Mitigation of enteric methane emissions: How can we speed up progress?

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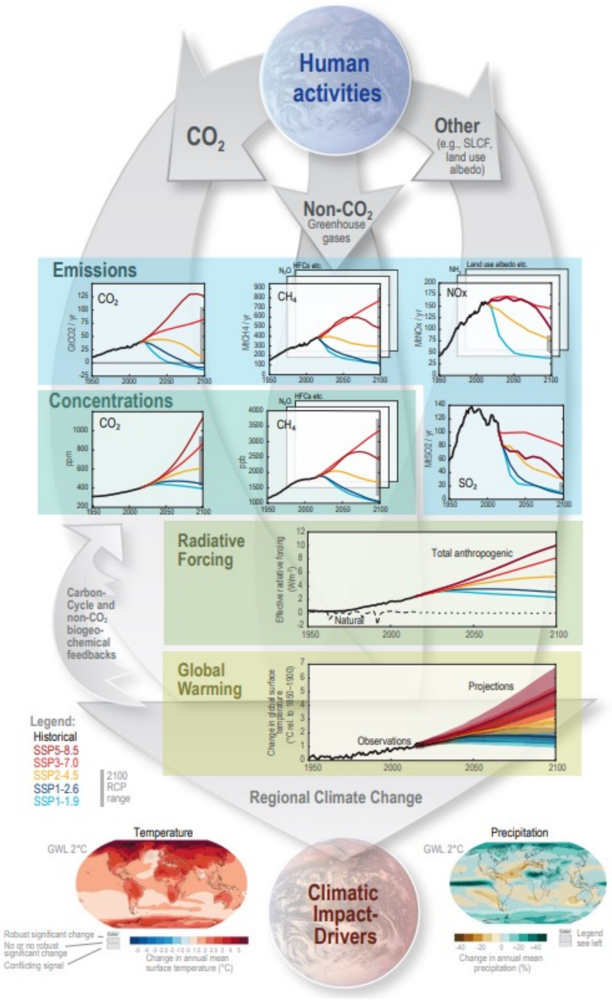
Climate change and animal ag

- ➢ Although our climate has not been stagnant "*…it is virtually certain that irreversible, committed change is already underway…*"

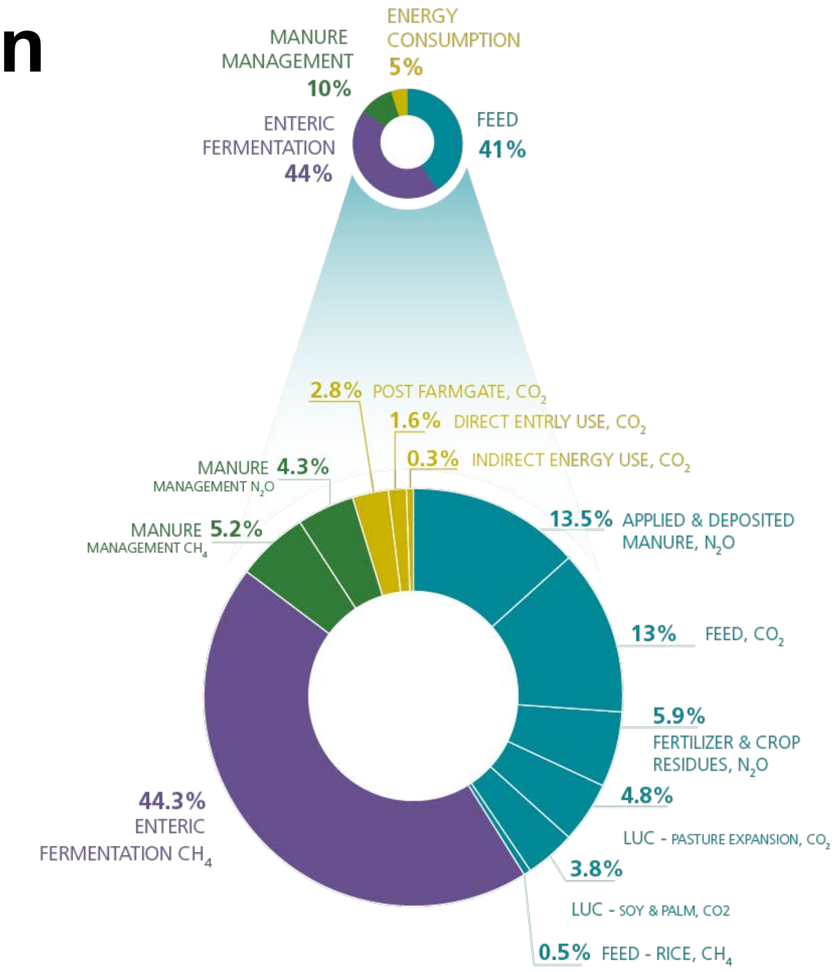
  – Intergovernmental Panel on Climate Change 2021

- ➢ Enhancing the adaptability and resiliency of animal agriculture has and will continue to be the smart approach to maintain food security



IPCC, 2021; NYSERDA, 2014 (ClimAID)

Global livestock supply chain emissions by source



FAO, 2022 (GLEAM 2.0)

ENERGY AND ENVIRONMENT

Cows are not the new coal — here’s why

BY JOSEPH W. MCFADDEN, OPINION CONTRIBUTOR - 12/16/21 10:30 AM ET

THE HILL

IDEAS • CLIMATE CHANGE

Cow Burps Have a Big Climate Impact. Solving That is Harder than You'd Think

BY **JOSEPH W. MCFADDEN** FEBRUARY 1, 2023 7:00 AM EST

TIME

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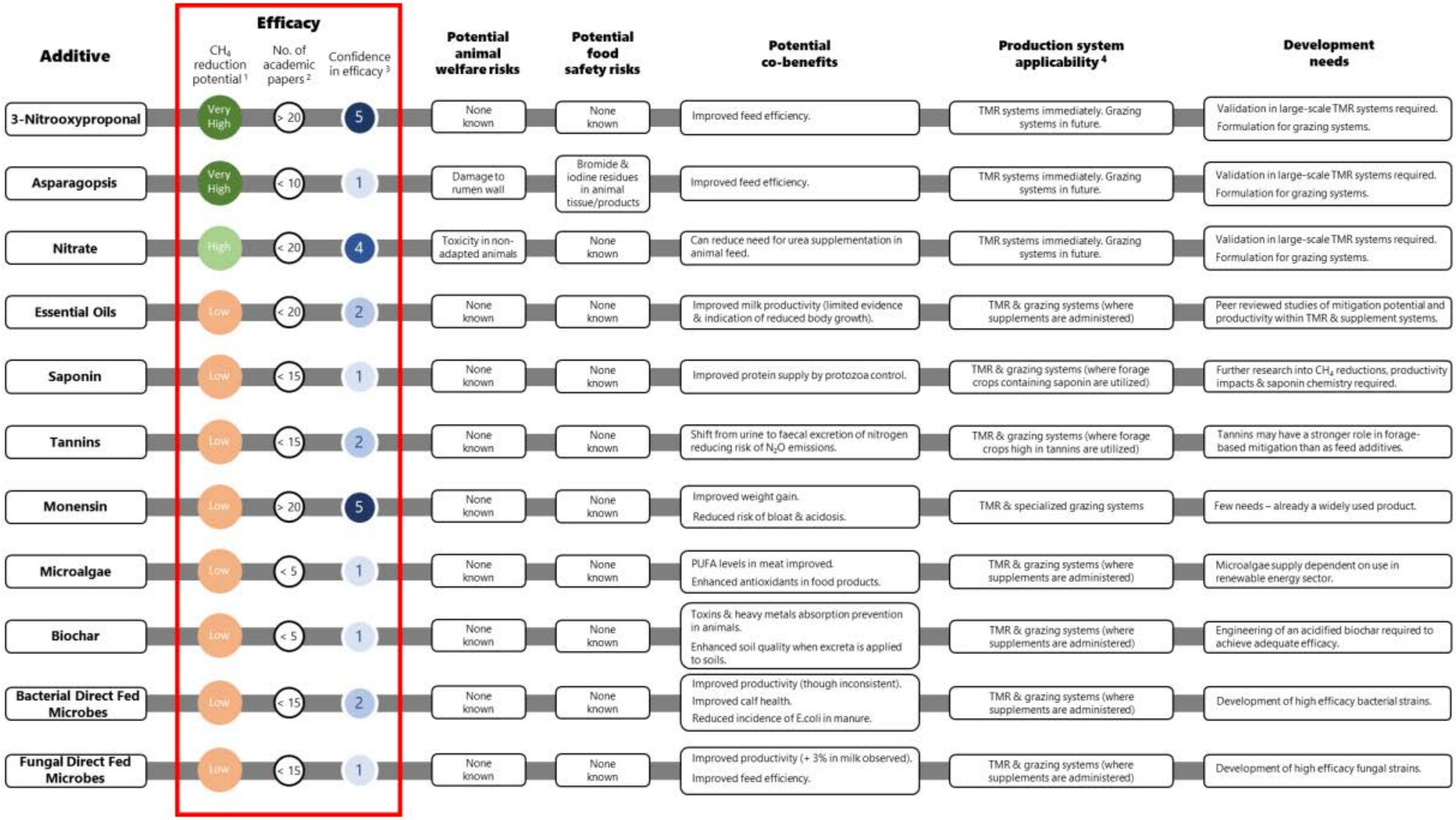
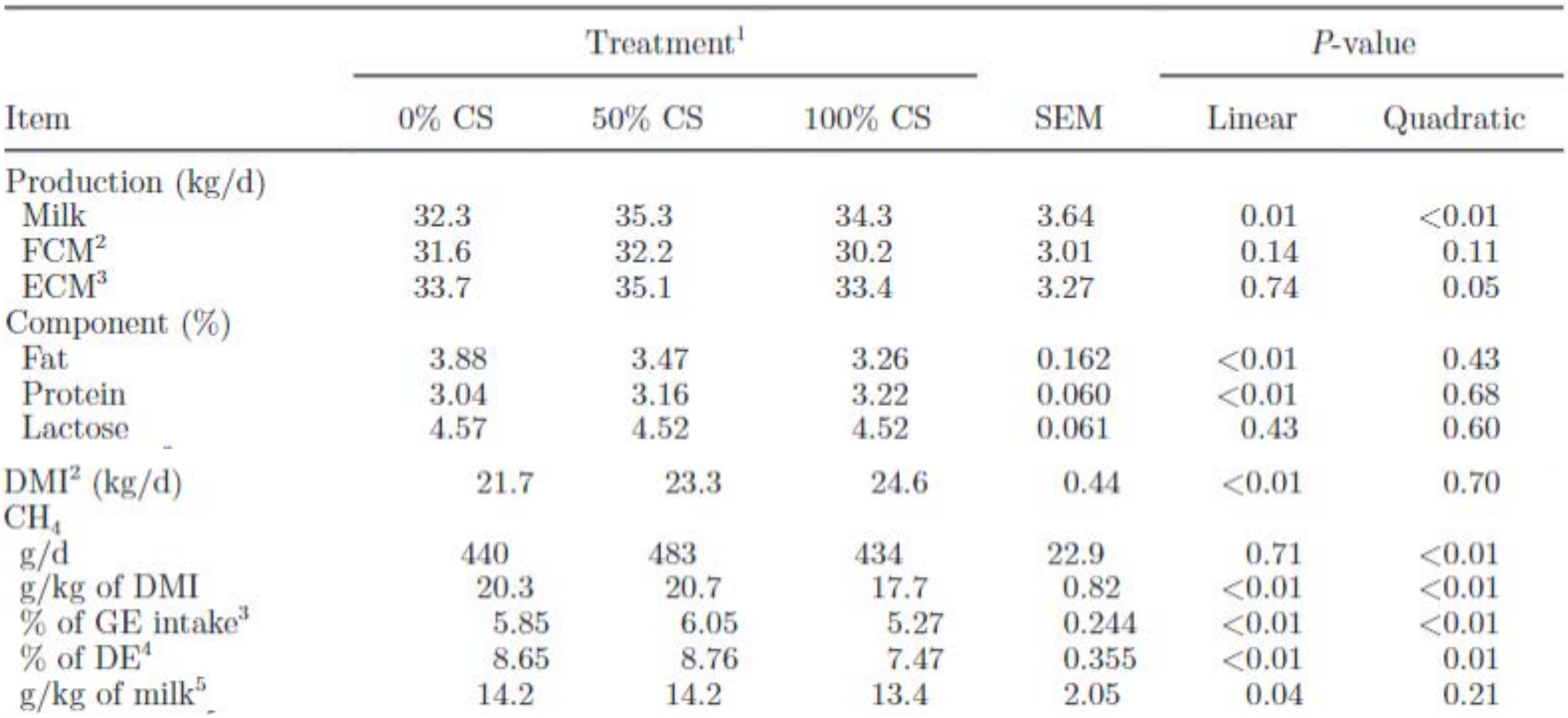
Global
Methane
Hub



