Livestock production and feeding to reduce GHG emission from livestock

André Bannink

Wageningen Livestock Research

acknowledging colleagues

Wageningen Livestock Research, Animal Nutrition

Wageningen University & Research, Animal Nutrition

Ministerie van Landbouw, Natuur en Voedselkwaliteit

Feed4 Foodure

vdn

ZuivelNL

KETENORGANISATIE VAN DE ZUIVELSECTOR

FACCE ERA-GAS

MONITORING & MITIGATION OF GREENHOUSE GASES FROM AGRI- AND SILVI-CULTURE

CEDERS 2017-2021

LIVESTOCK RESEARCH WAGENINGEN UR

Feeding measures to mitigate

Relevant questions :

- How to attribute GHG emission to a dietary component ?
- How to study differences between (quality of) components ?
- How do GHG emissions vary with feeding conditions ?

For some realism :

- Quantifying GHG accurately
- Distinguishing types of roughages and by-products / concentrates
- Evaluate at the dietary level (feed intake, diet type, digestibility effects)
- Integral assessment

  on-farm: enteric, excreta / manure, soil

  off-farm: production related GHG emissions,
  transport, soil C, deforestation, ...

Contents

1. Dietary measures

2. Feed additives (& fat supplement)

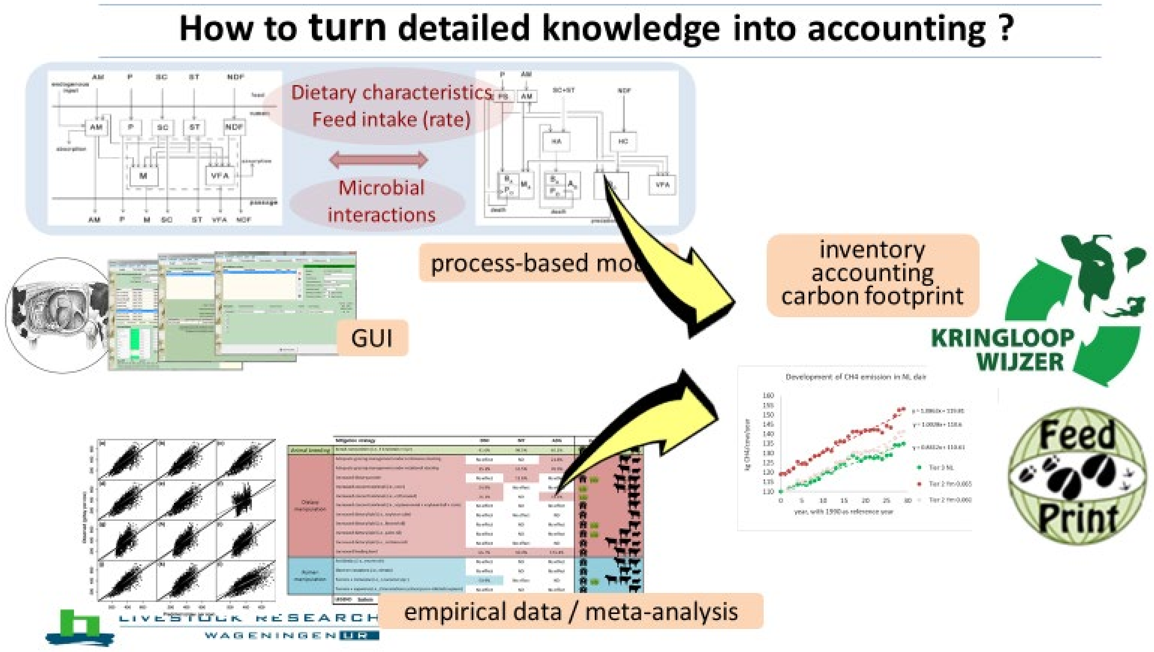
<u>Emissions today</u>

enteric CH_4

from excreted N

from excreted OM (‘*volatile solids*’)

3. How to account for these ?



1. Dietary measures to reduce enteric CH_4 per unit of feed

- Options
  - Harvesting grass silage and fresh herbage (grazing)
    - Cutting/grazing at younger stage, lower CH_4 yield (g CH_4/kg DM)
  - Whole plant silages (maize, wheat, ...)
    - Starch-rich, lower CH_4 yield than grass (*-10 to -15%*)
    - Protein-rich / fat-rich, lower CH_4 yield
  - Concentrates & byproducts
    - Same
- Early harvested grass, concentrates/by-products ferment well & much CH_4,
  - But also greater DM intake & faster fermentation → lower CH_4 yield
- Larger rumen 'bypass' fraction (e.g. starch, protein, fat), lower CH_4 yield
  - E.g. later cutting of maize, greater bypass starch fraction, less fermented OM
- And not to forget ..... physical aspects affecting intake & fermentation rate

LIVESTOCK RESEARCH
WAGENINGEN UR

Effect of grass silage quality on CH_4

Warner et al., 2017

	Stage of maturity at cutting					Maturity
	leafy	boot	early hdng	late hdng		*P*-value
OM dig (%)	77.7	78.2	74.3	68.5		<0.01
NDF dig (%)	76.4	79.4	69.8	61.0		<0.01
CH_4 (% GE)	5.7	6.5	6.5	6.8	+19%	<0.01
CH_4 (g/kg DMI)	**19.5**	**22.0**	**22.0**	**23.6**	**+21%**	<0.01
CH_4 (g/kg digOM)	**27.5**	**30.9**	**32.2**	**36.8**	**+34%**	<0.01
CH_4 (g/kg milk)	10.7	12.8	13.5	13.8	+29%	<0.01

