Emission of methane by enteric fermentation

factors impacting on methane formation / reduction options

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Wageningen Livestock Research

10 YEARS FACCEJPI

Global Network project

FACCE ERA-GAS

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

CEDERS project

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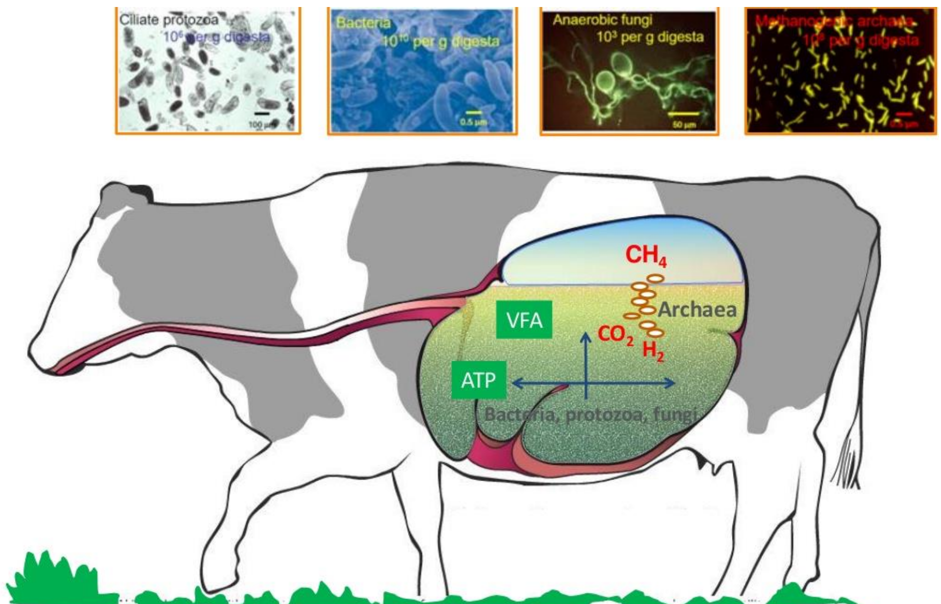
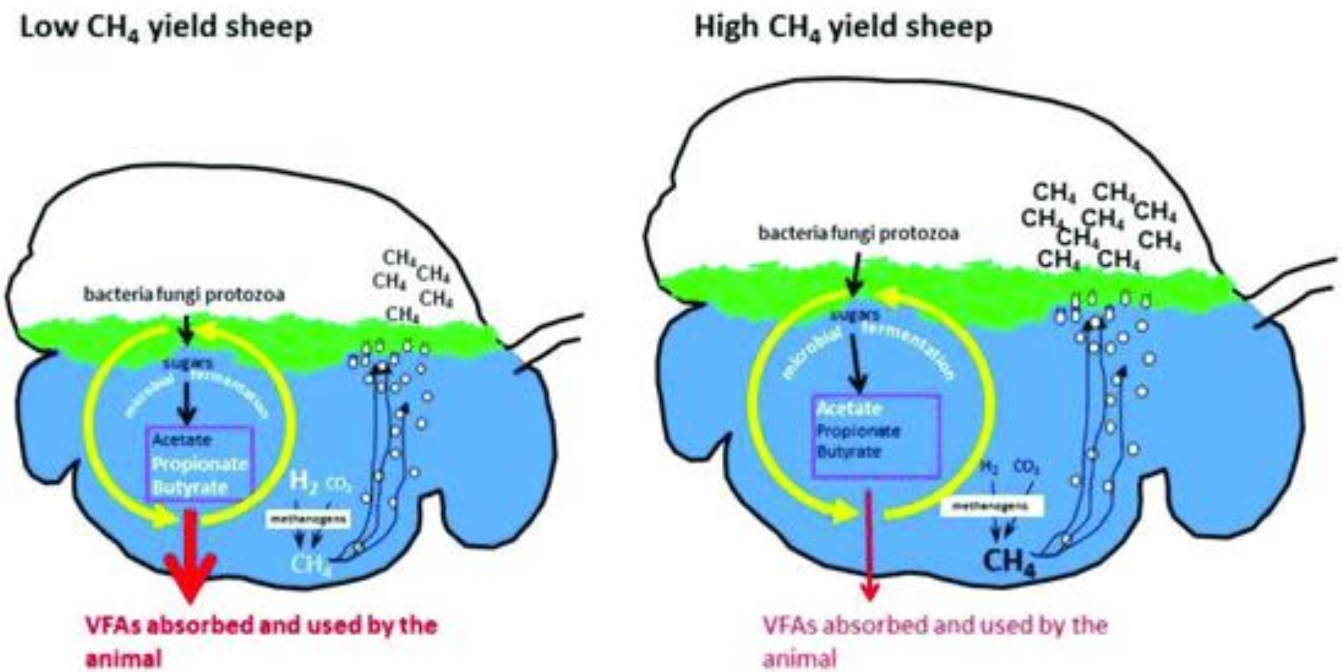
Outline