Additive	Efficacy			Potential animal welfare risks	Potential food safety risks	Potential co-benefits	Production system applicability [4]	Development needs
	CH_4 reduction potential [1]	No. of academic papers [2]	Confidence in efficacy [3]					
3-Nitrooxyproponal	Very High	> 20	5	None known	None known	Improved feed efficiency.	TMR systems immediately. Grazing systems in future.	Validation in large-scale TMR systems required. Formulation for grazing systems.
Asparagopsis	Very High	< 10	1	Damage to rumen wall	Bromide & iodine residues in animal tissue/products	Improved feed efficiency.	TMR systems immediately. Grazing systems in future.	Validation in large-scale TMR systems required. Formulation for grazing systems.
Nitrate	High	< 20	4	Toxicity in non-adapted animals	None known	Can reduce need for urea supplementation in animal feed.	TMR systems immediately. Grazing systems in future.	Validation in large-scale TMR systems required. Formulation for grazing systems.
Essential Oils	Low	< 20	2	None known	None known	Improved milk productivity (limited evidence & indication of reduced body growth).	TMR & grazing systems (where supplements are administered)	Peer reviewed studies of mitigation potential and productivity within TMR & supplement systems.
Saponin	Low	< 15	1	None known	None known	Improved protein supply by protozoa control.	TMR & grazing systems (where forage crops containing saponin are utilized)	Further research into CH_4 reductions, productivity impacts & saponin chemistry required.
Tannins	Low	< 15	2	None known	None known	Shift from urine to faecal excretion of nitrogen reducing risk of N_2O emissions.	TMR & grazing systems (where forage crops high in tannins are utilized)	Tannins may have a stronger role in forage-based mitigation than as feed additives.
Monensin	Low	> 20	5	None known	None known	Improved weight gain. Reduced risk of bloat & acidosis.	TMR & specialized grazing systems	Few needs – already a widely used product.
Microalgae	Low	< 5	1	None known	None known	PUFA levels in meat improved. Enhanced antioxidants in food products.	TMR & grazing systems (where supplements are administered)	Microalgae supply dependent on use in renewable energy sector.
Biochar	Low	< 5	1	None known	None known	Toxins & heavy metals absorption prevention in animals. Enhanced soil quality when excreta is applied to soils.	TMR & grazing systems (where supplements are administered)	Engineering of an acidified biochar required to achieve adequate efficacy.
Bacterial Direct Fed Microbes	Low	< 15	2	None known	None known	Improved productivity (though inconsistent). Improved calf health. Reduced incidence of E.coli in manure.	TMR & grazing systems (where supplements are administered)	Development of high efficacy bacterial strains.
Fungal Direct Fed Microbes	Low	< 15	1	None known	None known	Improved productivity (+ 3% in milk observed). Improved feed efficiency.	TMR & grazing systems (where supplements are administered)	Development of high efficacy fungal strains.

Hegarty et al. (2021)

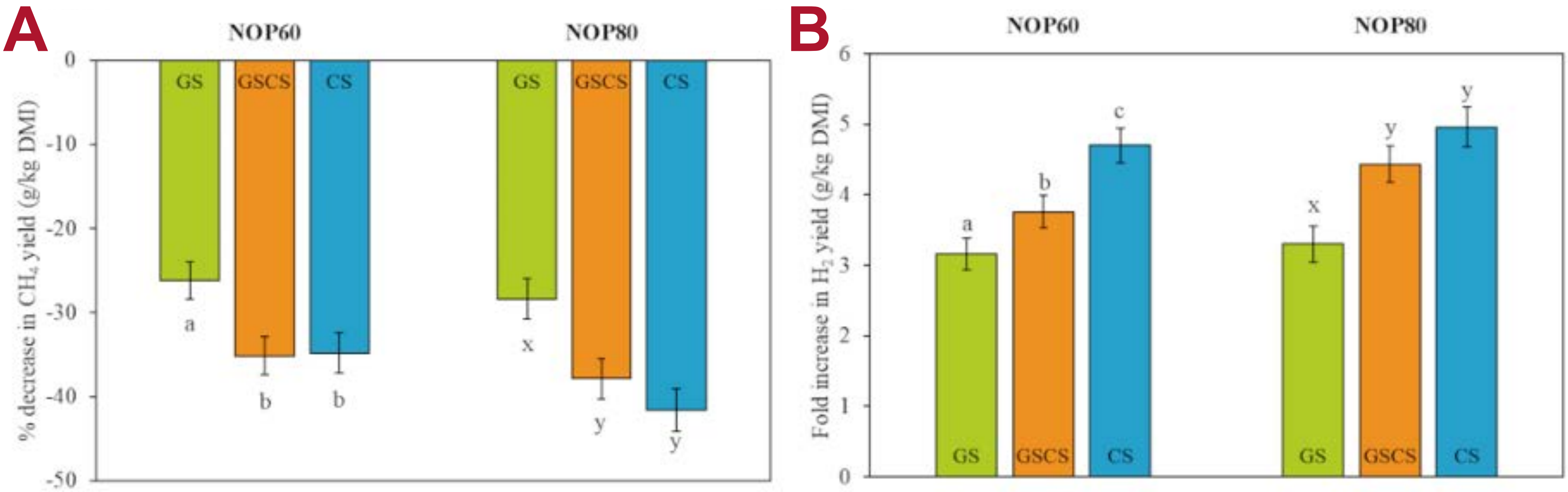
Forage type influences methane emissions



	Treatment[1]				*P*-value	
Item	0% CS	50% CS	100% CS	SEM	Linear	Quadratic
Production (kg/d)						
Milk	32.3	35.3	34.3	3.64	0.01	<0.01
FCM[2]	31.6	32.2	30.2	3.01	0.14	0.11
ECM[3]	33.7	35.1	33.4	3.27	0.74	0.05
Component (%)						
Fat	3.88	3.47	3.26	0.162	<0.01	0.43
Protein	3.04	3.16	3.22	0.060	<0.01	0.68
Lactose	4.57	4.52	4.52	0.061	0.43	0.60
DMI[2] (kg/d)	21.7	23.3	24.6	0.44	<0.01	0.70
CH_4						
g/d	440	483	434	22.9	0.71	<0.01
g/kg of DMI	20.3	20.7	17.7	0.82	<0.01	<0.01
% of GE intake[3]	5.85	6.05	5.27	0.244	<0.01	<0.01
% of DE[4]	8.65	8.76	7.47	0.355	<0.01	0.01
g/kg of milk[5]	14.2	14.2	13.4	2.05	0.04	0.21

Hassanat et al. (2013); Hatew et al. (2016)

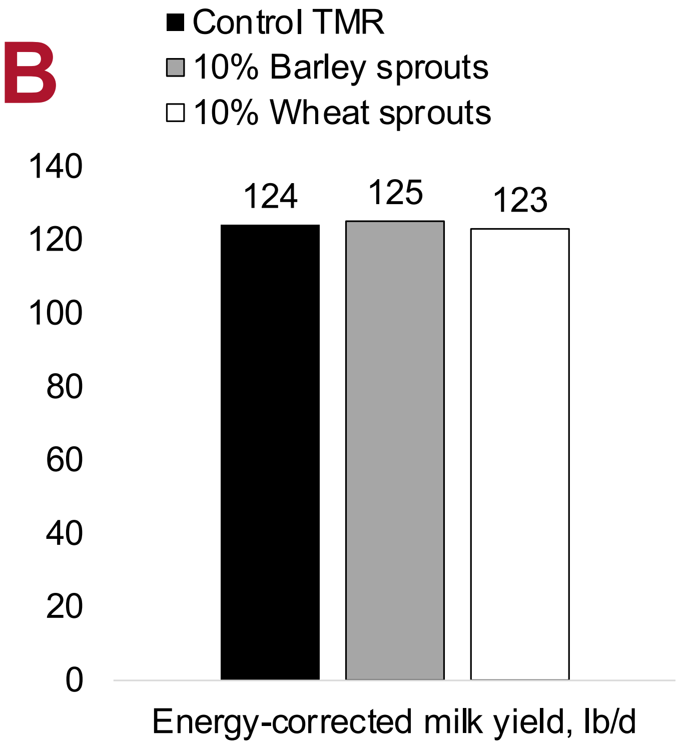
Percent methane mitigation influenced by basal diet

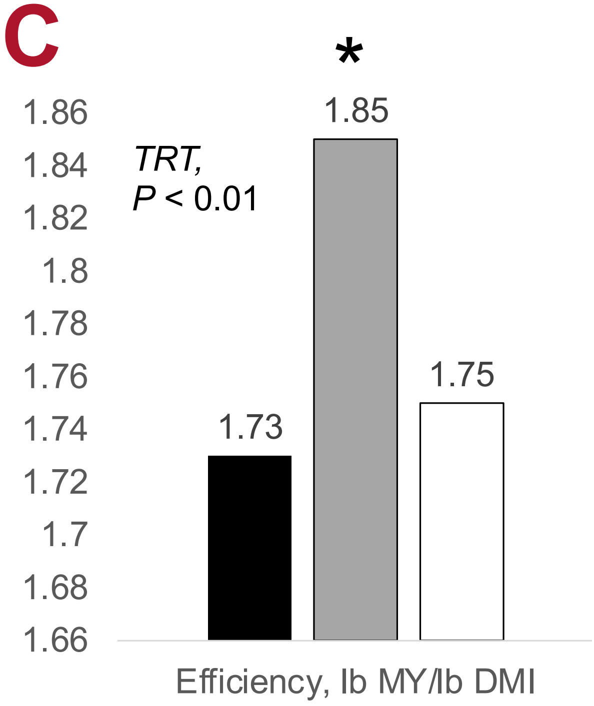


- ➢ No MY, fat, or protein response when comparing 0 vs 60 mg 3NOP/kg DM

van Gastelen et al. (2022)

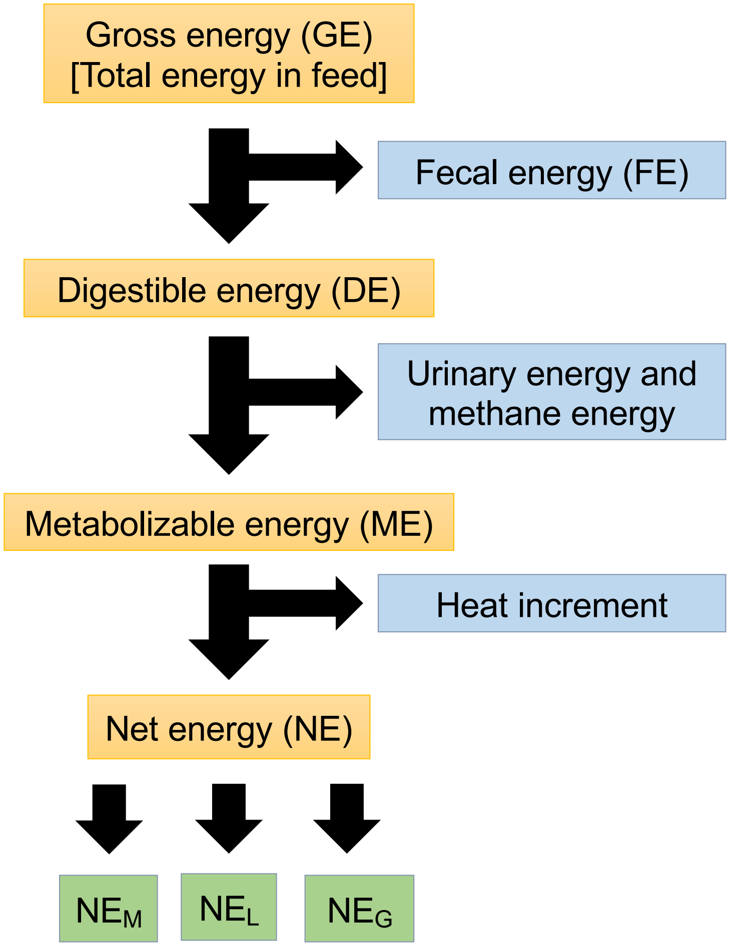
Nutrient digestibility of forages deserves consideration





McFadden Lab (unpublished)

Understanding the energetics of methane and milk production is a priority



Gross energy (GE)
[Total energy in feed]

Fecal energy (FE)

Digestible energy (DE)

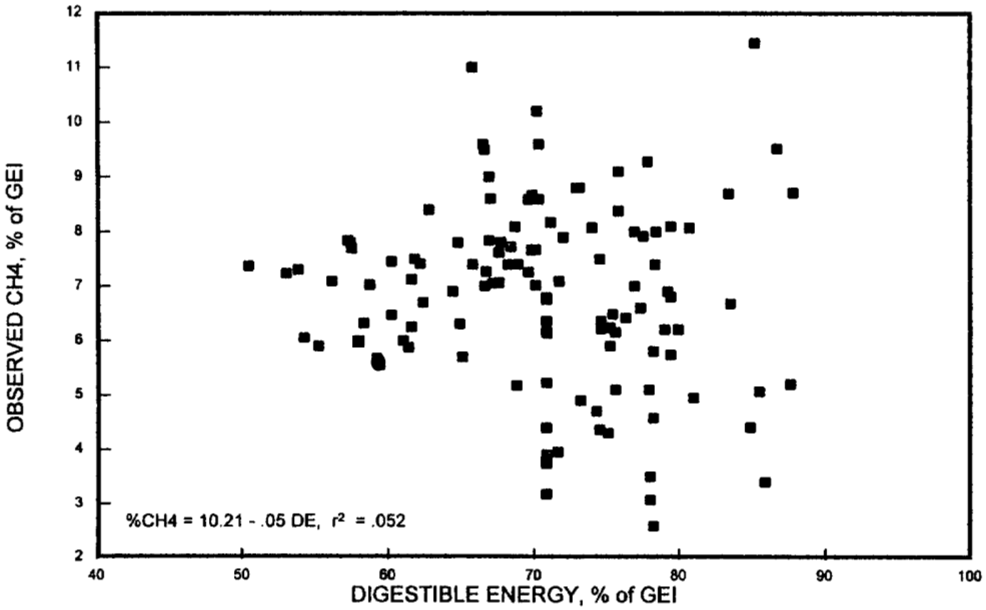
Urinary energy and methane energy

Metabolizable energy (ME)