70% grass silage : 30% concentrates
respiration chambers

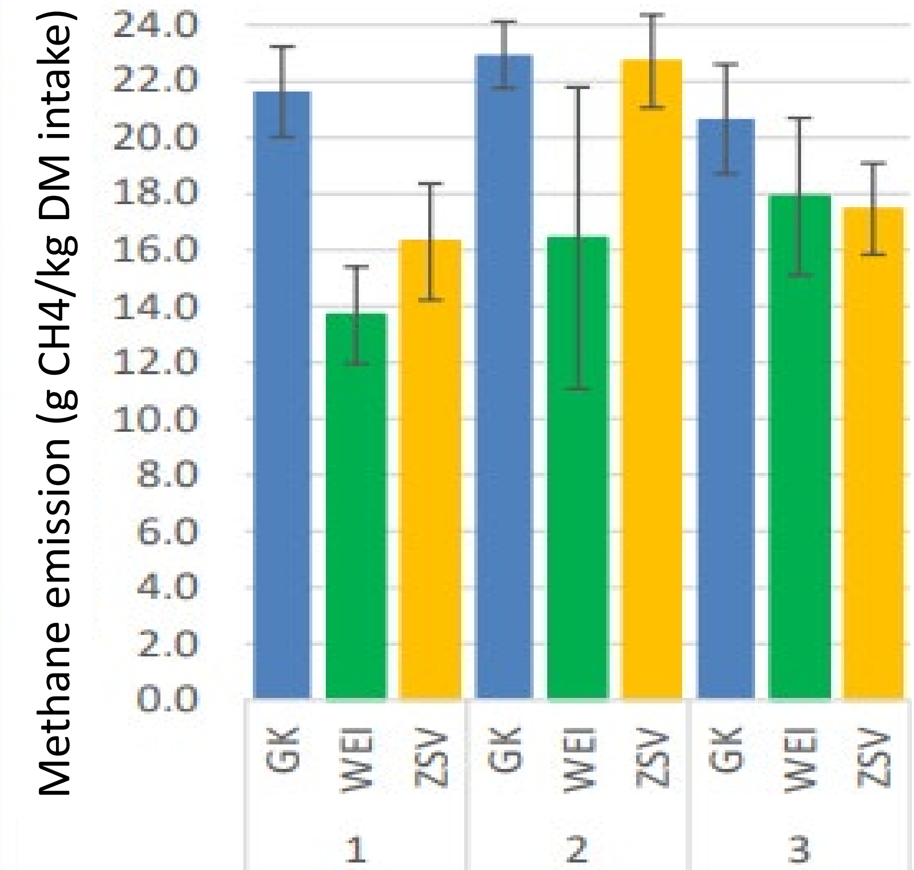
LIVESTOCK RESEARCH
WAGENINGEN UR

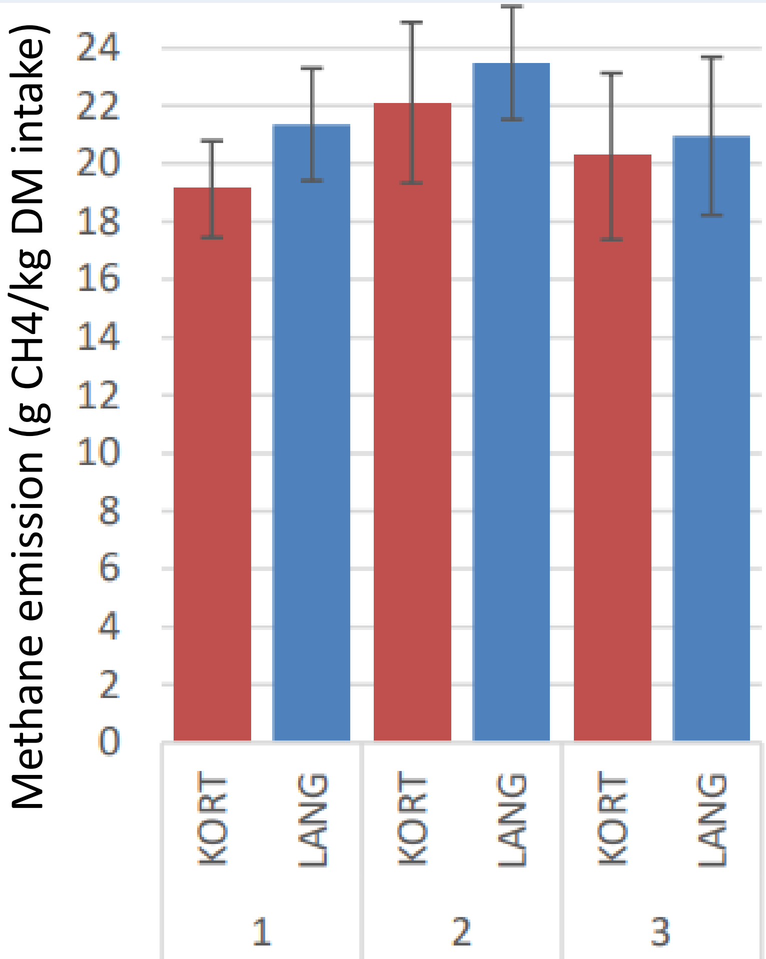
Comparing grass products on CH_4

Klootwijk et al., 2021

GK grass silage
WEI fresh herbage / grazing
ZSV fresh herbage / summer feeding

KORT short grass height
LANG long grass height





GreenFeed during grazing and in stall
~ 80% grass product : 20% concentrates

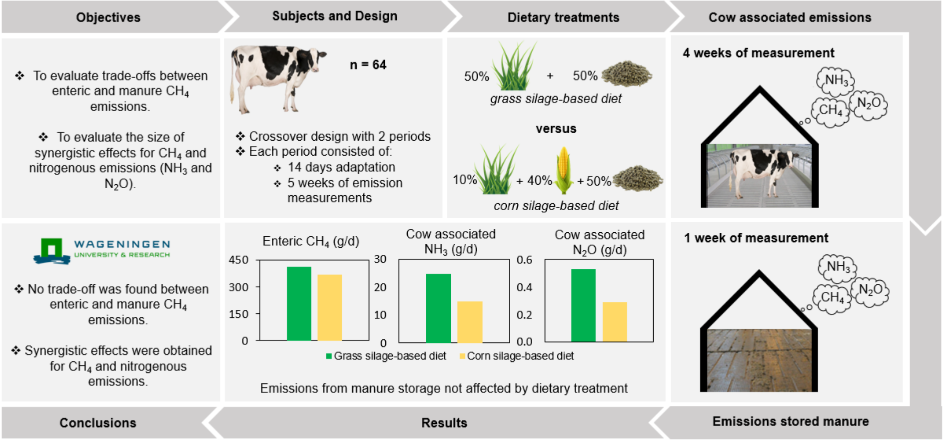
GreenFeed during grazing and in stall
40% fresh grass : 40% grass silage : 20% concentrates

Exchanging types of roughages, e.g. grass vs. maize

- Maize thought to produce considerably less CH_4 than grass
- According to meta-analysis : effective mitigation options

- Also under practical conditions ?

  >>> see presentation by *Sanne van Gastelen* this afternoon



LIVESTOCK RESEARCH
WAGENINGEN UR

Trade-offs / synergies / limitations dietary measures

- Grass, earlier stage of maturity
  - Trade-off: potentially higher N content & excretion
  - Synergy: less manure OM and manure CH_4
  - Trade-off: lower yield grass sward
  - Limitation: difficult to unify with biodiversity & low N fertilization
- More maize / starch-rich plant silage
  - Limitation: not unifiable with EU-derogation
  - Limitation: not unifiable with more grazing ?
  - Trade-off: decline of soil C and nitrate leaching
- More dietary fat, starch, protein
  - Trade-off: relying on imports and emissions elsewhere
  - Limitation: less unifiable with circularity aim ?
  - Synergy: higher DMI & production level
  - Trade-off: decreased digestibility, increased N & OM excretion and emissions