- Enteric methane production
  - Factors involved
  - Nutrition solutions to mitigate
  - Trade-offs to consider
  - Methods to quantify



from presentaion of Ilma Tapio (2017)

Animal factors involved



Smaller	Rumen size	Larger
Shorter	Mean retention time	Longer
Higher	H_2 concentration	Lower
Slower	H_2 turnover	Faster
More propionate, butyrate	Volatile fatty acids	More acetate
Lower	Methanogenesis gene expression	Higher
Lower	Methane yield	Higher

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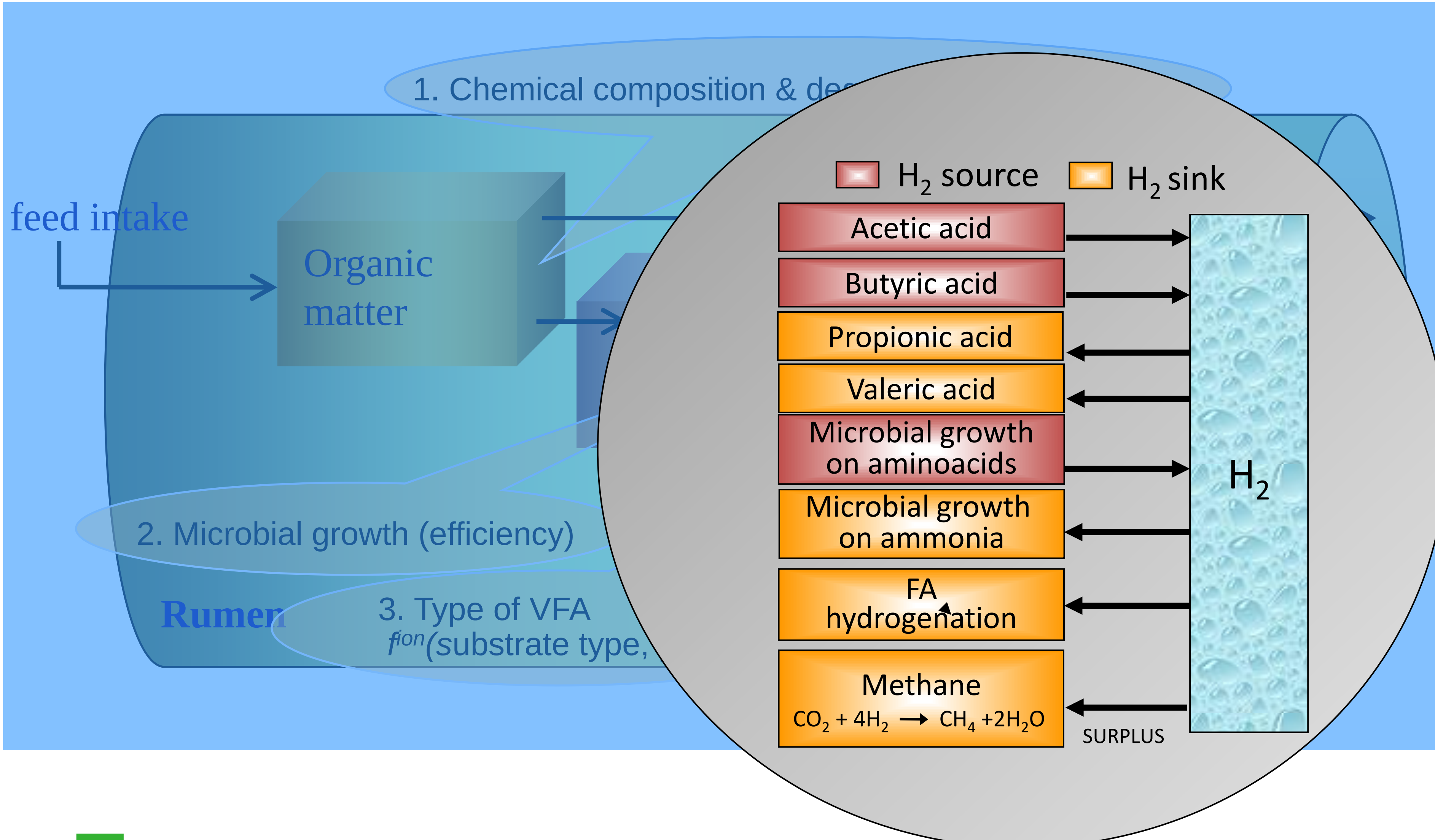
from Attwood et al.; Front. Nutr. 2019, 00107