Heat increment

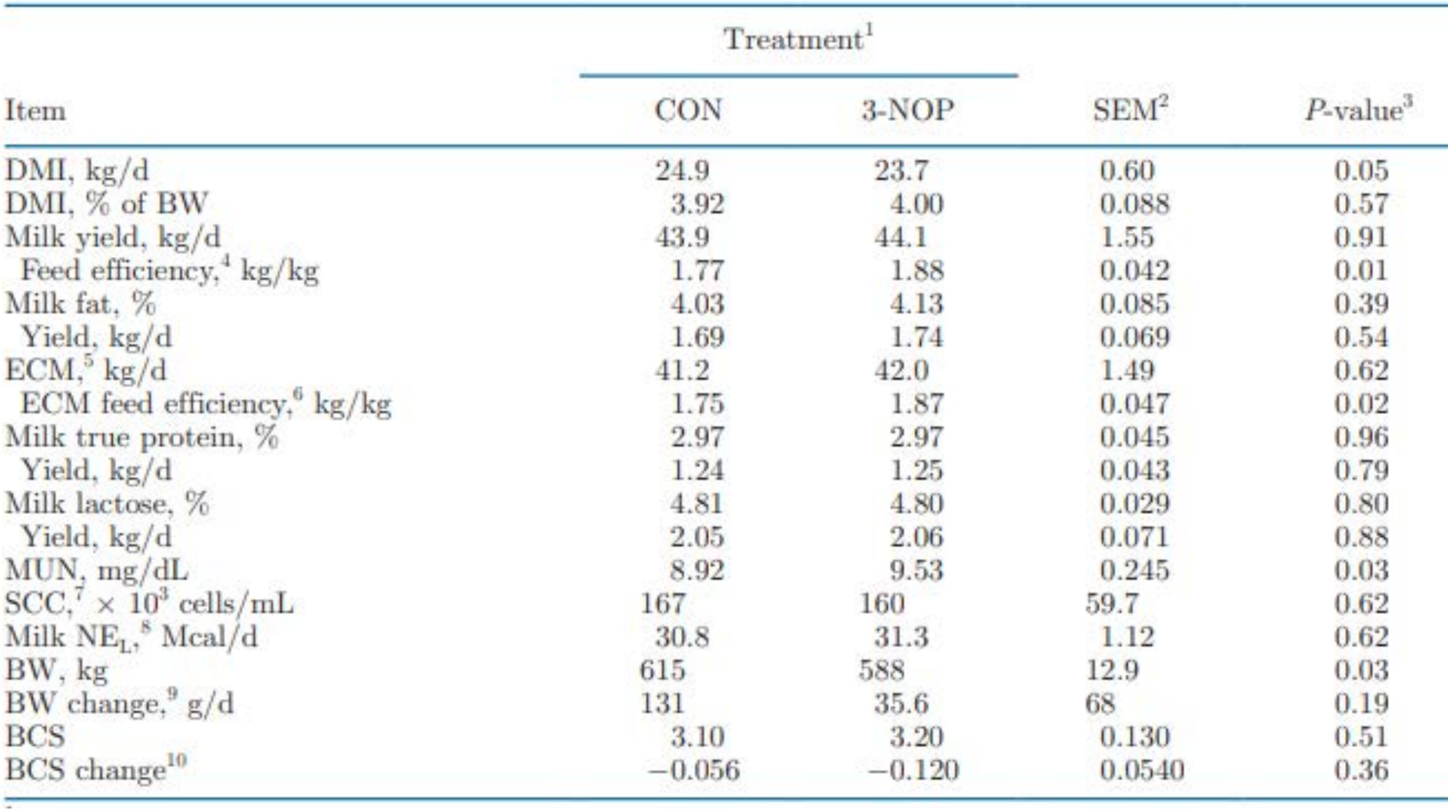
Net energy (NE)

NE_M NE_L NE_G



Johnson and Johnson, 1995

Interactions between energy balance and methane reduction needs clarity



Item	Treatment[1] CON	Treatment[1] 3-NOP	SEM[2]	*P*-value[3]
DMI, kg/d	24.9	23.7	0.60	0.05
DMI, % of BW	3.92	4.00	0.088	0.57
Milk yield, kg/d	43.9	44.1	1.55	0.91
Feed efficiency,[4] kg/kg	1.77	1.88	0.042	0.01
Milk fat, %	4.03	4.13	0.085	0.39
Yield, kg/d	1.69	1.74	0.069	0.54
ECM,[5] kg/d	41.2	42.0	1.49	0.62
ECM feed efficiency,[6] kg/kg	1.75	1.87	0.047	0.02
Milk true protein, %	2.97	2.97	0.045	0.96
Yield, kg/d	1.24	1.25	0.043	0.79
Milk lactose, %	4.81	4.80	0.029	0.80
Yield, kg/d	2.05	2.06	0.071	0.88
MUN, mg/dL	8.92	9.53	0.245	0.03
SCC,[7] × 10^3 cells/mL	167	160	59.7	0.62
Milk NE_L,[8] Mcal/d	30.8	31.3	1.12	0.62
BW, kg	615	588	12.9	0.03
BW change,[9] g/d	131	35.6	68	0.19
BCS	3.10	3.20	0.130	0.51
BCS change[10]	−0.056	−0.120	0.0540	0.36

Melgar et al. (2020)

Duration of efficacy can be short-lived; influenced by production system and mode of delivery

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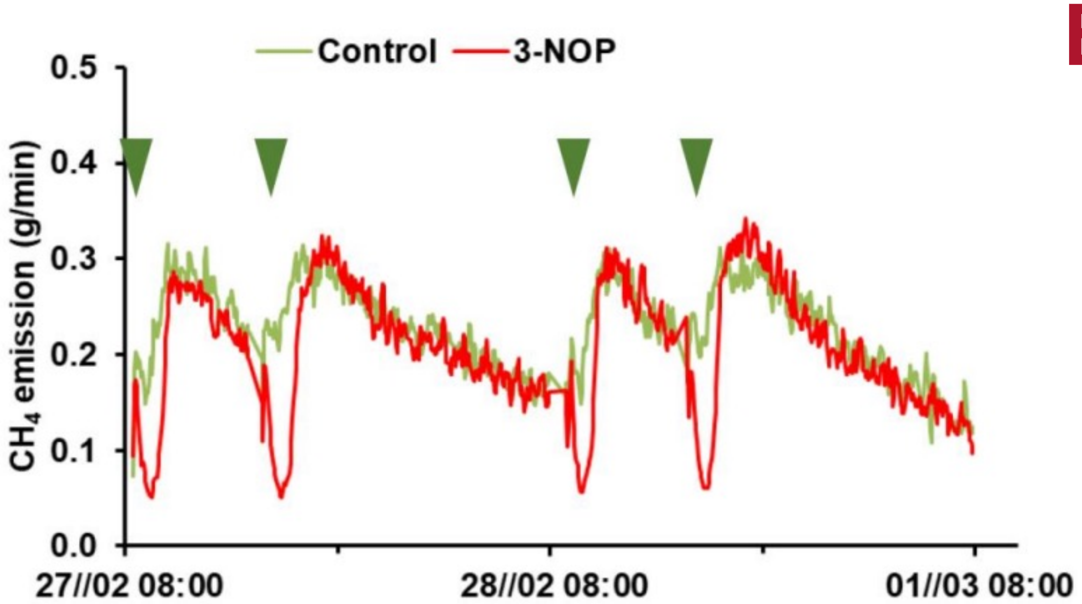

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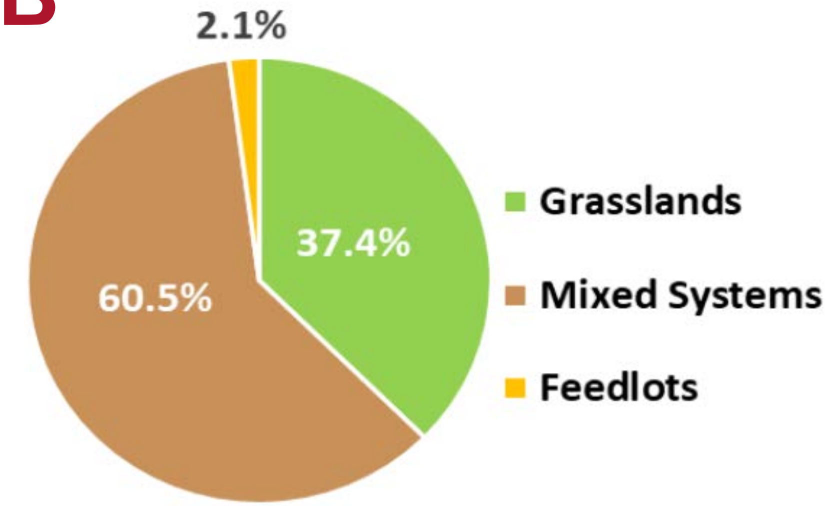

Muetzel et al. (2019); Hegarty et al. (2021)

Percent CH_4 reduction is unlikely to be constant

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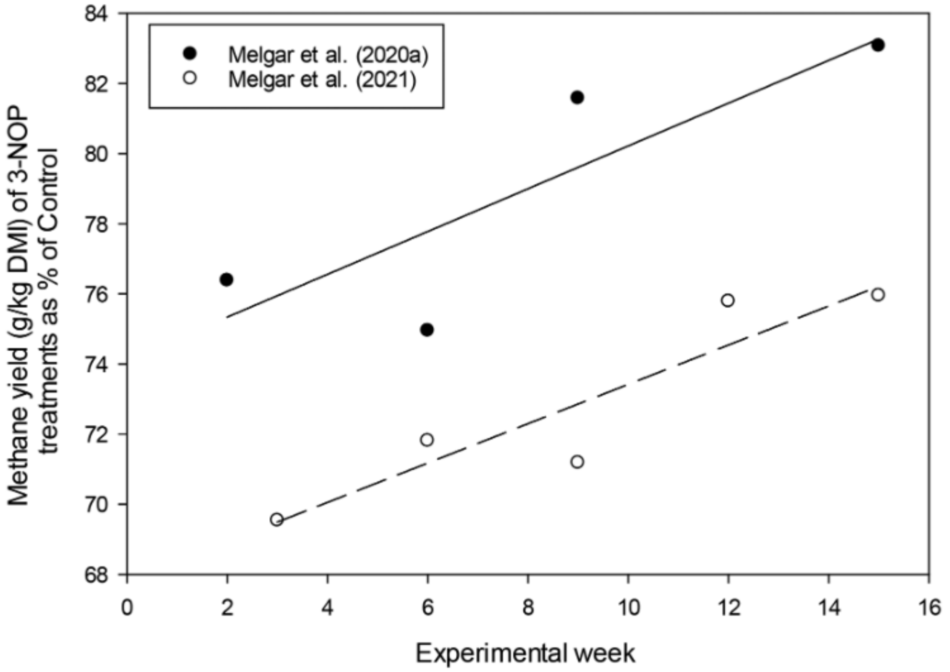