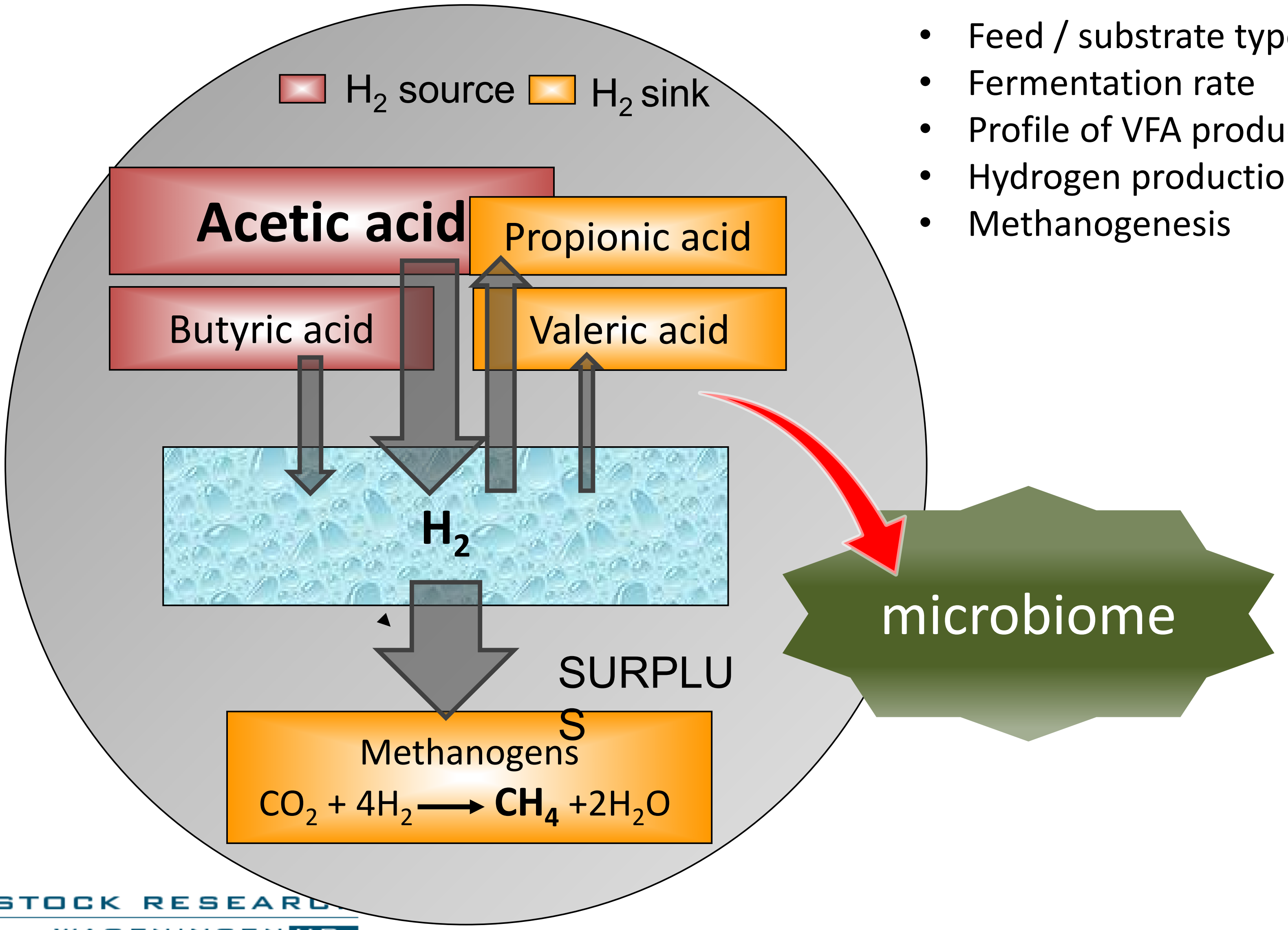
2. Additives / fat supplements to reduce enteric CH_4

- Options dietary supplements & feed additives
  - 3 categories of additives to reduce CH_4
    - Scavenging hydrogen (nitrate)
    - Methanogen inhibitors (bromoform, 3-nitrooxypropanol)
    - Plant extracts / herbs (essential oils, tannins, etc.)
  - 1 category of (unprotected) fat supplement
    - Crude fat (long chain fatty acids, triglycerides)

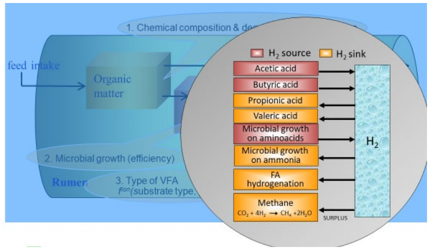
Feed additives

--- Hydrogen dynamics rumen = key ? ---

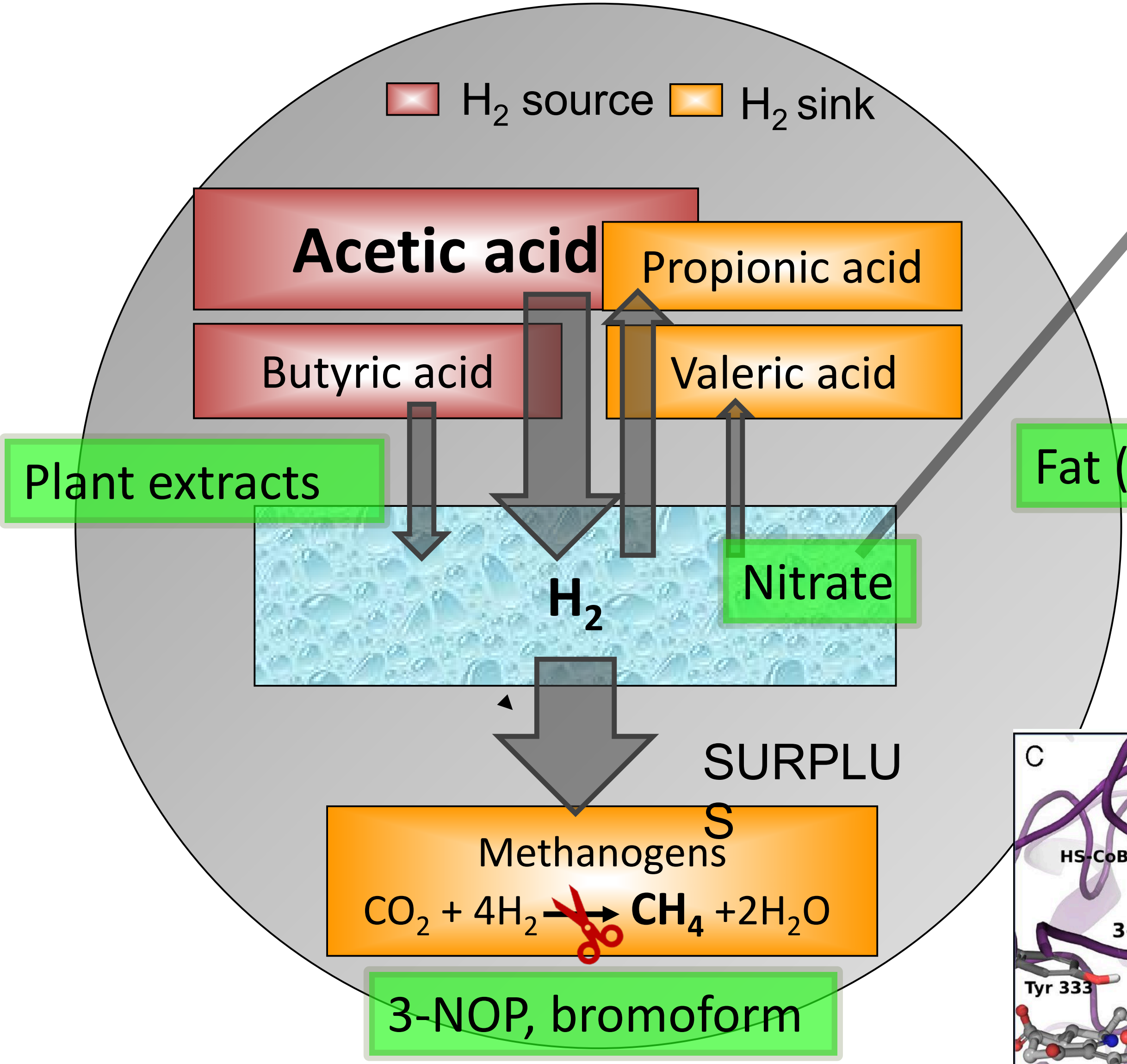
Van Lingen et al., 2019

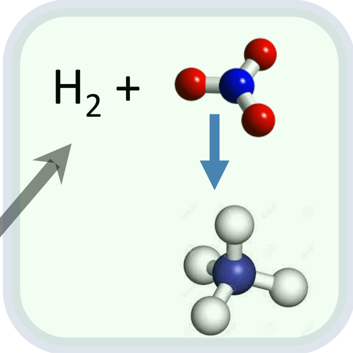


- Feed / substrate type
- Fermentation rate
- Profile of VFA produced
- Hydrogen production / pressure
- Methanogenesis



