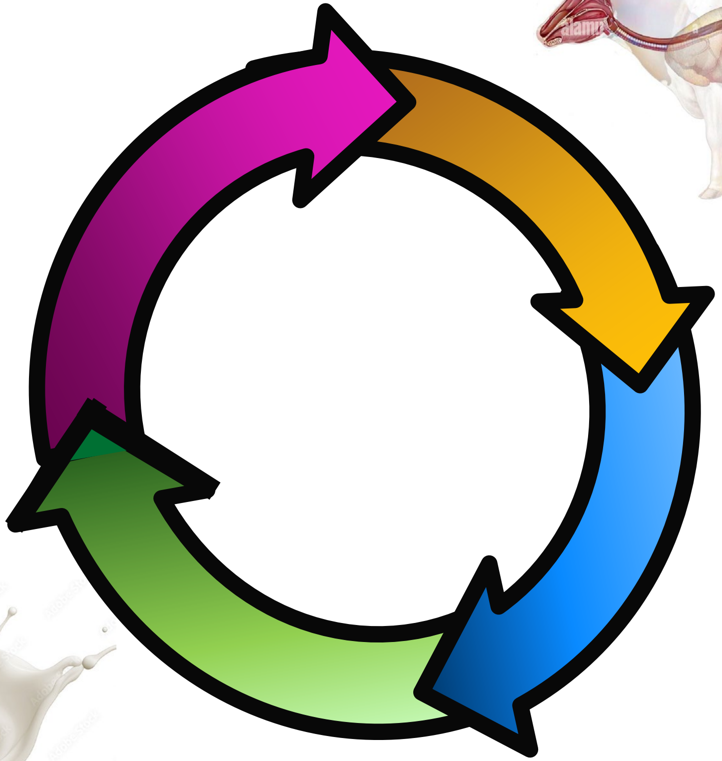
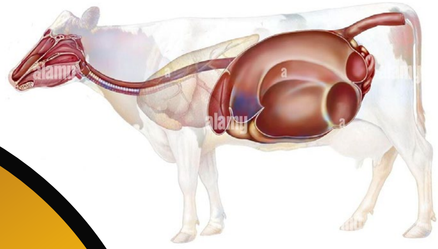
Conclusions on methane emission

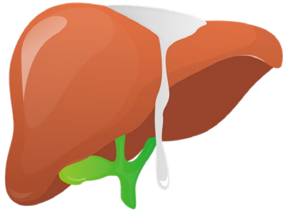
- No / limited effectiveness of many mitigation strategies
- Several strategies high potential / readily applied
  - forage type/quality; anti-methanogenic feed additives
- Implementation requires (government) policies / incentives
- Quantification of variation in efficacy is vital
  - based on solid scientific evidence