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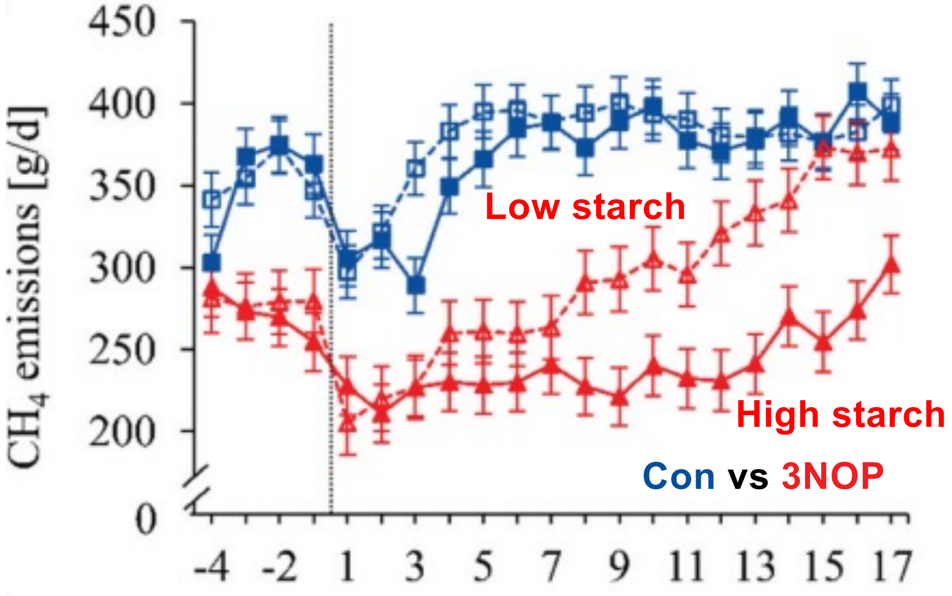
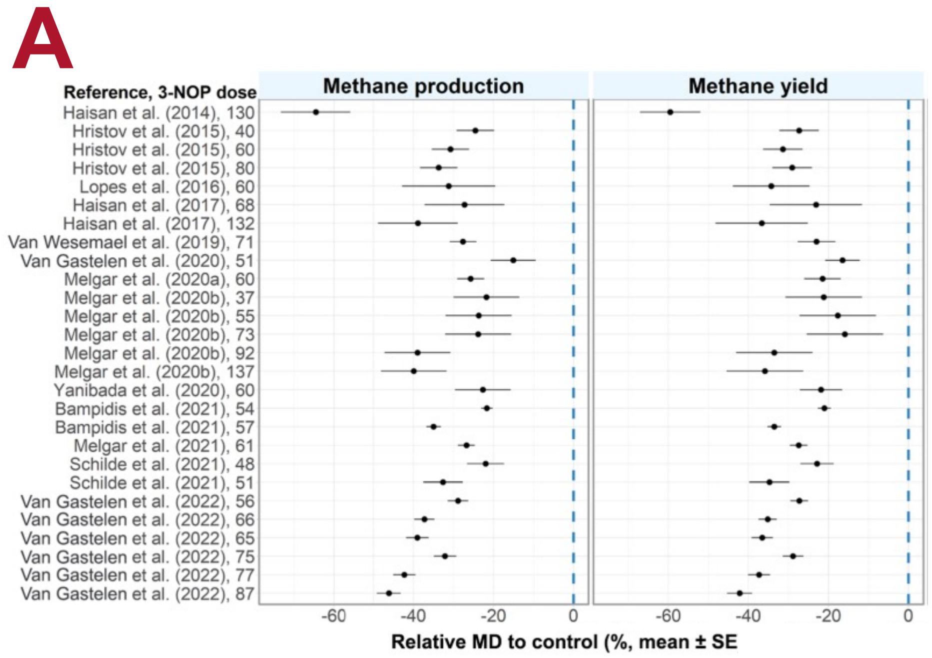
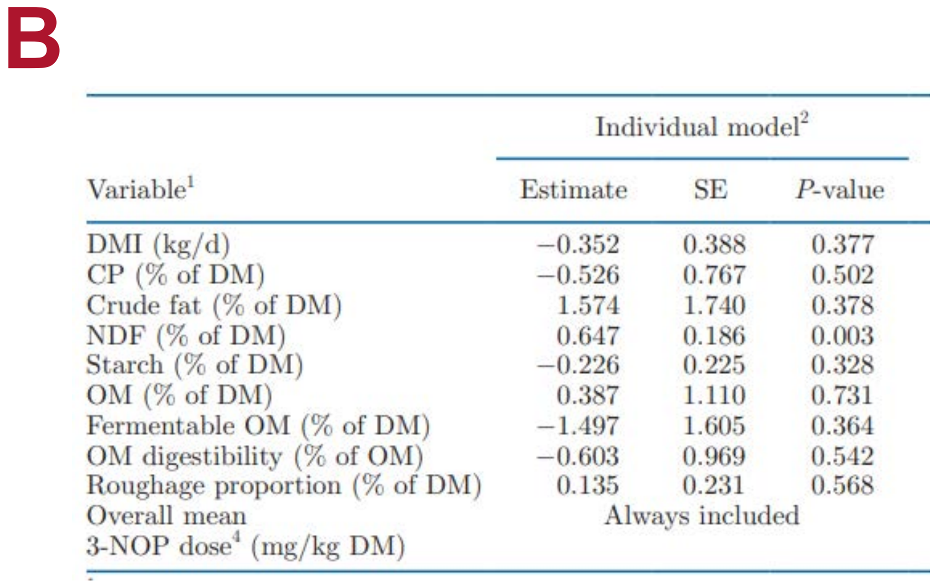


Melgar et al. (2020a; 2021); Schilde et al. (2021)

Meta-analyses provide confidence; can examine interactions





	Individual model[2]		
Variable[1]	Estimate	SE	*P*-value
DMI (kg/d)	−0.352	0.388	0.377
CP (% of DM)	−0.526	0.767	0.502
Crude fat (% of DM)	1.574	1.740	0.378
NDF (% of DM)	0.647	0.186	0.003
Starch (% of DM)	−0.226	0.225	0.328
OM (% of DM)	0.387	1.110	0.731
Fermentable OM (% of DM)	−1.497	1.605	0.364
OM digestibility (% of OM)	−0.603	0.969	0.542
Roughage proportion (% of DM)	0.135	0.231	0.568
Overall mean	Always included		
3-NOP dose[4] (mg/kg DM)			

Kebreab et al. (2023)

Manure GHG emissions are likely impacted by feed additives

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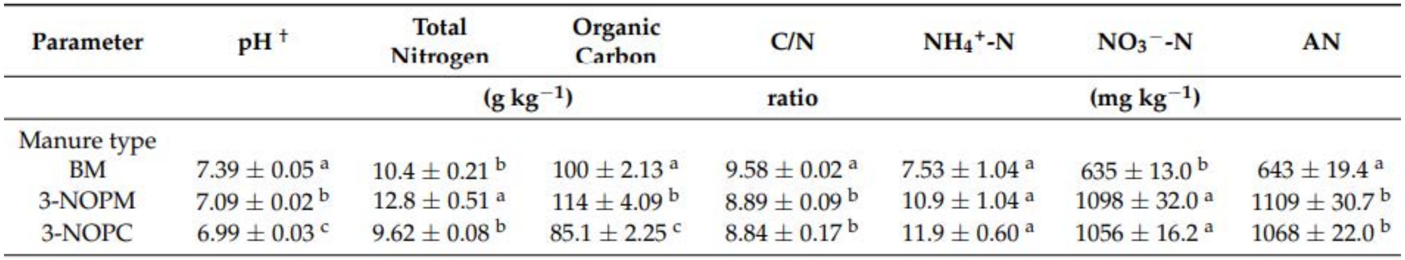

Parameter	pH †	Total Nitrogen	Organic Carbon	C/N	NH_4^+-N	NO_3^--N	AN
		($g\ kg^{-1}$)		ratio		($mg\ kg^{-1}$)	
Manure type							
BM	7.39 ± 0.05 ^{a}	10.4 ± 0.21 ^{b}	100 ± 2.13 ^{a}	9.58 ± 0.02 ^{a}	7.53 ± 1.04 ^{a}	635 ± 13.0 ^{b}	643 ± 19.4 ^{a}
3-NOPM	7.09 ± 0.02 ^{b}	12.8 ± 0.51 ^{a}	114 ± 4.09 ^{b}	8.89 ± 0.09 ^{b}	10.9 ± 1.04 ^{a}	1098 ± 32.0 ^{a}	1109 ± 30.7 ^{b}
3-NOPC	6.99 ± 0.03 ^{c}	9.62 ± 0.08 ^{b}	85.1 ± 2.25 ^{c}	8.84 ± 0.17 ^{b}	11.9 ± 0.60 ^{a}	1056 ± 16.2 ^{a}	1068 ± 22.0 ^{b}

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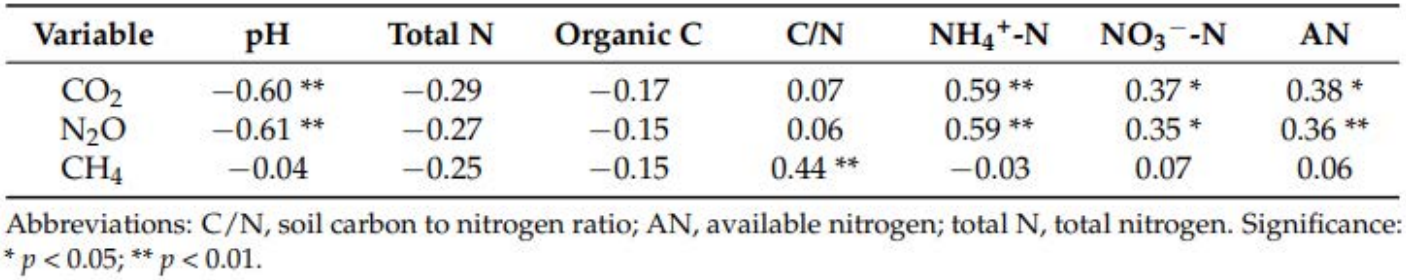

Variable	pH	Total N	Organic C	C/N	NH_4^+-N	NO_3^--N	AN
CO_2	−0.60 **	−0.29	−0.17	0.07	0.59 **	0.37 *	0.38 *
N_2O	−0.61 **	−0.27	−0.15	0.06	0.59 **	0.35 *	0.36 **
CH_4	−0.04	−0.25	−0.15	0.44 **	−0.03	0.07	0.06

Abbreviations: C/N, soil carbon to nitrogen ratio; AN, available nitrogen; total N, total nitrogen. Significance: * $p < 0.05$; ** $p < 0.01$.

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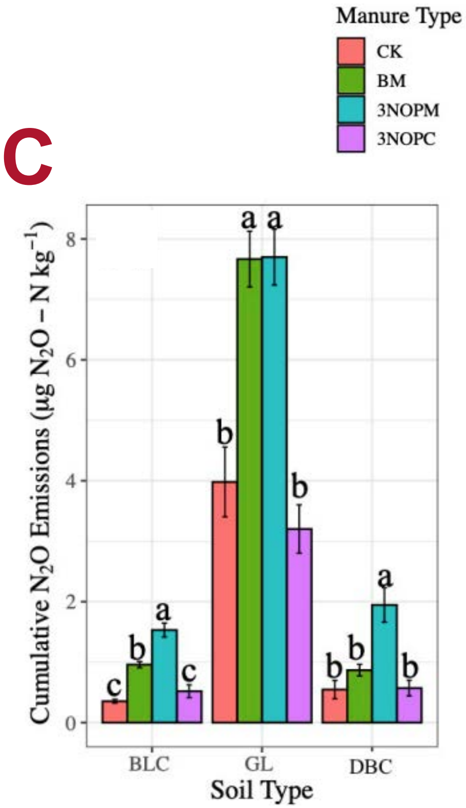
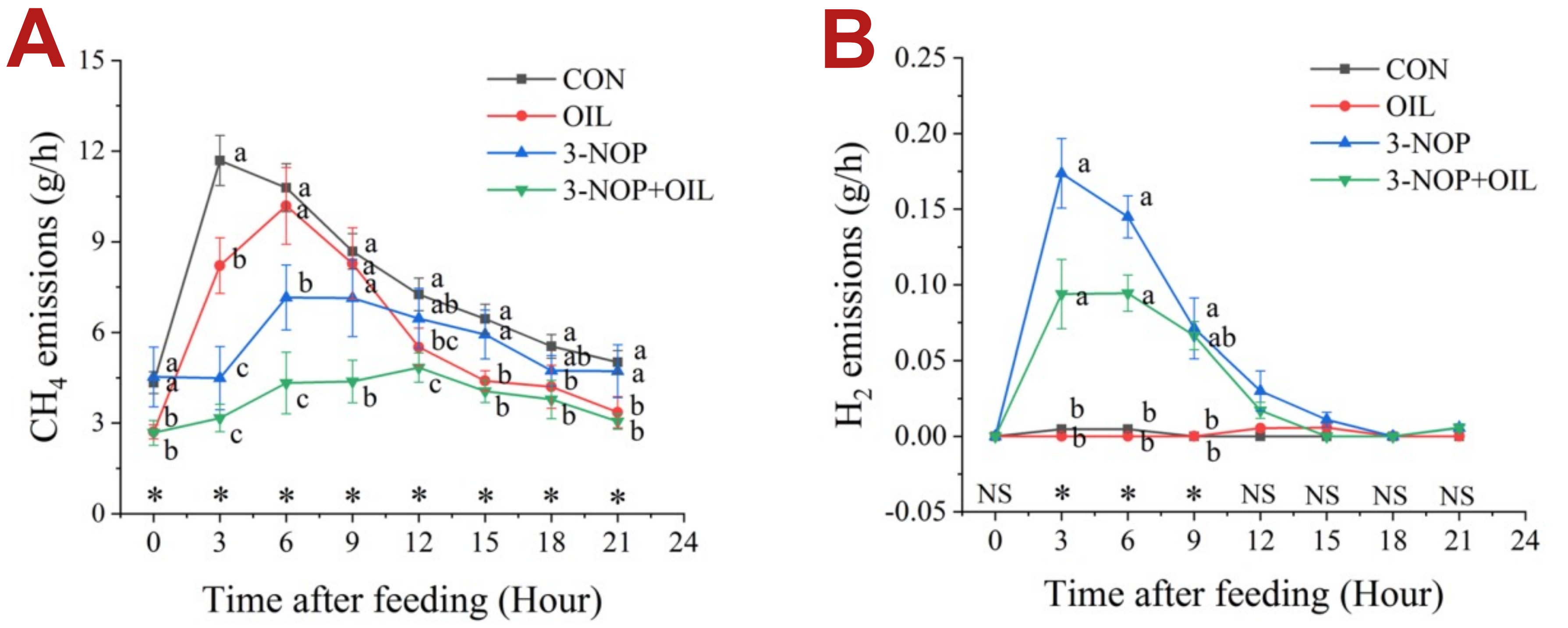


Weber et al. (2021)