Feed additives / supplements (4 mode-of-actions)





Fat (inert, no H_2)

Inhibition of **methanogen-unique**
Methyl-**C**oM-**R**eductase activity

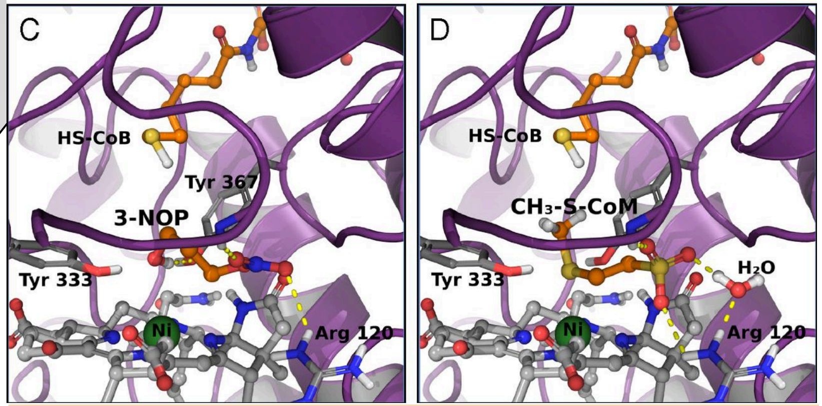
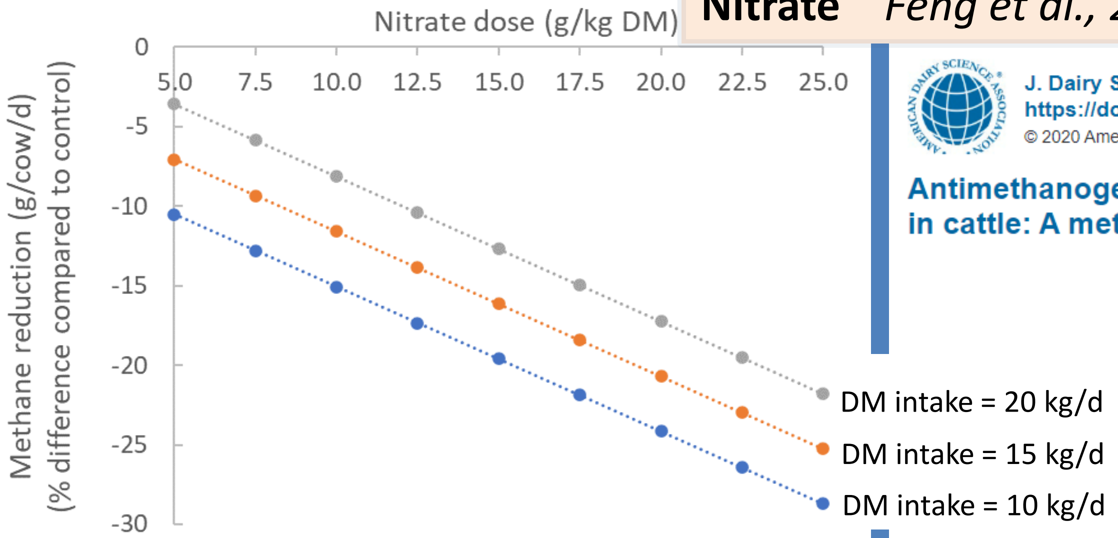


Figure derived from Duin et al. (2016)

Meta-analysis of 2 example additives (dairy)

Nitrate *Feng et al., 2020*

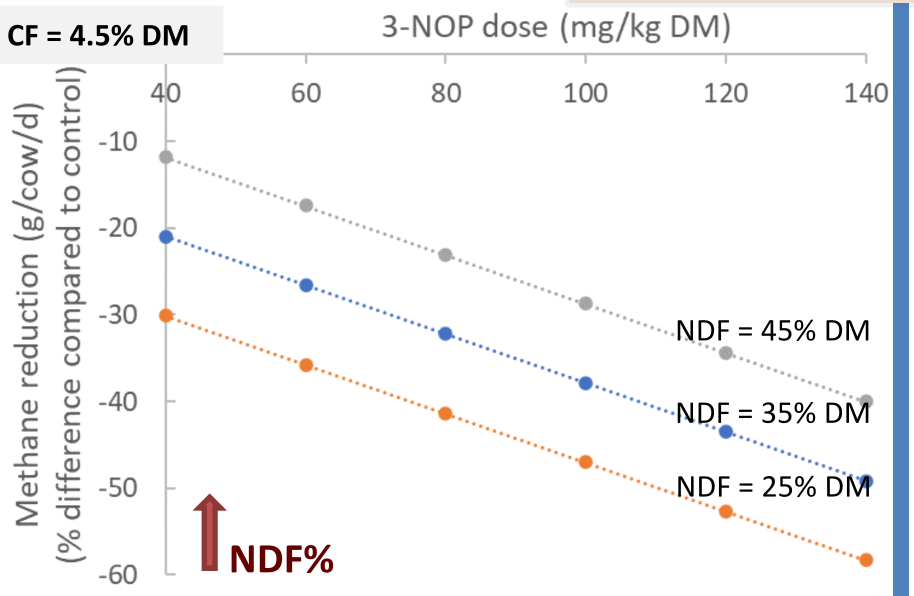


J. Dairy Sci. 103:11375–11385
https://doi.org/10.3168/jds.2020-18541

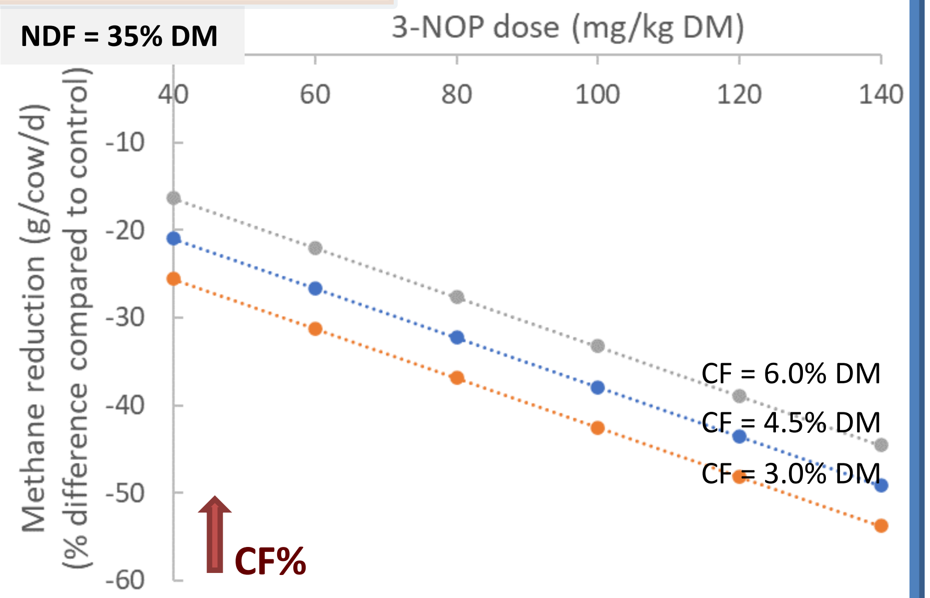
Antimethanogenic effects of nitrate supplementation in cattle: A meta-analysis