Dietary factors most impact

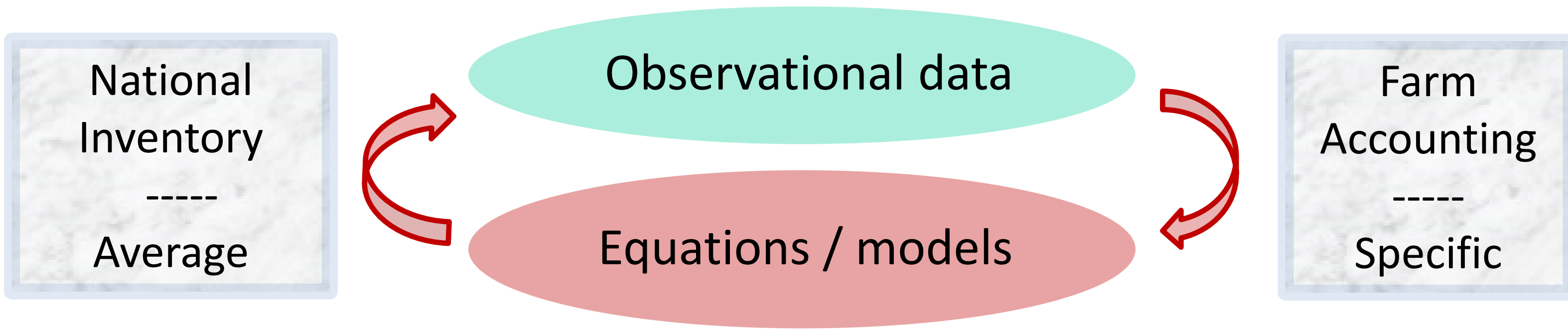


Bannink et al., 2011

Nutritional measures to mitigate enteric CH_4

- Dietary measures that mitigate per unit of feed
  - Higher feed intake / higher rate of fermentation
  - Increased digestibility / higher feed conversion
  - Starch instead of fibre
  - Rumen bypass / escape (reducing fermentable OM)
    - Protein
    - Starch
    - Fat
- Additives as dietary measures
  - Hydrogen sink (nitrate)
  - Specific fatty acids / fat
  - Methanogen inhibitors
  - Plant extracts, secondary metabolites, ...

How to quantify CH_4 (and its trade-offs)



1. Empirical equations from databases
2. Mechanistic models representing the process of enteric fermentation (concentration-dependency of the process !)
3. 'Hybrid' methods ..... making use of both

- Which equation/model to use depends on:
  - The database available / empirical base that is preferred
  - Detail of interest / the mechanism or 'biology' explored
  - Ease of application (input data)
  - Preference / experience

Quantifying CH_4 (1) empirical models

- A global database of individual cow enteric CH_4 data

  (*Niu et al., 2018; FACCE-JPI Global Network project*)

  - **CH_4 yield** (g/kg DMI) best predicted by milk & diet composition

Model development				Model performance[d]		
Equation	Category	Prediction equation[a]	n[b]	Region[c]	RMSPE, %	CCC
(38)	Diet_Com_C	15.4 (0.76) − 0.354 (0.0756) × EE + 0.173 (0.0145) × NDF	2,667	Intercontinental	17.0	0.38
				EU	15.1	0.27
				US	20.0	0.13
(41)	ECM + Com_C	21.1 (0.77) − 0.105 (0.0081) × ECM + 1.30 (0.077) × MF − 0.952 (0.1667) × MP	3,384	Intercontinental	16.5	0.42
				EU	15.1	0.30
				US	19.1	0.21
(42)	Animal_no_DMI_C	15.4 (1.08) − 0.291 (0.0733) × EE + 0.144 (0.0141) × NDF − 0.104 (0.0094) × ECM + 1.34 (0.087) × MF − 1.12 (0.187) × MP + 0.00330 (0.000729) × BW	2,566	Intercontinental	16.1	0.49
				EU	14.7	0.37
				US	18.7	0.30