Co-supplementation (or replacement) strategies needed



Gruninger et al. (2022); 3NOP at 200 mg/kg DM; canola at 50 g/kg DM

Co-supplementation (or replacement) strategies needed

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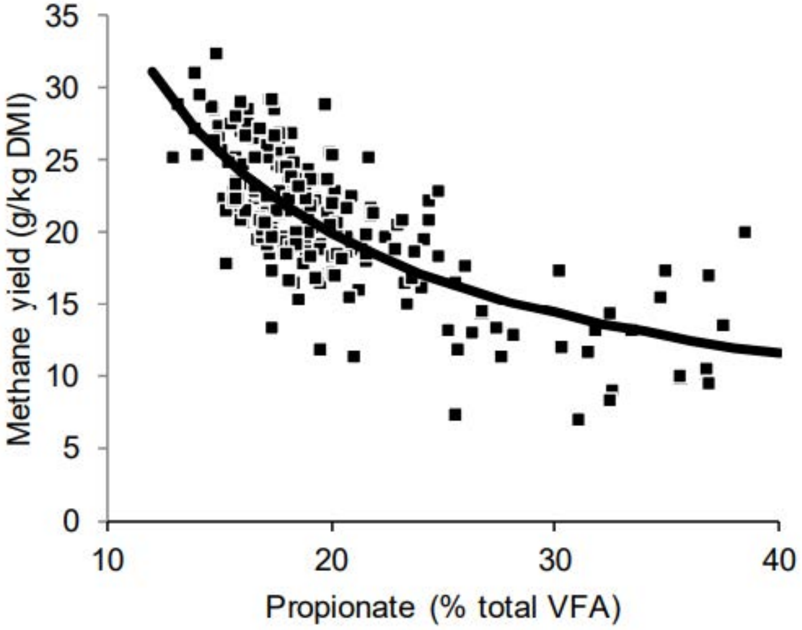

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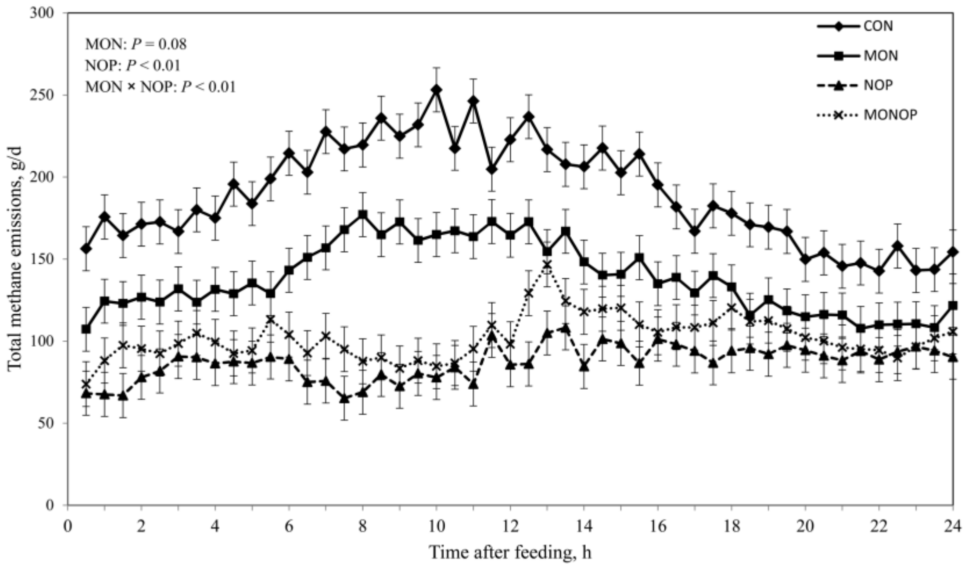
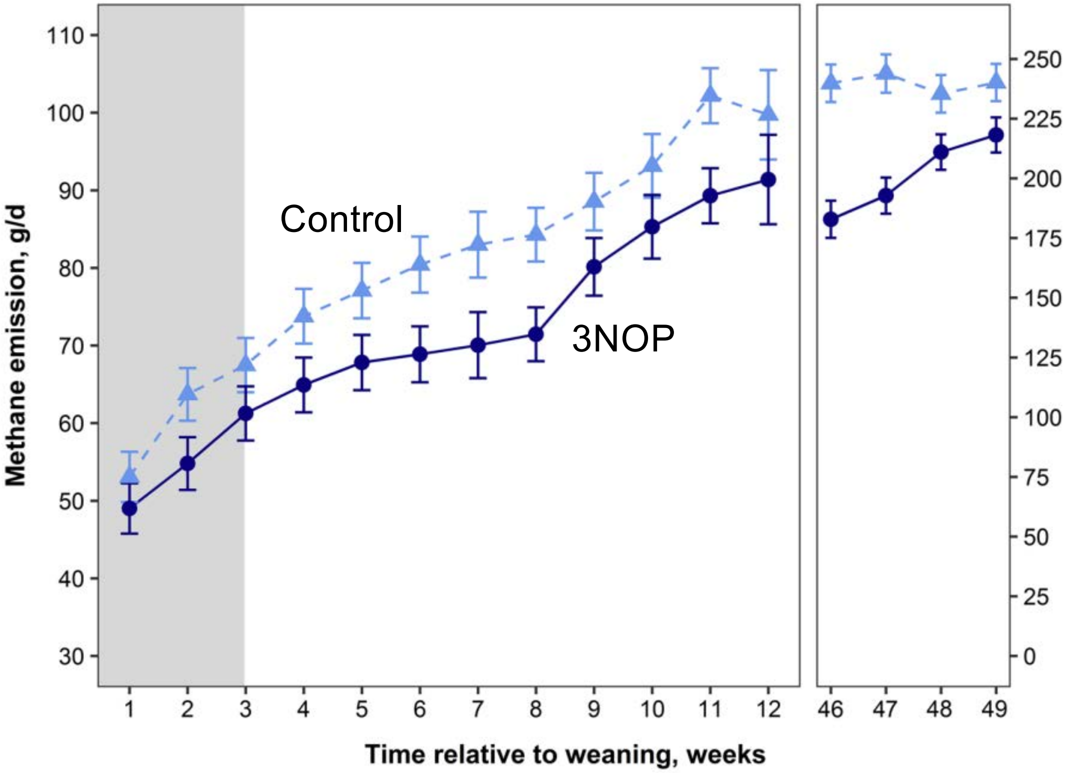


Vyas et al. (2018); Williams et al. (2019)

Early life interventions to inhibit methanogenesis are poorly defined

No change in
BW, ADG, VFA



Meale et al. (2021); 9 calves/treatment; Con vs 3NOP birth to 3 wk post-weaning.

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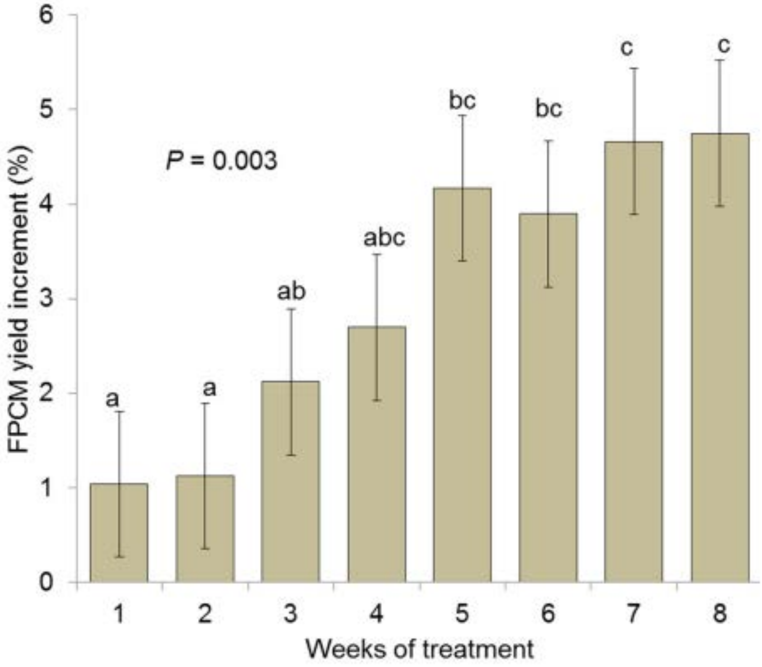
Mode of action cannot be a mystery

Essential oils (Agolin Ruminant; GRAS)

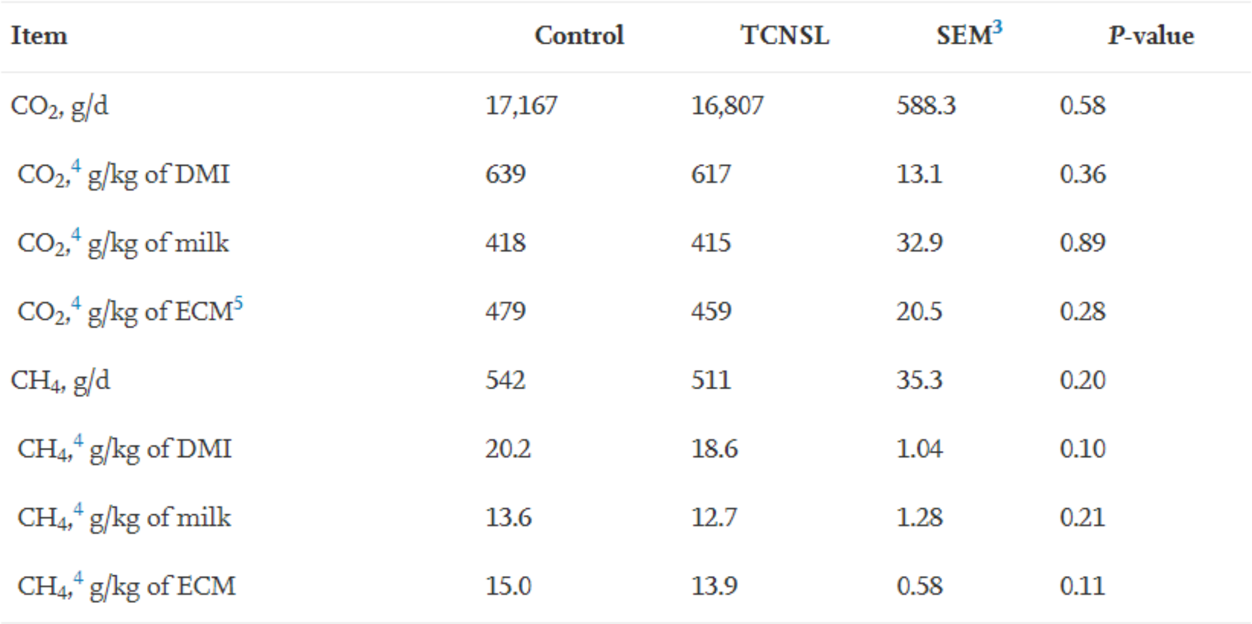
- Blend of essential oils: coriander seed oil, eugenol, geranyl acetate, and geraniol
- Increases ECM and feed efficiency
  - Milk and ECM response depends on duration of feeding (5 to 8 wk min); but, consistent and convincing 2-3% increase in yields
- Reduces methane production or intensity by ~10%
- No apparent change in DMI
- No apparent change on milk composition
- Paying carbon credits to dairies



Belanche et al. (2020); Carrazco et al. (2020)

Processed form of additive may impact efficacy

Cashew nut shell liquid: heated vs cold-pressed?



Item	Control	TCNSL	SEM[3]	*P*-value
CO_2, g/d	17,167	16,807	588.3	0.58
CO_2,[4] g/kg of DMI	639	617	13.1	0.36
CO_2,[4] g/kg of milk	418	415	32.9	0.89
CO_2,[4] g/kg of ECM[5]	479	459	20.5	0.28
CH_4, g/d	542	511	35.3	0.20
CH_4,[4] g/kg of DMI	20.2	18.6	1.04	0.10
CH_4,[4] g/kg of milk	13.6	12.7	1.28	0.21
CH_4,[4] g/kg of ECM	15.0	13.9	0.58	0.11

Branco et al. (2015)

In vitro testing has limited utility

- Garlic (allicin) and flavonoid-containing citrus extract (Mootral)
  - Proposed mode of action: Reduces methanogenic archaea populations
  - Efficacy superior in vitro and more specific for garlic
  - Efficacy in vivo uncertain; potentially 5 to 30%

- Oregano and green tea extract
  - Proposed mode of action: modified microbial community
  - No apparent impact on nutrient digestibility or milk production and composition
  - Potential reductions in ruminal protein degradation and ammonia production
  - Reduces methane/kg of digestible DM
  - Efficacy in vivo uncertain

- Cinnamon, clove, and thyme oil
  - No apparent effect on methane production in vivo

Seaweed is a potent methane inhibitor

- Methanogenesis inhibition proven for red macroalgae (e.g., *Asparagopsis armata*)

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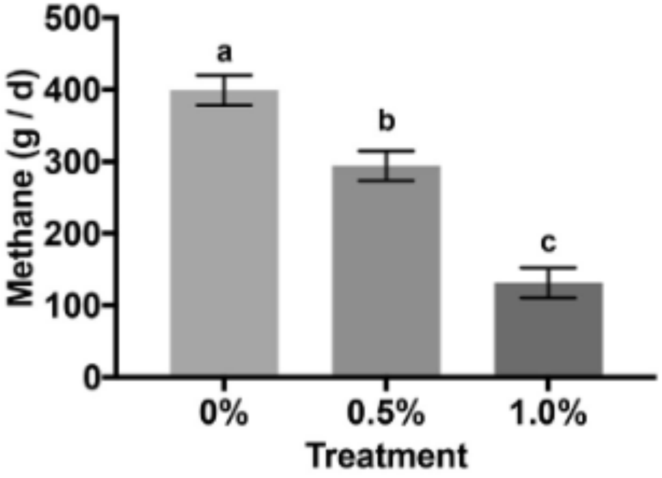