3-NOP *Kebreab et al., submitted*

CF = 4.5% DM



NDF = 35% DM



Trade-offs / limitations feed additives

<u>Estimated effect</u>

- Hydrogen sink (nitrate) *effect -10%*
  - Extra N intake and NH_3 (can replace feed urea)
  - Up to 1% nitrate in DM no decline in DM intake
- Fats/fatty acids *effect -10%*
  - C footprint / origin fat (e.g. palm oil)
  - Up to 7% crude fat in DM, decline / reduction DM intake & digestibility marginal
- Methanogen inhibitors *effect -30%*
  - 3-NOP, no clear trade-offs; rumen degradation products naturally occur in silage
  - Bromoform, highly effective but questions on bromoform
- Plant extracts *effect -0 / -10%*
  - Considered ‘natural’, affecting the microbiome, but rumen adaptation likely
  - Effects on DM intake and digestibility variable

3. Accounting for mitigating feeding measures

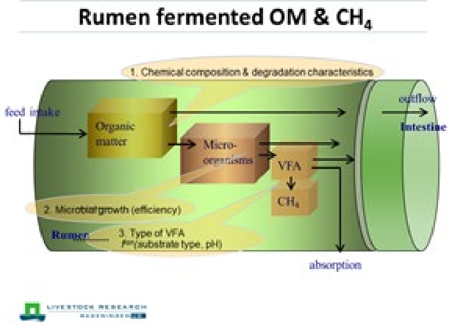
- Empirical data ~ regression equations / meta-analysis
  - Rather generic approach & use of general factors
  - Interaction between factors not included

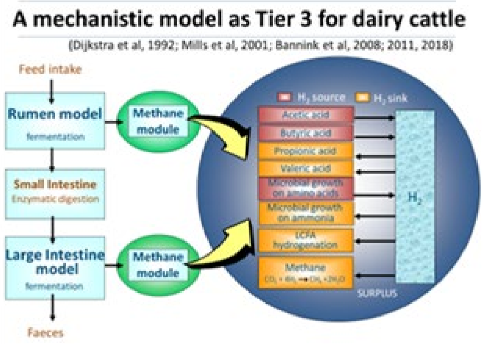
		Mitigation strategy	Potential emissions reduction				Relevant production system
Absolute & Product-Based Reductions	1	CH_4 inhibitors	Daily CH_4 -35% CH_4Y -34%		CH_4I_G No Data CH_4I_M -32%		
	2	Oils & fats	Daily CH_4 -19% CH_4Y -15%		CH_4I_G -22% CH_4I_M -12%		
	3	Oilseeds	Daily CH_4 -20% CH_4Y -14%		CH_4I_G No Effect CH_4I_M -12%		Lactating only
	4	Electron sinks	Daily CH_4 -17% CH_4Y -15%		CH_4I_G -12% CH_4I_M -13%		
	5	Tanniferous forages	Daily CH_4 -12% CH_4Y -10%		CH_4I_G No Data CH_4I_M -18%		
Product-Based Reductions	6	Decreasing dietary forage-to-concentrate ratio	CH_4I_G -9% CH_4I_M -9%				
	7	Increasing feeding level	CH_4I_G No Data CH_4I_M -17%				
	8	Decreasing grass maturity	CH_4I_G No Data CH_4I_M -13%				Lactating only

LEGEND
SYSTEM: CONFINED, GRAZING
ANIMAL SPECIES: CATTLE, SHEEP, SMALL RUMINANTS, OTHER RUMINANTS

		Mitigation strategy	Relative Treatment Effect on Animal Performance: Intake	Digestibility	Gain	Milk
Absolute & Product-Based Reductions	1	CH_4 inhibitors	No Effect	No Effect	No Effect	No Effect
	2	Oils & fats	-6%	-4%	No Effect	No Effect
	3	Oilseeds	No Effect	-8%	-13%	No Effect
	4	Electron sinks	-2%	No Effect	No Effect	+3%
	5	Tanniferous forages	No Effect	-7%	No Effect	No Effect
Product-Based Reductions	6	Decreasing dietary forage-to-concentrate ratio	+9%	No Effect	+21%	+17%
	7	Increasing feeding level	+58%	-7%	+162%	+17%
	8	Decreasing grass maturity	No Effect	+15%	No Data	+9%

- Modelling mode-of-action & mechanism
  - Allows to account for more details
  - Representing (variation in) the fermentation process
  - Interaction between factors included





Empirical approach, global meta-analysis

- Meta-analysis of feeding measures to mitigate CH_4
- Using a global dataset of treatment means data

Arndt et al., 2022, PNAS, in press

Strategies to Mitigate Enteric Methane Emissions by Ruminants – A Way to Approach the 2.0°C Target