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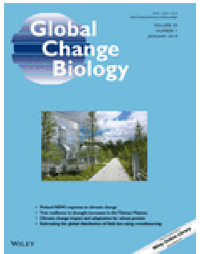
WILEY Global Change Biology

PRIMARY RESEARCH ARTICLE

Prediction of enteric methane production, yield, and intensity in dairy cattle using an intercontinental database

Mutian Niu[1] | Ermias Kebreab[1] | Alexander N. Hristov[2] | Joonpyo Oh[2] |



Quantifying CH_4 (1) empirical models

- e.g. Low-forage (<18% DM) diets database beef cattle

  (Van Lingen et al., 2019; FACCE-JPI Global Network project)

  - NDF or EE add to prediction next to DM intake (or GE intake)
  - **CH_4 production** equations differ from IPCC Tier 2 (2006)

Model development			Model performance			
Category[§]	Prediction equation[*]	n[†]	(Sub)set[‡]	p[†]	RMSPE %	CCC
DMI + NDF_C	112 (47) + 9.46 (1.79) × DMI – 2.58 (1.72) × NDF	139	Lower-forage	139	29.3	0.25
DMI + EE_C	57.0 (18.1) + 8.84 (1.74) × DMI – 1.17 (2.03) × EE	110	Lower-forage	110	24.1	0.26
GLOBAL NETWORK Tier 2	[0.045 (0.002) × GEI] / 0.05565	139	Lower-forage	139	27.9	0.39
			Lower-forage[♪,‖]	101	25.2	0.41
IPCC Tier 2 (2006)	(0.030 × GEI) / 0.05565	–	Lower-forage[♪]	139	42.1	0.17
Lower-forage[¶]			Lower-forage[♪,‖]	101	39.0	0.16

¶ IPCC = Intergovernmental Panel on Climate Change.

♪ Performance was evaluated, not cross-validated.

♫ No independent evaluation.

‖ A subset containing ≤10% forage records only was used (as recommended by the IPCC, 2006).

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ELSEVIER

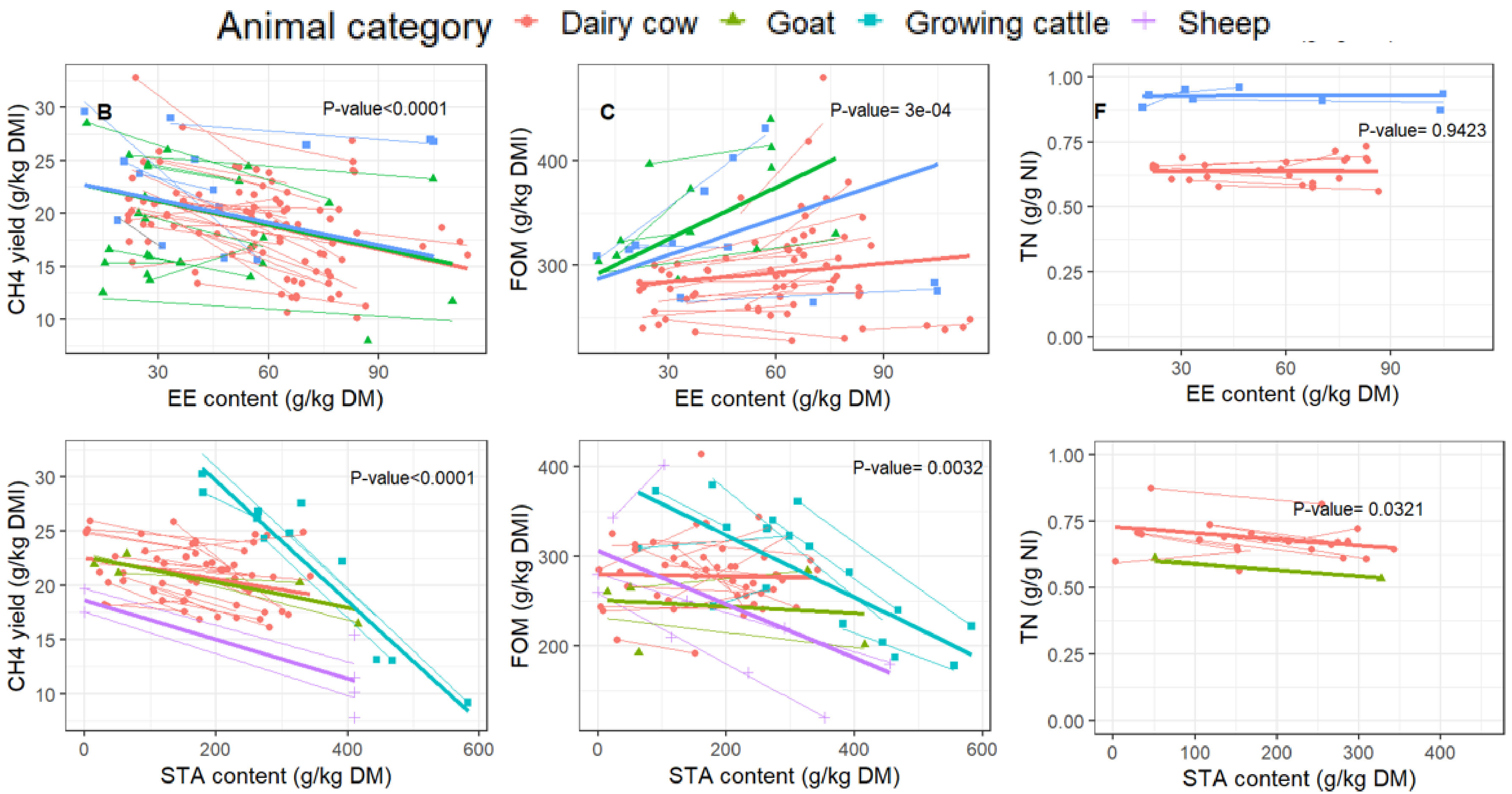
Prediction of enteric methane production, yield and intensity of beef cattle using an intercontinental database