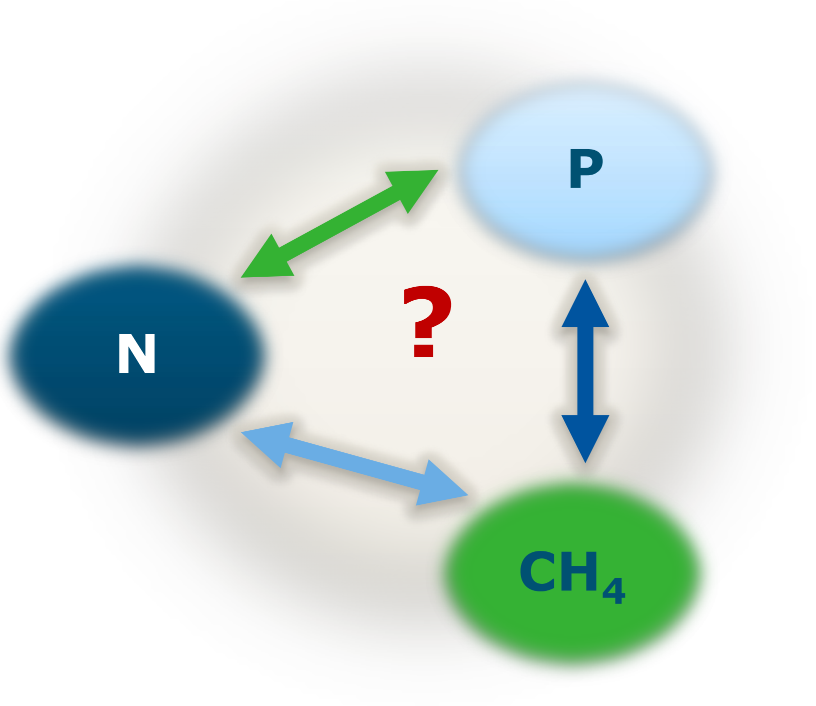
Synergies and trade-offs



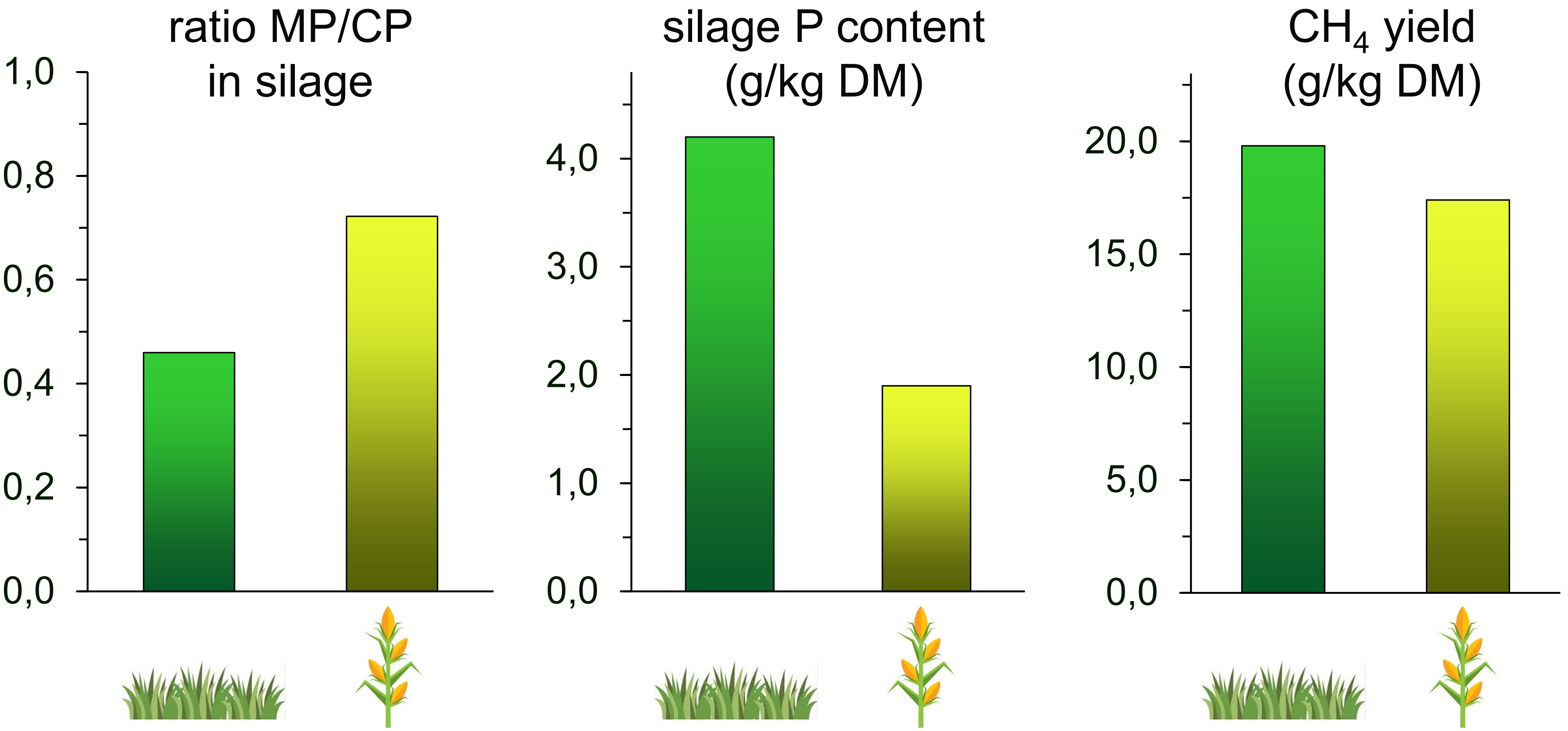








Example: grass silage *vs.* maize silage



CVB (2023) / Vellinga et al. (2013)