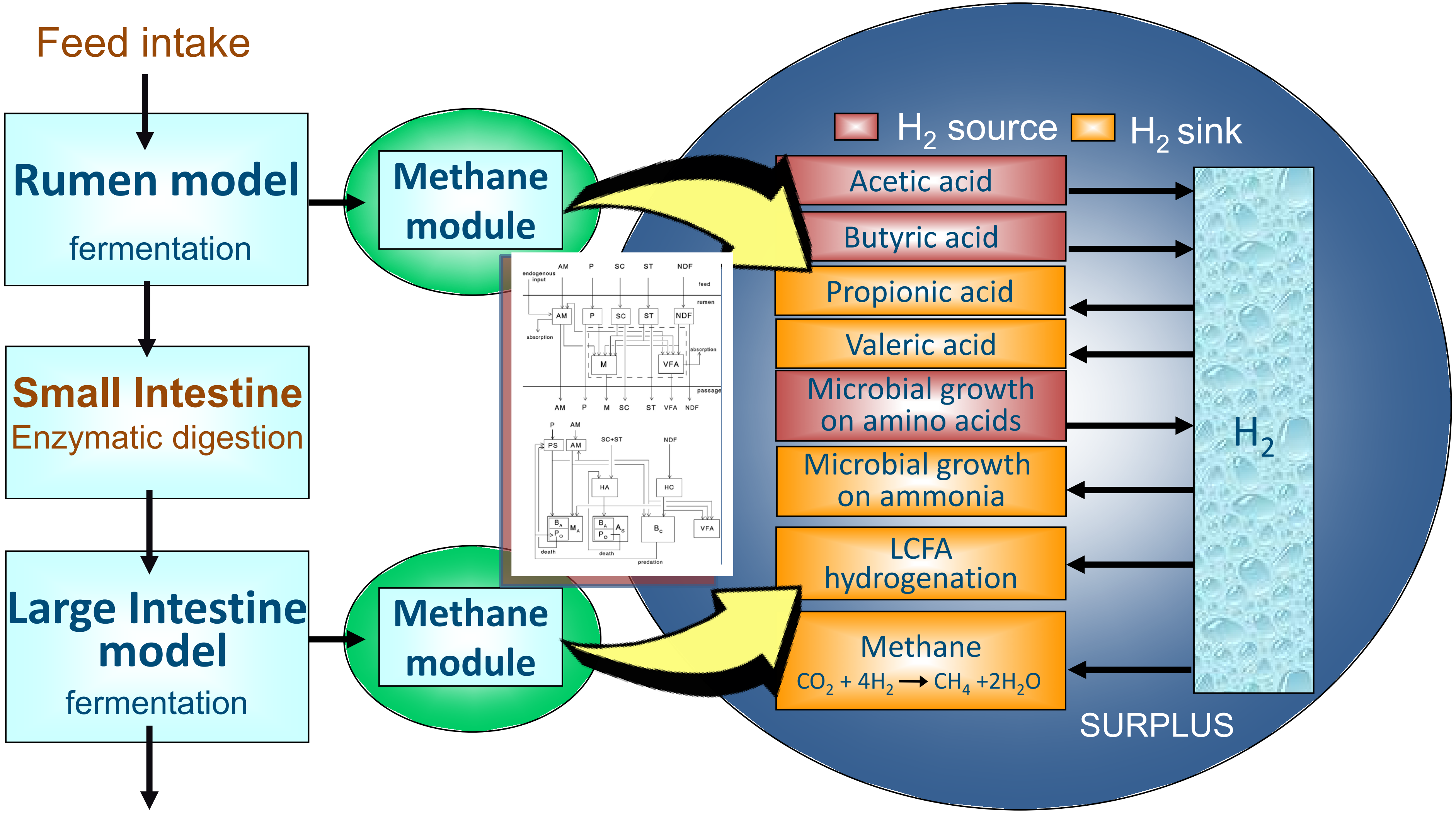
Claudia Arndt[a*], Alexander N. Hristov[b], William J. Price[c], Shelby C. McClelland[d], Amalia M. Pelaez[e], Sergio F. Cueva[b], Joonpyo Oh[b], André Bannink[e], Ali R. Bayat[f], Les A. Crompton[g], Jan Dijkstra[e], Maguy A. Eugène[h], Ermias Kebreab[i], Michael Kreuzer[j], Mark McGee[k], Cécile Martin[h],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

LIVESTOCK RESEARCH
WAGENINGEN UR

Applicability empirical approaches

- Can be accurate, but dependant on dataset used / conditions met
- Equations
  - General explanatory factors & prediction average
  - May not reflect conditions of interest
  - No specific measures or details (e.g. digestive aspects, fermentable OM)
  - Boundaries for application
- Mechanistic / process-based approaches needed to
  - Predict (variation in) efficacy of measures
  - Perform condition-specific evaluations
  - Derive values for feed ingredients and diet types

A process-based approach (Dutch Tier 3)

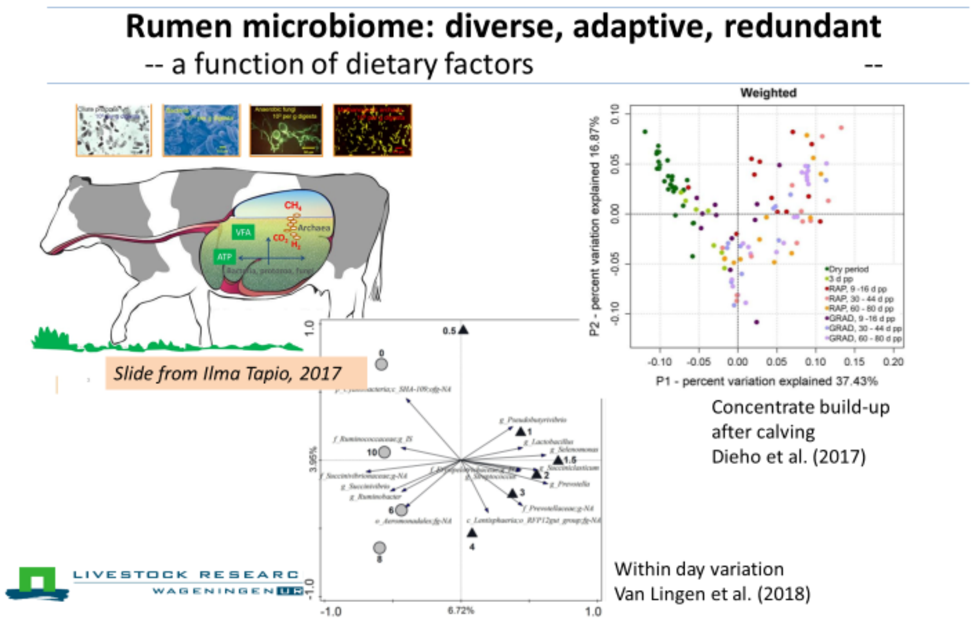


Dijkstra et al., 1992; Mills et al., 2001; Bannink et al., 2011, 2018

Why process-based relevant for CH_4 ?

- Microbial processes in soils & stored manure, conditions and microbiota determine N_2O, CH_4 and CO_2 emissions

- In analogy, same expected for feedstuffs entering the rumen ?
- The cow rumen is a much better host-regulated environment
  - continuous inflow / outflow
  - chewed / chopped / fine-particulate feed
  - adaptive capacity absorbing rumen wall
  - relatively constant temperature
  - strictly anaerobic
  - acidity, osmotic value, moisture content
  - an adaptive/ redundant microbiome
- Still, dynamics in rumen are strong due to diet & feeding behaviour !



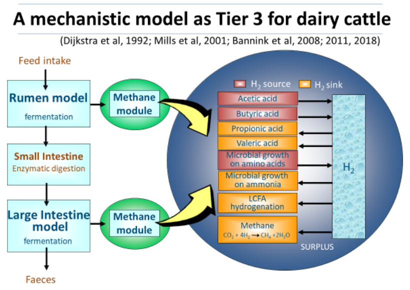
LIVESTOCK RESEARCH
WAGENINGEN UR

How to derive CH_4 for feeds(tuffs) ?

- Variation in diet gives variation in rumen conditions & microbiome
- Variation in rumen conditions (e.g. passage, acidity, pH, DM intake, type of substrate substrate, etc.) gives variation in microbial activity
- Hence, also variation to be expected in CH_4 yield
- Hence, a feedstuff does not have a single 'CH_4 value' but a rumen-condition dependant CH_4 'value'
- How to quantify this, to be used in linear programming and when formulating low-CH_4 dairy rations ?