Henk J. van Lingen[a,*], Mutian Niu[a,b], Ermias Kebreab[a], Sebastião C. Valadares Filho[c],

Quantifying CH_4 & trade-offs (1) empirical models

- (Global) treatment means database
- Mitigation by starch (STA) & lipid (EE) supplementation

(Benaouda et al., 2021; preliminary results ERAGAS-CEDERS project)



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FOM= fecal organic matter

TN= N excreted as proportion of N intake

Quantifying trade-offs (1) empirical models

- Meta-analysis Benaouda et al. (2021)
  *(preliminary results ERAGAS-CEDERS project on **yields** (g/kg DMI))*

Studies with lipid supplementation

Simple = Only EE varies (>1.5% DM)
Complex = EE & other nutrients vary

Name	Model	n	RMSPE %	CCC
Simple CH4	CH4 yield = 25.0 (0.84) -0.08 (0.01) × **EE**	147	24,4	0,18
Complex CH4	CH4 yield = 29.9 (1.47) – 2.34 (0.50) × **FL** -0.08 (0.01) × **EE**	193	24,3	0,35
Simple FOM	FOM yield = 267 (7.26)+0.57 (0.18) × **EE**	99	17,0	0,01
Complex FOM	FOM yield = 349 (18.7)+0.42 (0.03) × **NDF** – 394 (31.1) × **NDFD**	85	11,9	0,85
Simple TN	TN yield = 17.2 (0.56) -0.01 (0.01) × **EE**	51	10,5	-0,06
Complex TN	TN yield = 1.88 (2.57) -1.78 (0.69) × **FL** + 0.14 (0.01) × **CP**	51	18,3	0,77
Simple FN	FN yield = 8.65 (0.25) - 0.006 (0.003) × **EE**	51	13,5	-0,03
Complex FN	FN yield = 4.01 (0.85) +0.03 (0.004) × **CP** -0.003 (0.001) × **STA**	51	9,16	0,72
Simple UN	UN yield = 8.78 (0.64) -0.005 (0.007) × **EE**	51	22,7	-0,04
Complex UN	UN yield = -5.59 (2.51) -0.01 (0.004) × **BW** +0.12 (0.01) × **CP**	51	32,8	0,70

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Quantifying trade-offs (1) empirical models

- Meta-analysis Benaouda et al. (2021)
  *(preliminary results ERAGAS-CEDERS project on **yields** (g/kg DMI))*

Studies with starch supplementation

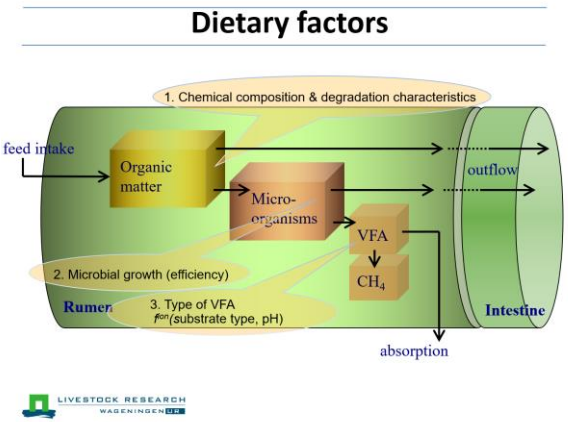
Simple = Only STA varies (>8% DM)
Complex = STA & other nutrients vary