Example: multi-criteria evaluation

	Intercept	Slope		
		DMI (kg/d)	ADF (% DM)	CP (% DM)
CH_4 emission (g/d)	−7.5	14.0	5.20	−2.67
dVS excretion (g/d)	−1020	383	53.3	−65.5
Total N excretion (g/d)	−246	14.8	1.50	15.9

dVS: digestible volatile solids

ELSEVIER
Animal
Volume 12, Supplement 2, 2018, Pages s310-s320

Multi-criteria evaluation of dairy cattle feed resources and animal characteristics for nutritive and environmental impacts

H.J. van Lingen [1], J.G. Fadel [1], A. Bannink [2], J. Dijkstra [3], J.M. Tricarico [4], D. Pacheco [5], D.P. Casper [6], E. Kebreab [1]

Van Lingen et al. (2018)

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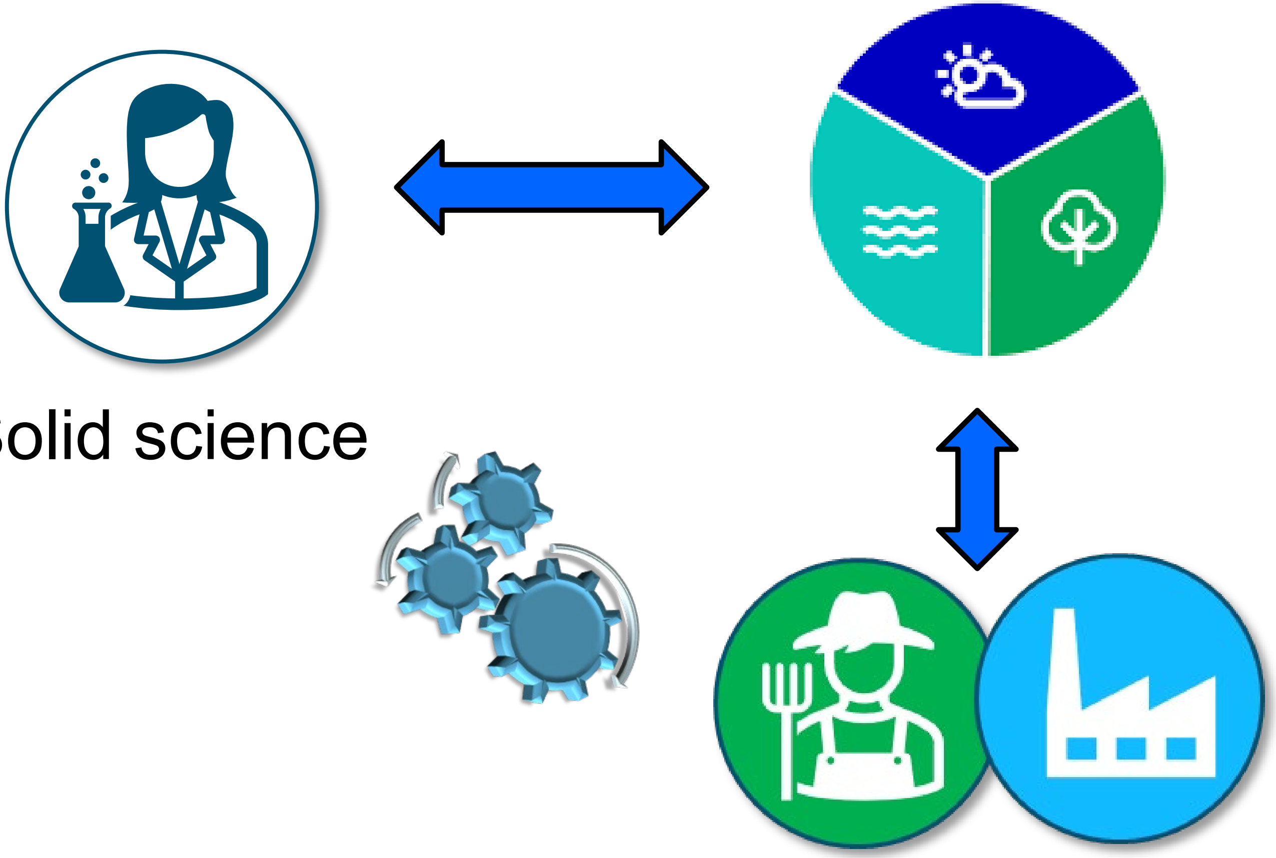
Take home message

Reducing environmental impact



Trade-offs

Quantify mitigation

License to produce

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