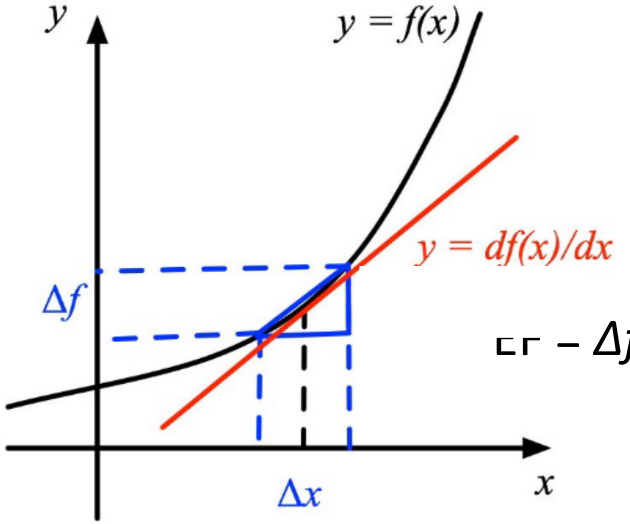
A process-based model to derive CH_4 for feedstuffs
-- following a 'derivative' approach --

- A **CH_4 emission Factor (EF)** in g CH_4/kg DM
- A process-based model to account for rumen conditions



- Calculate an EF by 5% feedstuff inclusion in a given diet
- Assume the change in CH_4 (ΔCH_4) due to inclusion
- Derive EF feedstuffs DM from ΔCH_4

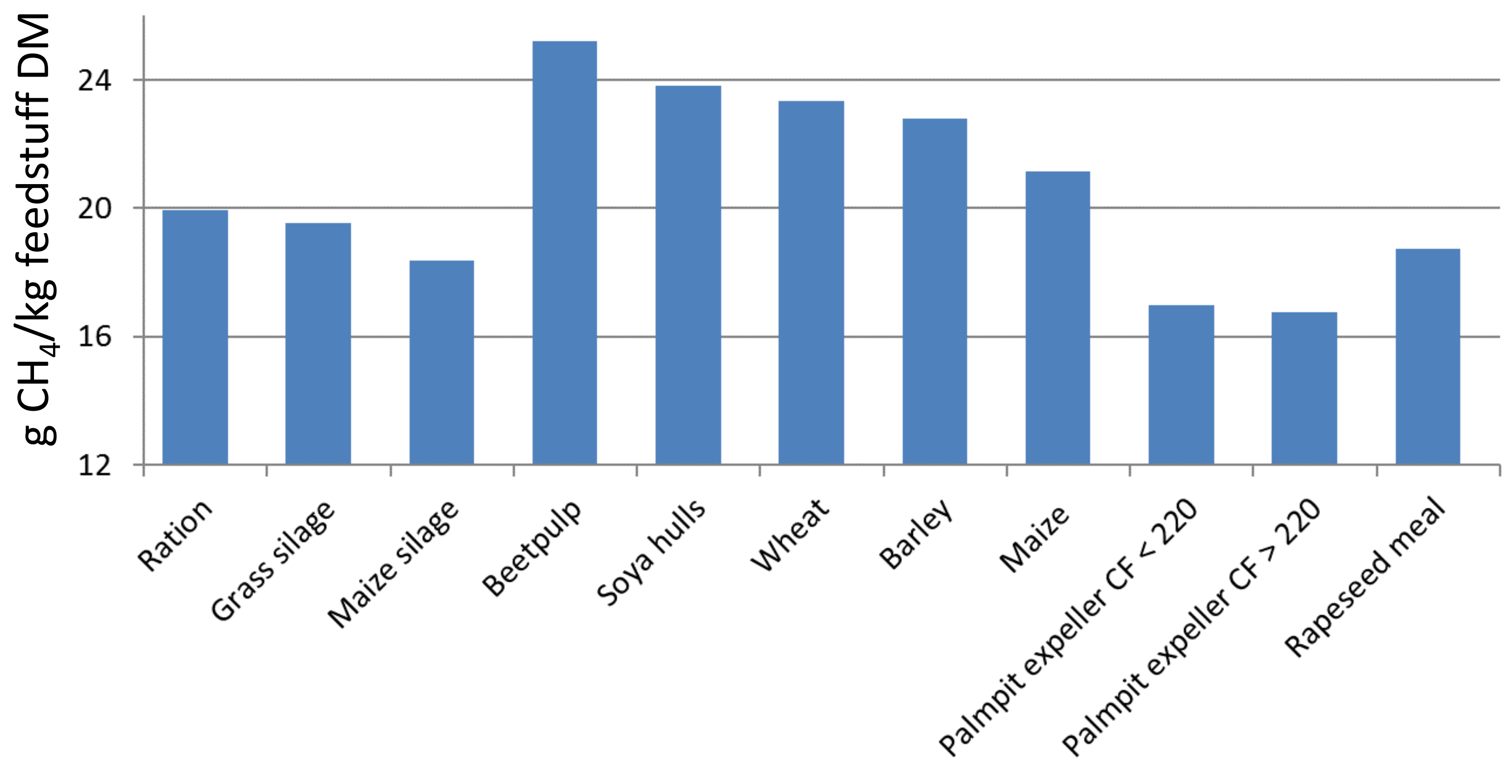
- Repeat with different diets to obtain a diet-specific EF for a feedstuff