Name	Model	n	RMSPE %	CCC
Simple CH4	CH4 yield = 25,5 (0.91) – 0.022 (0.003) × **STA**	97	24,2	0,09
Complex CH4	CH4 yield = 30.8 (1.62) – 3.25 (0.51) × **FL** -0.01 (0.003) × **STA**	92	19,4	0,55
Simple FOM	FOM yield = 278 (22.7) -3.72 (1.76) × **STA**	81	18,7	0,17
Complex FOM	FOM yield = 273 (19.6) + 0.37 (0.04) × **NDF** – 311 (25.8) × **NDFD** + 0.75 (0.23) × **Ash**	52	8,34	0,86
Simple TN	TN yield = 18.8 (1.18) - 0.01 (0.004) × **STA**	27	19,0	0,04
Complex TN	TN yield = -3.37 (1.38) + 0.04 (0.01) × **PCO** + 0.12 (0.01) × **CP**	32	7,18	0,92
Simple FN	FN yield = 9.37 (0.32) - 0.004 (0.001) × **STA**	51	13,5	0,07
Complex FN	FN yield = 7.30 (0.35) +0.05 (0.01) × **PCO** -0.006 (0.002) × **STA**	54	12,8	0,49
Simple UN	UN yield = 9.35 (0.78) -0.003 (0.002) × **STA**	42	34,6	-0,01
Complex UN	UN yield = -9.17 (1.51) + 0.12 (0.01) × **CP**	28	23,4	0,80

Quantifying CH_4 (2) mechanistic models

- Representing elements of the fermentation process
  - Substrate supply by feed (& recycling N from blood)
  - Feed substrate characteristics
  - Microbial activity
  - Rumen fermentation conditions (acidity, passage rate, volume)

- Dietary factors & feed intake as input



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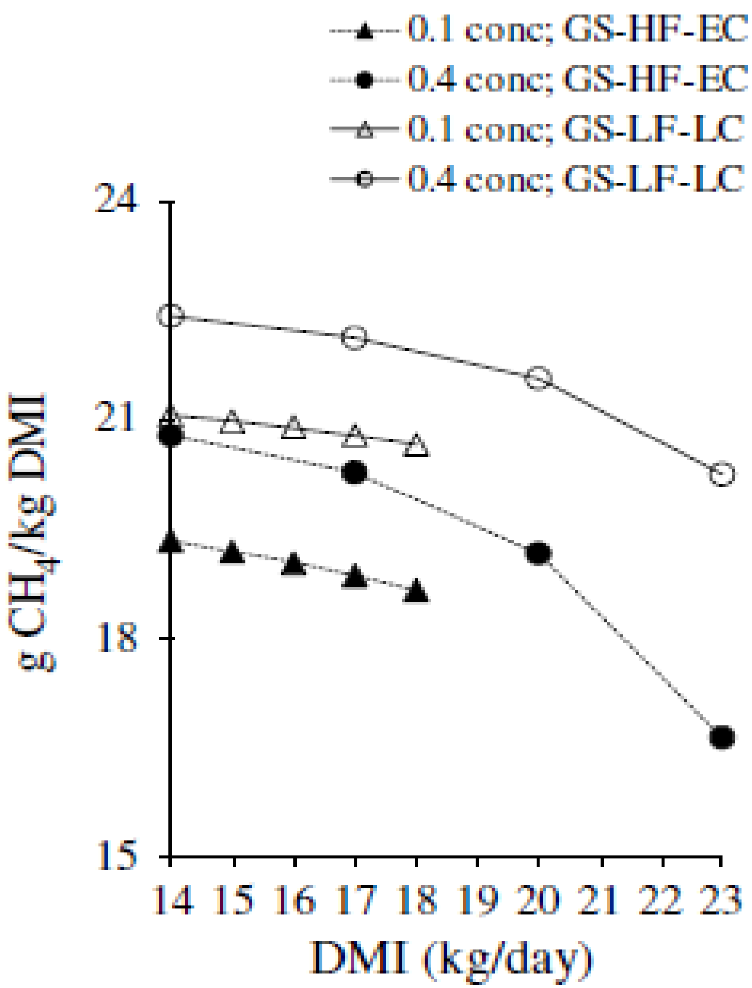
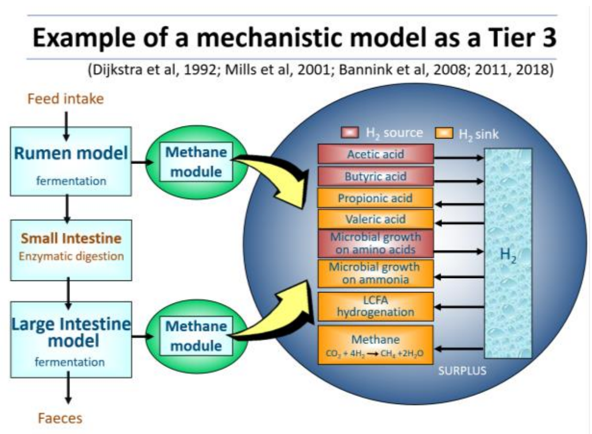
Example, simulation grass quality & CH_4