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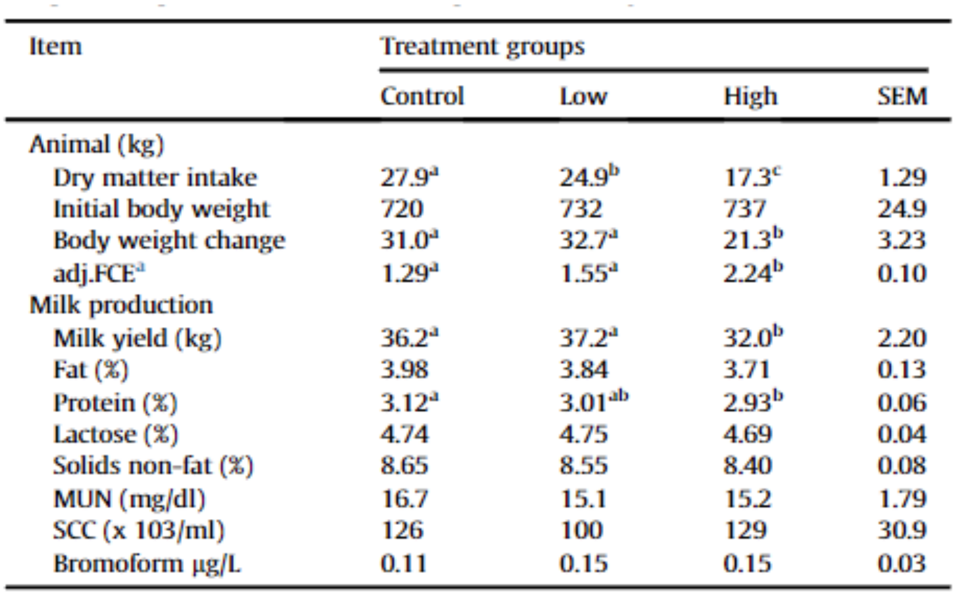

Item	Treatment groups			
	Control	Low	High	SEM
Animal (kg)				
Dry matter intake	27.9^{a}	24.9^{b}	17.3^{c}	1.29
Initial body weight	720	732	737	24.9
Body weight change	31.0^{a}	32.7^{a}	21.3^{b}	3.23
adj.FCE^{a}	1.29^{a}	1.55^{a}	2.24^{b}	0.10
Milk production				
Milk yield (kg)	36.2^{a}	37.2^{a}	32.0^{b}	2.20
Fat (%)	3.98	3.84	3.71	0.13
Protein (%)	3.12^{a}	3.01^{ab}	2.93^{b}	0.06
Lactose (%)	4.74	4.75	4.69	0.04
Solids non-fat (%)	8.65	8.55	8.40	0.08
MUN (mg/dl)	16.7	15.1	15.2	1.79
SCC (x 103/ml)	126	100	129	30.9
Bromoform µg/L	0.11	0.15	0.15	0.03

Roque et al. (2019)

Impact on animal health undefined; stability potential issue

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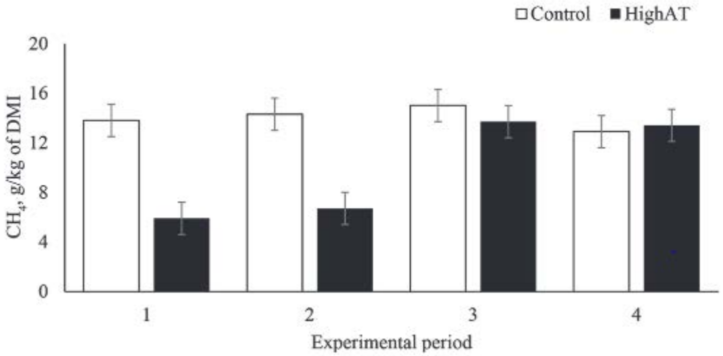

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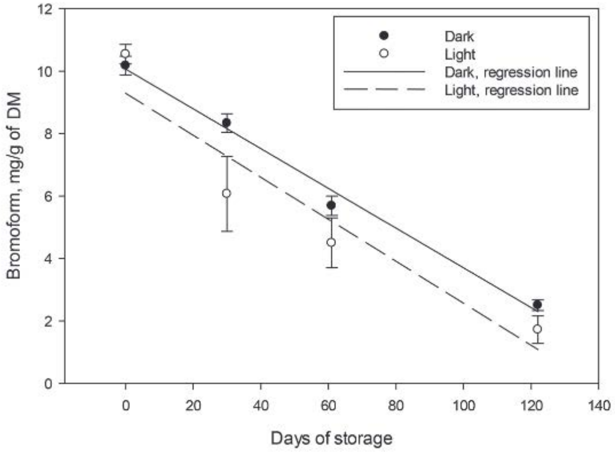


THE HILL

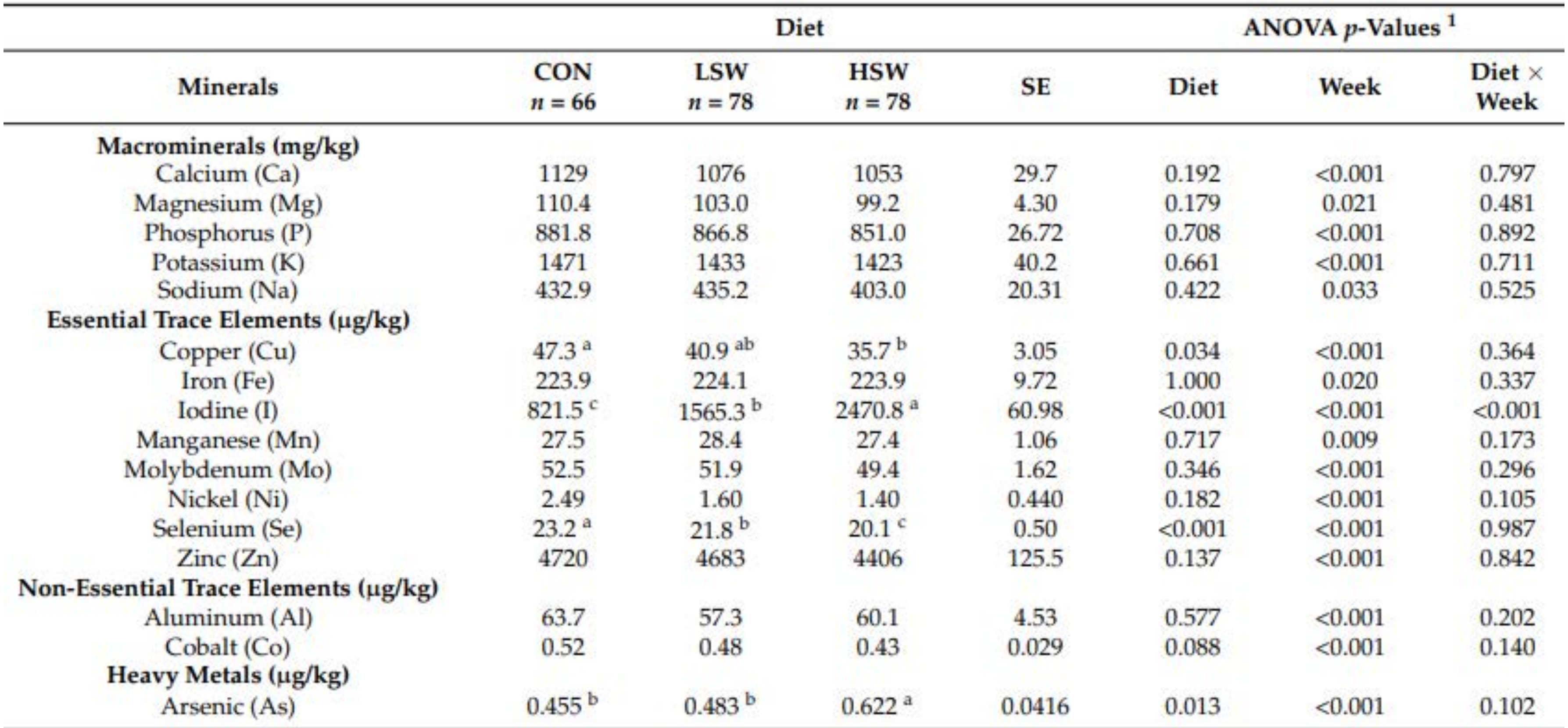
Hold off — for now — on feeding seaweed to cows to reduce methane

BY JOSEPH MCFADDEN, OPINION CONTRIBUTOR — 02/01/22 05:00 PM EST
THE VIEWS EXPRESSED BY CONTRIBUTORS ARE THEIR OWN AND NOT THE VIEW OF THE HILL

156 COMMENTS

Stefenoni et al. (2020); Muizelaar et al. (2021); McFadden (2022)

Nutrient composition of meat and milk can’t be ignored

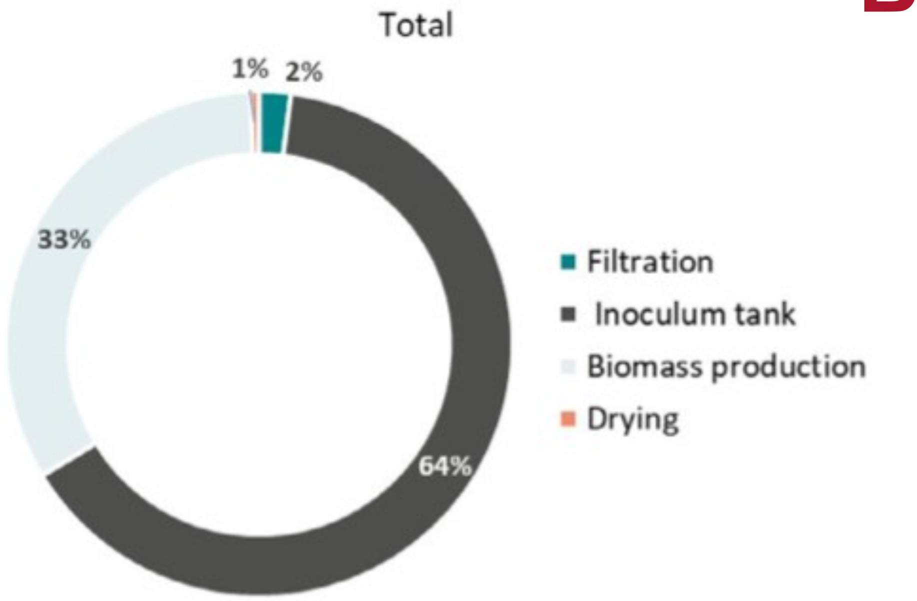


Minerals	Diet CON $n = 66$	Diet LSW $n = 78$	Diet HSW $n = 78$	Diet SE	ANOVA p-Values[1] Diet	ANOVA p-Values[1] Week	ANOVA p-Values[1] Diet × Week
Macrominerals (mg/kg)							
Calcium (Ca)	1129	1076	1053	29.7	0.192	<0.001	0.797
Magnesium (Mg)	110.4	103.0	99.2	4.30	0.179	0.021	0.481
Phosphorus (P)	881.8	866.8	851.0	26.72	0.708	<0.001	0.892
Potassium (K)	1471	1433	1423	40.2	0.661	<0.001	0.711
Sodium (Na)	432.9	435.2	403.0	20.31	0.422	0.033	0.525
Essential Trace Elements (μg/kg)							
Copper (Cu)	47.3^{a}	40.9^{ab}	35.7^{b}	3.05	0.034	<0.001	0.364
Iron (Fe)	223.9	224.1	223.9	9.72	1.000	0.020	0.337
Iodine (I)	821.5^{c}	1565.3^{b}	2470.8^{a}	60.98	<0.001	<0.001	<0.001
Manganese (Mn)	27.5	28.4	27.4	1.06	0.717	0.009	0.173
Molybdenum (Mo)	52.5	51.9	49.4	1.62	0.346	<0.001	0.296
Nickel (Ni)	2.49	1.60	1.40	0.440	0.182	<0.001	0.105
Selenium (Se)	23.2^{a}	21.8^{b}	20.1^{c}	0.50	<0.001	<0.001	0.987
Zinc (Zn)	4720	4683	4406	125.5	0.137	<0.001	0.842
Non-Essential Trace Elements (μg/kg)							
Aluminum (Al)	63.7	57.3	60.1	4.53	0.577	<0.001	0.202
Cobalt (Co)	0.52	0.48	0.43	0.029	0.088	<0.001	0.140
Heavy Metals (μg/kg)							
Arsenic (As)	0.455^{b}	0.483^{b}	0.622^{a}	0.0416	0.013	<0.001	0.102

Newton et al. (2021)