⊏Γ – $\Delta f(x) / \Delta x$

EF values for individual feedstuffs

- A feedstuff an **EF** (g CH_4/kg feedstuff DM) calculated for a given diet



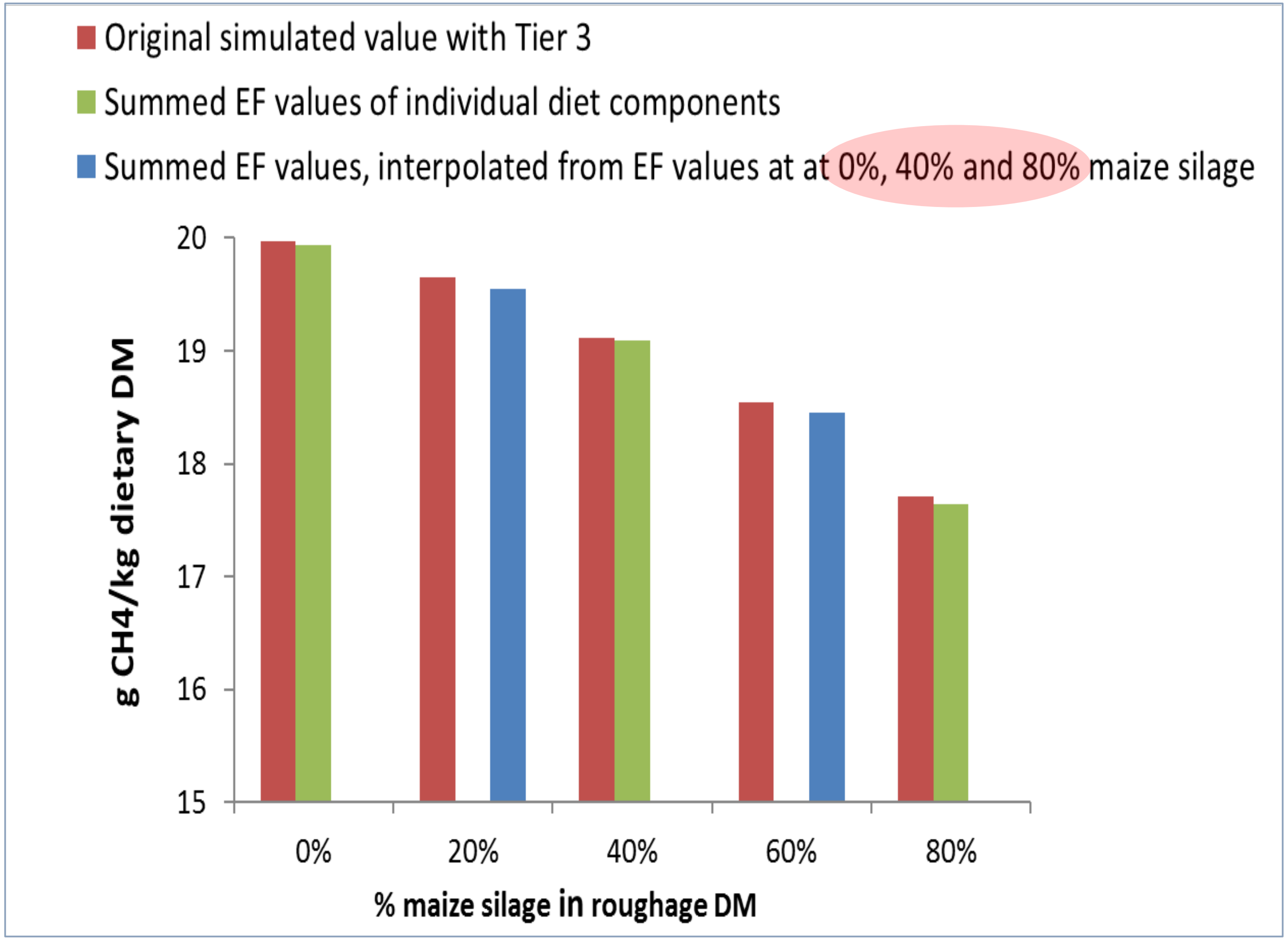
LIVESTOCK RESEARCH
WAGENINGEN UR

Feedstuff EF for different diet types

- 3 diet types with 0%, 40% and 80% maize silage in roughage DM
- An EF Table (g CH_4/kg feed DM) derived for each diet type

..... but .....
different diet types possible

e.g. based on
CP, NDF, starch, fat content
% concentrates in DM
OM digestibility
rumen pH
..... or .....



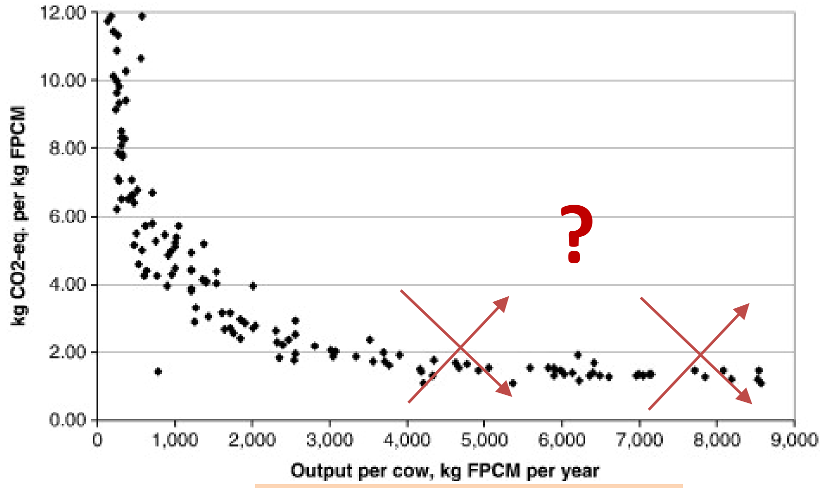
When using details, when empirical equations ?

- Empirical approaches suffice for an average 'picture'
  - but not very specific for dietary measures or farm type
  - may still be accurate as average on a larger scale

    (national inventories, IPCC)

- When aiming to account for
  - diet- or farm-specific conditions
  - other variation in rumen conditions
  - efficacy of dietary measures
  - trends in EF
  - details on rumen manipulation
  - ....

more details to be accounted for, represent the largest part of observed variation in the rumen, aiming to diversify EF values



Gerber et al., 2011

Concluding remarks

- Dietary measures to mitigate enteric CH_4
  - Potential dietary measures moderate (-10 to -15%)
  - Potential feed additives appears larger (-10 to -40%)

- Awareness of trade-offs/limitations, but synergies possible as well
  - DM intake, OM digestibility and N digestibility and excreted urine N
  - Legislation or farm management may limit implementation of measures
  - Careful ration formulation needed to prevent trade-offs
  - Dietary measures require much effort / change in farm management

- Diet- and farm-specific accounting of feeding measures
  - In reality, no fixed CH_4 value of feeds(tuffs) or efficacies of measures
  - Empirical approach for averages, more details for specificity
  - More representation of mechanisms / mode-of-action worthwhile

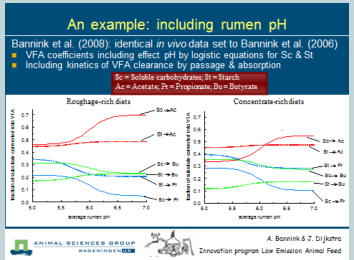
- Both empirical and process-based approaches useful; the choice depends on specificity & goal one pursuits

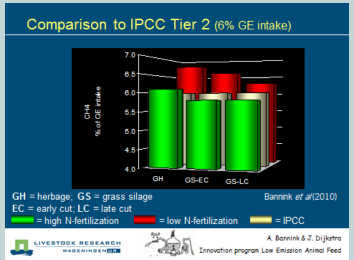
Thank you

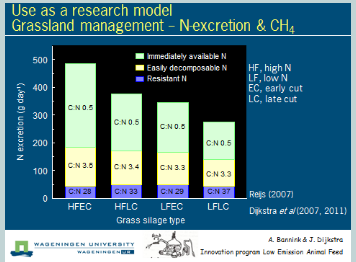
Questions ?

andre.bannink@wur.nl

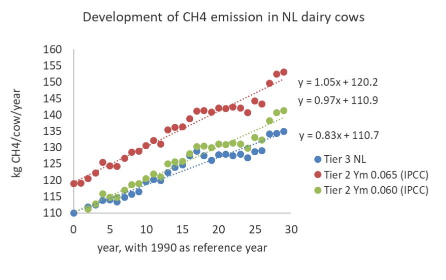
for research & experimentation

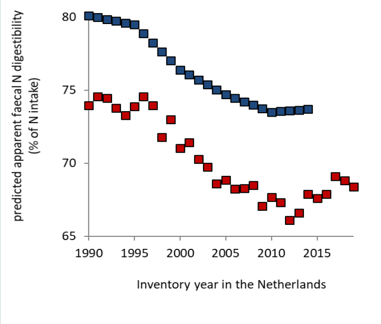


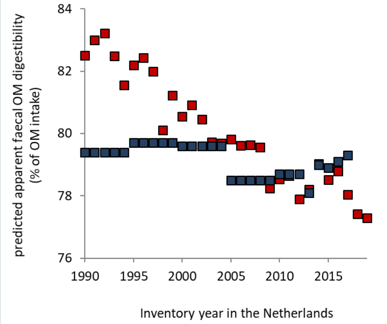




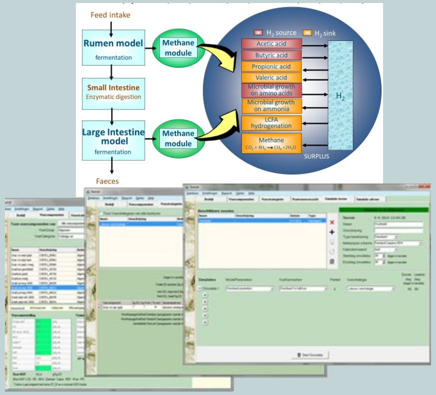
for inventory & accounting







for practice



KRINGLOOP WIJZER

Feed Print

LIVESTOCK RESEARCH
WAGENINGEN UR