-- impact of maturity & N fertilisation --



EC/LC	= Early/Late cut
HF/LF	= High/Low N fertilization
GS	= Grass silage



Journal of Agricultural Science (2010), **148**, 55–72. © *Cambridge University Press* 2009 55
doi:10.1017/S0021859609990499

MODELLING ANIMAL SYSTEMS PAPER

Simulating the effects of grassland management and grass ensiling on methane emission from lactating cows

A. BANNINK[1*], M. C. J. SMITS[1], E. KEBREAB[2], J. A. N. MILLS[3], J. L. ELLIS[4], A. KLOP[1], J. FRANCE[4] AND J. DIJKSTRA[5]

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Experimental evaluation grass quality

Study on wide range in maturity stage (Warner et al., 2017)

	Treatment – Stage of maturity					*P*-value – Stage of maturity
	leafy	boot	early hdng	late hdng		
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 DOM)	27.5	30.9	32.2	36.8	+34%	<0.01
CH_4 (g/kg FPCM)	10.7	12.8	13.5	13.8	+29%	<0.01

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Effects of grass silage quality and level of feed intake on enteric methane production in lactating dairy cows[1]

D. Warner,*[2] A. Bannink,† B. Hatew,*[3] H. van Laar,*‡ and J. Dijkstra*[4]

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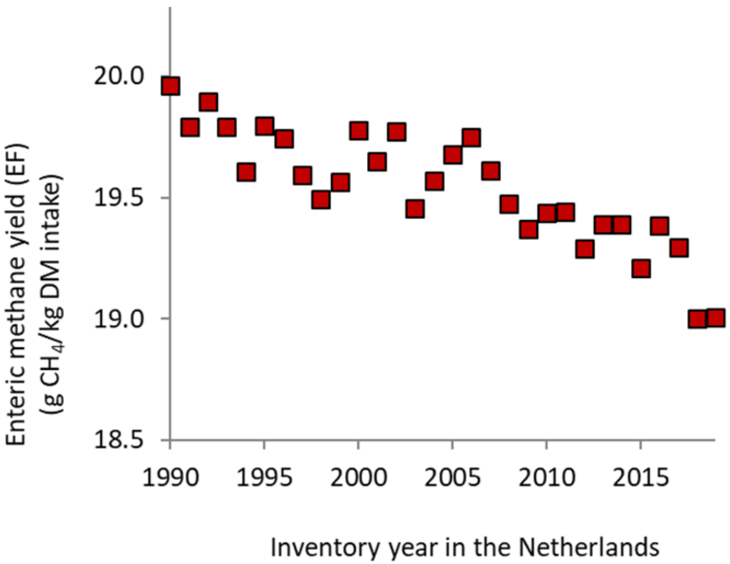
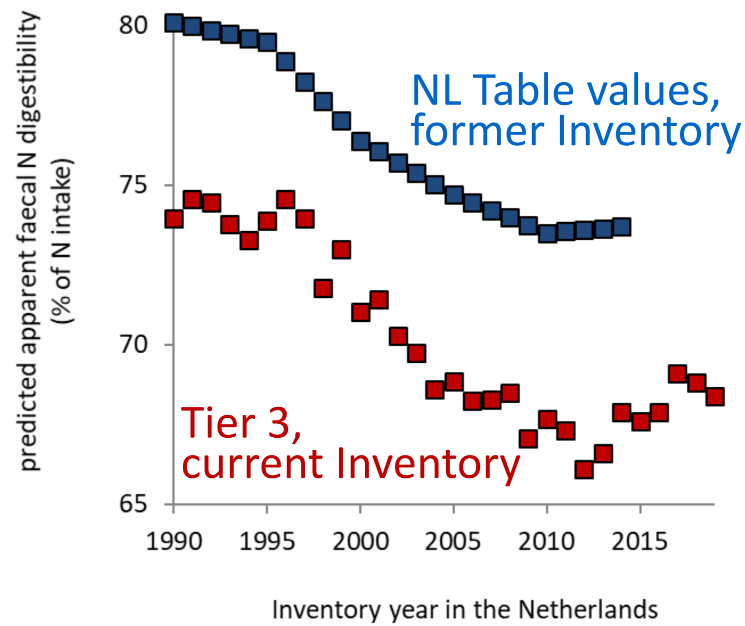
 J. Anim. Sci. 2017.95:3687–3699
doi:10.2527/jas2017.1459