Additive manufacturing has an environmental impact

A



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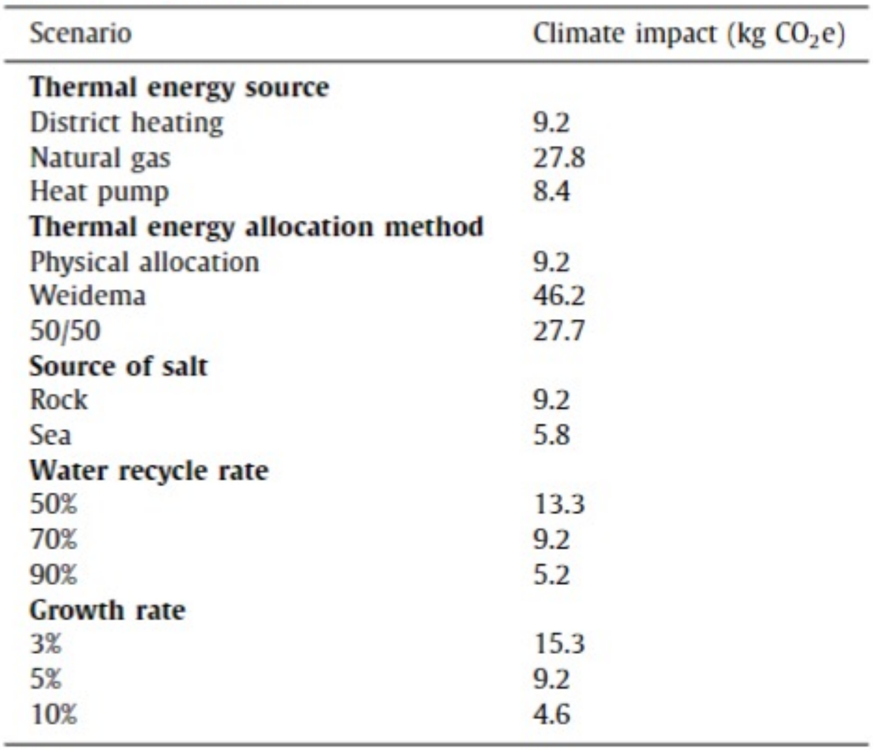
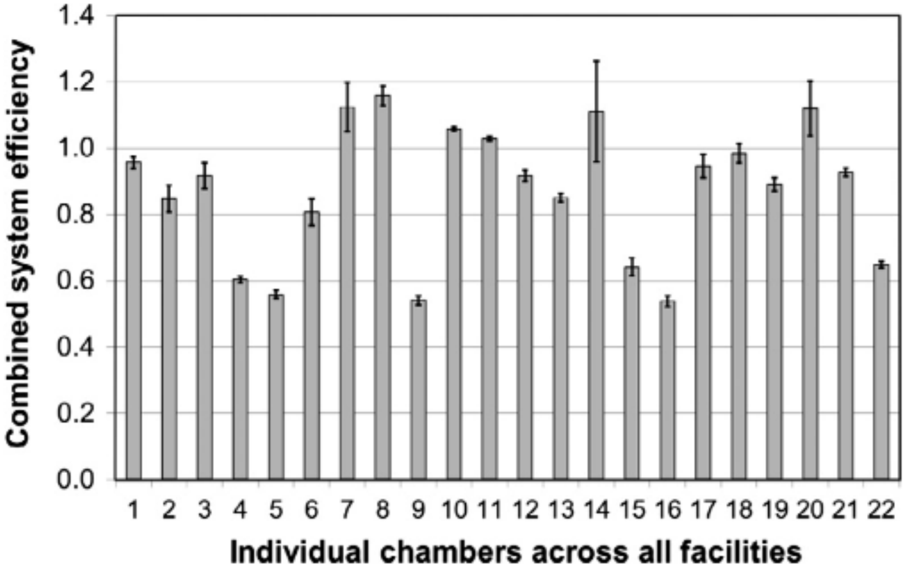


Scenario	Climate impact (kg CO_2e)
Thermal energy source	
District heating	9.2
Natural gas	27.8
Heat pump	8.4
Thermal energy allocation method	
Physical allocation	9.2
Weidema	46.2
50/50	27.7
Source of salt	
Rock	9.2
Sea	5.8
Water recycle rate	
50%	13.3
70%	9.2
90%	5.2
Growth rate	
3%	15.3
5%	9.2
10%	4.6

Nilsson and Martin (2022)

We can benefit from method standards

A



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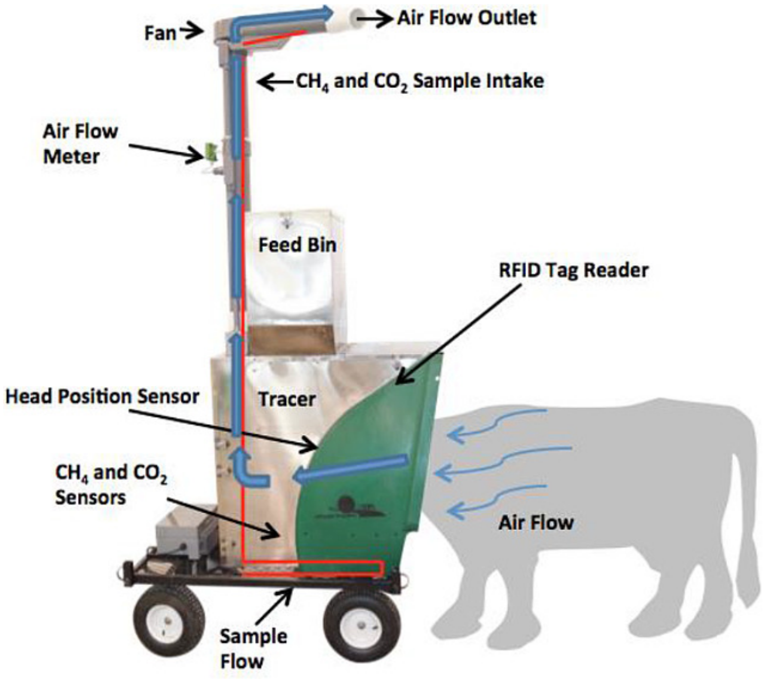
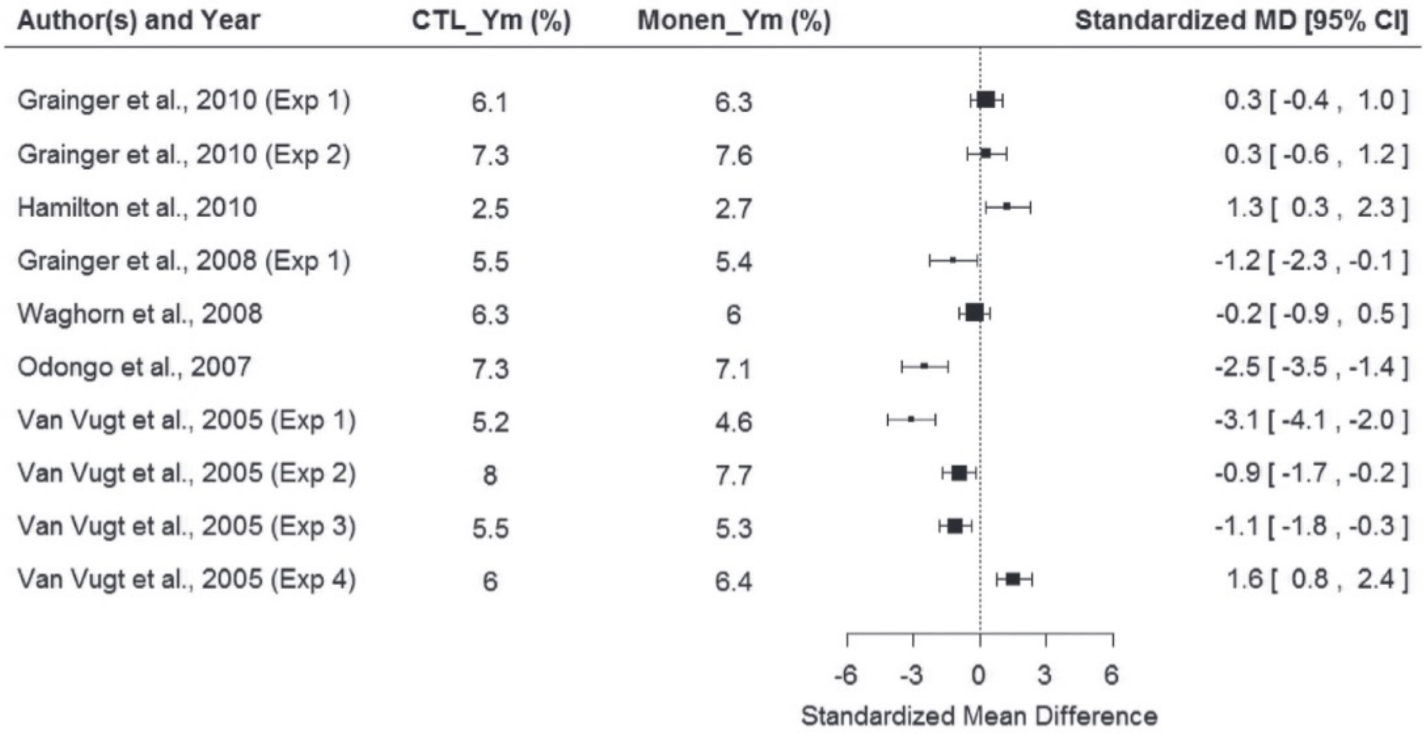


Hristov et al. (2015); Gardiner et al. (2015); Gerrits et al. (2018)

Detecting a 5% reduction in CH_4 requires high cow numbers

Observing significant methane reduction with ionophores not a given

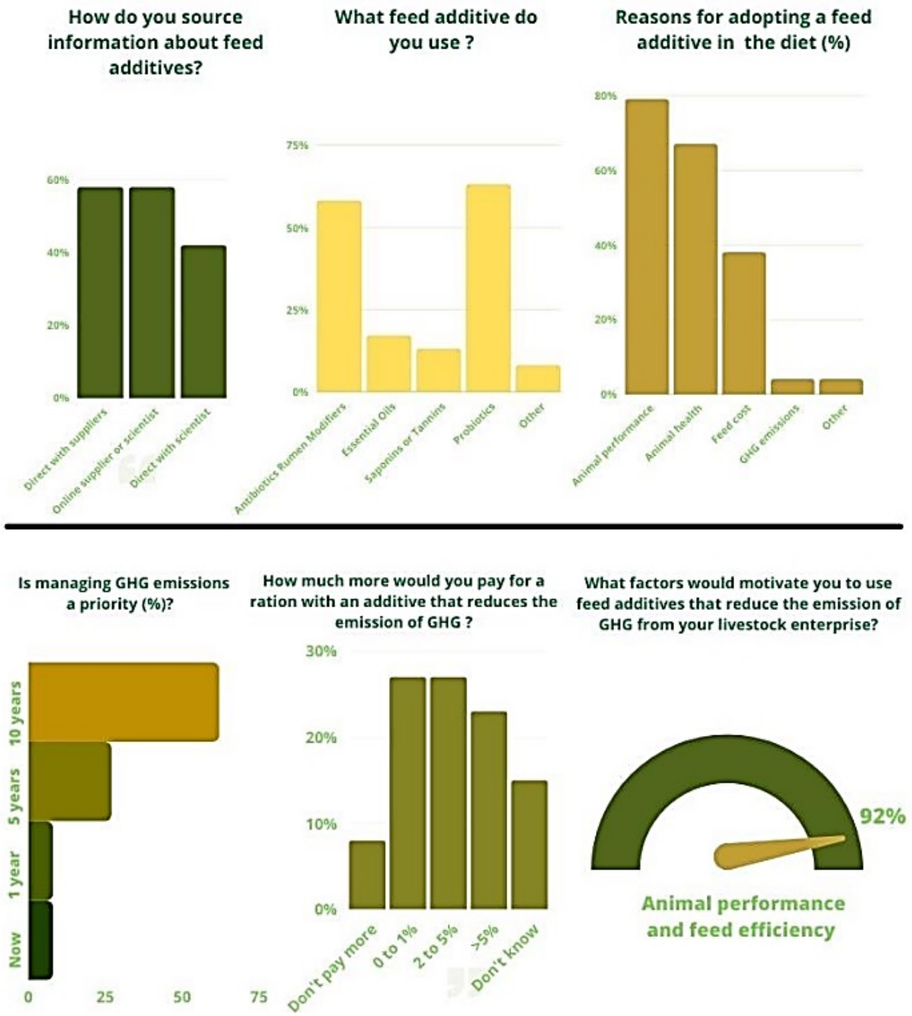


Author(s) and Year	CTL_Ym (%)	Monen_Ym (%)	Standardized MD [95% CI]
Grainger et al., 2010 (Exp 1)	6.1	6.3	0.3 [-0.4 , 1.0]
Grainger et al., 2010 (Exp 2)	7.3	7.6	0.3 [-0.6 , 1.2]
Hamilton et al., 2010	2.5	2.7	1.3 [0.3 , 2.3]
Grainger et al., 2008 (Exp 1)	5.5	5.4	-1.2 [-2.3 , -0.1]
Waghorn et al., 2008	6.3	6	-0.2 [-0.9 , 0.5]
Odongo et al., 2007	7.3	7.1	-2.5 [-3.5 , -1.4]
Van Vugt et al., 2005 (Exp 1)	5.2	4.6	-3.1 [-4.1 , -2.0]
Van Vugt et al., 2005 (Exp 2)	8	7.7	-0.9 [-1.7 , -0.2]
Van Vugt et al., 2005 (Exp 3)	5.5	5.3	-1.1 [-1.8 , -0.3]
Van Vugt et al., 2005 (Exp 4)	6	6.4	1.6 [0.8 , 2.4]

Appuhamy et al. (2013)