Quantifying CH_4 and trade-offs (2)
A mechanistic model for CH_4, urine N & fecal OM

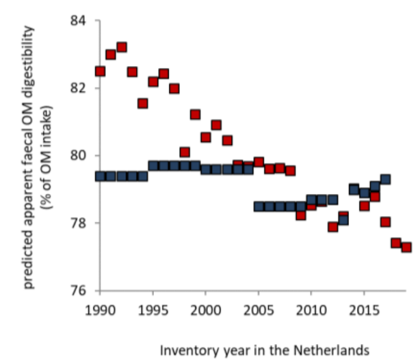
- Faecal N digestibility
  - more responsive to changes in feed and N intake
  - required to calculate urine N excretion & ammonia





A Tier 3 Method for Enteric Methane in Dairy Cows Applied for Fecal N Digestibility in the Ammonia Inventory

André Bannink[1], Wouter J. Spek[1], Jan Dijkstra[2] and Leon B. J. Šebek[1]*



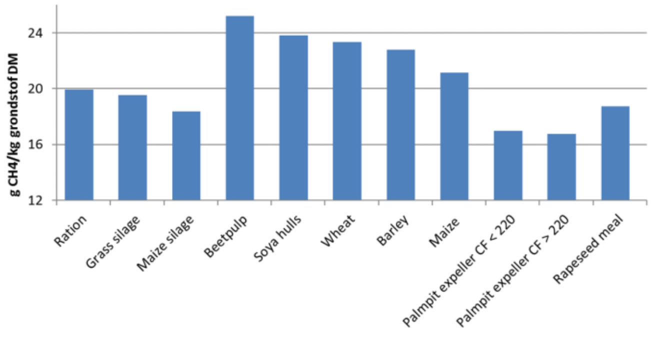
Quantifying (3) ‘hybrid’ approaches

- Empirical base but adopting biology as well
  - Studies Niu et al. (2018) & Van Lingen et al. (2019) used with 2019 refinement of emission factor estimates in IPCC guidelines

  - Translating results from a mechanistic model into table values for feedstuff emissions factors (g CH_4/kg DM) in a farm accounting and a CFP tool

KRINGLOOP WIJZER

Feed Print



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Message on CH_4 quantification

- Many equations/models exist to estimate enteric CH_4
- Choice of equation/model depends on use / aim
  - For average or specific conditions ?
  - For general use or for specific feeding measures ?
  - Same, i.r.t. consistency enteric CH_4, faecal OM & excreted N ?
  - For current situation, or for extremes, unknowns, extrapolation into future ?
- Trade-offs CH_4 mitigation appear small, but easily triggered
- For choice, define / list :
  - Available data as model input
  - Variation of interest / what a model can/cannot do
  - Accuracy / consistency required
  - Type of trade-offs / synergies that are to be accounted for

Perspective to reduce CH_4

- Notwithstanding (counteracting) restrictions by more biodiversity, derogation (less crop feed), less feedstuff imports, more grazing, protein self-sufficiency, ...

  seek for CH_4 mitigating principles with a farm-specific approach:
  - Improve feed quality and intake (OM digestibility, feeding value)
  - Less fibrous feeds of low digestibility
  - Grass at early growth stage with high feeding value
  - Feed crops/low-N feed to control N excretion/emissions
  - CH_4-lowering supplements (starch, fat) & additives !
  - ?? Implementation of biodiverse swards

- Other options
  - Interventions to create/select low-CH_4 animals (*if demonstrated*)
  - Mitigation of manure CH_4 emissions
  - Decrease of livestock numbers / lower production

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THANK YOU

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