Survey of cattle producers and managers

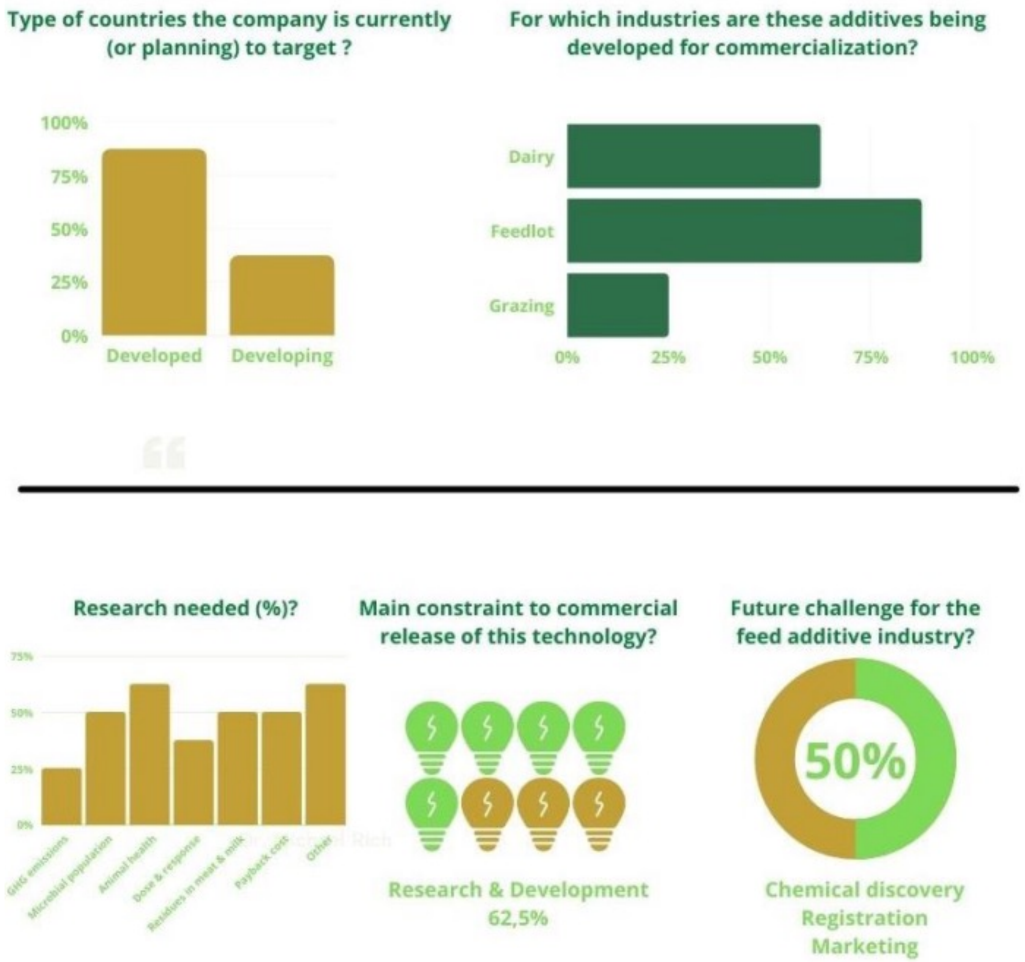
- Identified greenhouse gas reduction as a low priority but as increasing concern over the next 10 years.
- Expected methane inhibitors to deliver an increase in animal performance and feed efficiency.
- Need additional information to support decisions on feed additive use for methane, with the majority anticipating seeking that information from current feed/additive suppliers.



Hegarty et al. (2021)

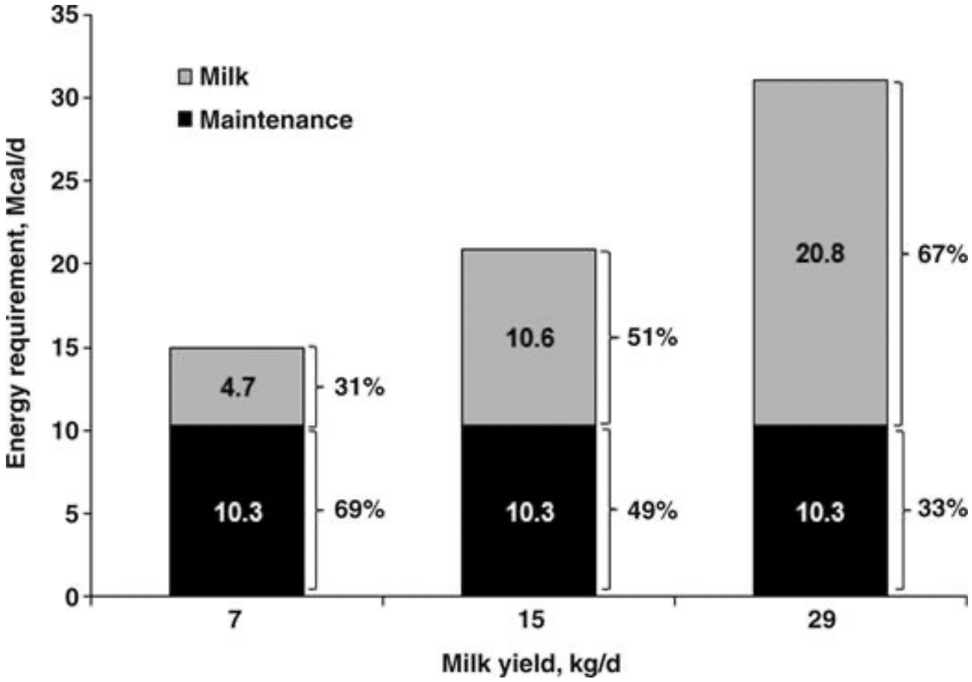
Survey of feed additive developers

- ➢ Targeting livestock in the developed rather than developing world.
- ➢ Data suggests pulsed intake of supplements won't work for developing world.
- ➢ Manufacturers are poorly informed regarding additives with highest efficacy.
- ➢ Low number of additives identified with high level mitigation is concerning; novel products needed.



Hegarty et al. (2021)

Efficiency is not equal in all countries



Enteric GHG emissions intensities (kg of CO_2e kg^{-1} milk):

USA

Holstein cow: 0.25

India

Crossbred cow: 1.21

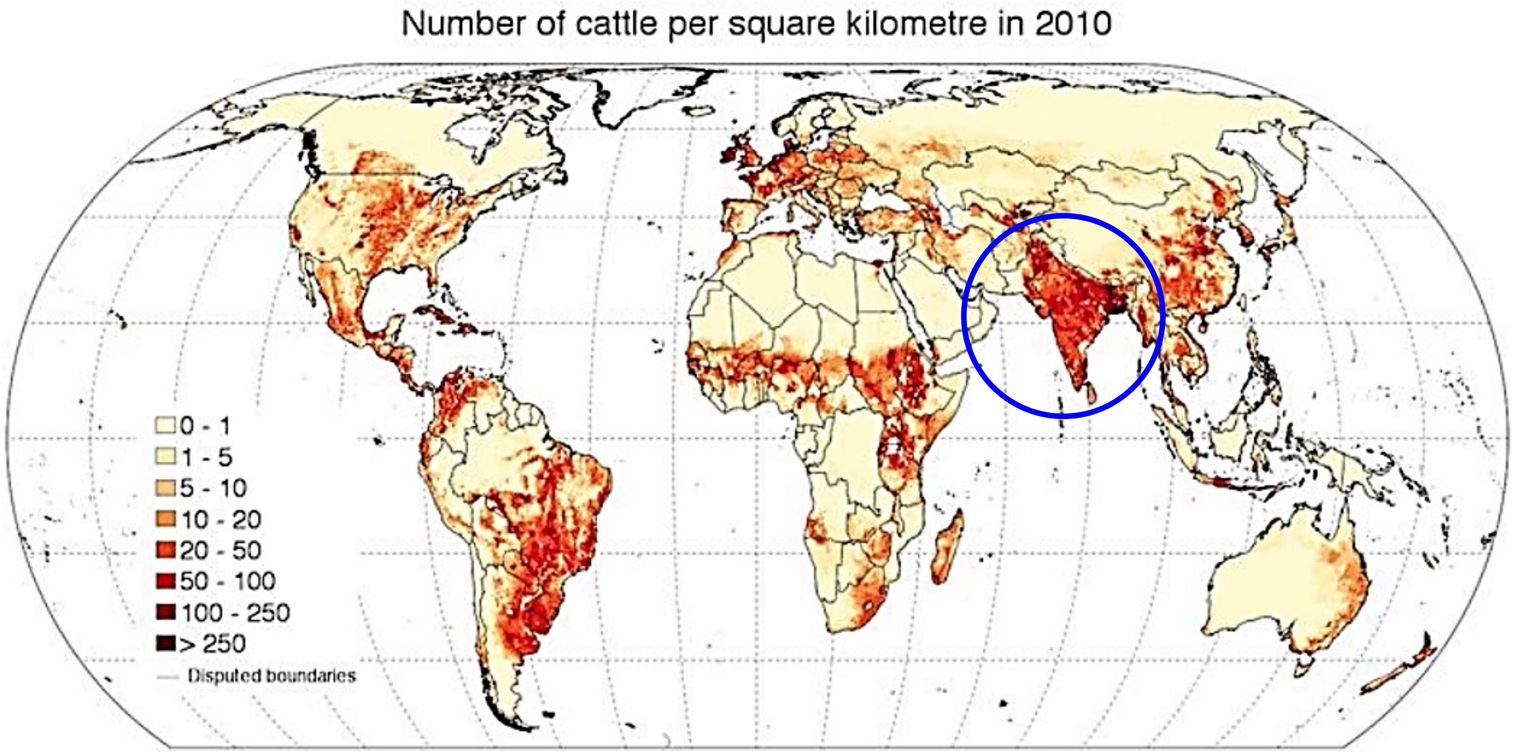
Buffalo: 1.85

Goat: 2.54

Indigenous cow: 2.96

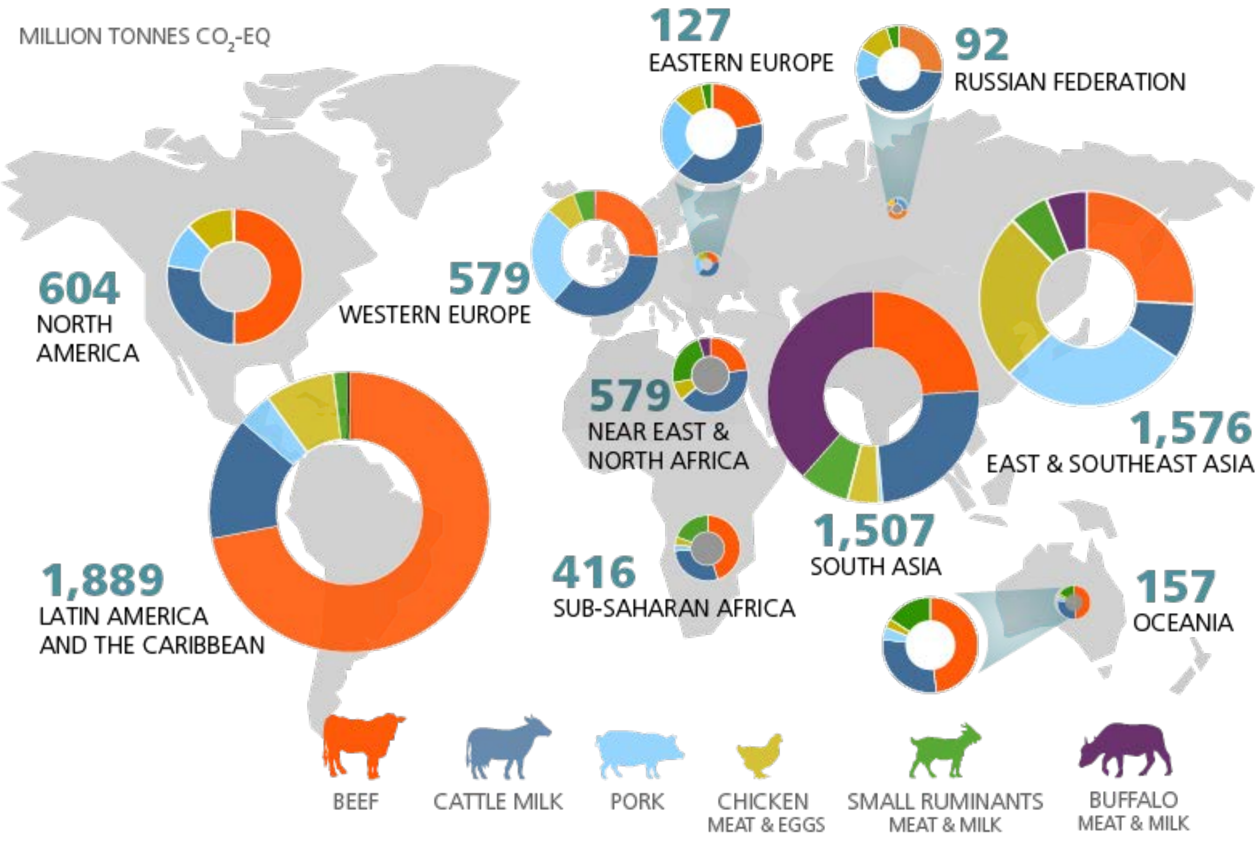
Capper et al. (2008); Patra (2017); Tricarico et al. (2020)

300+ million cattle and buffaloes in India



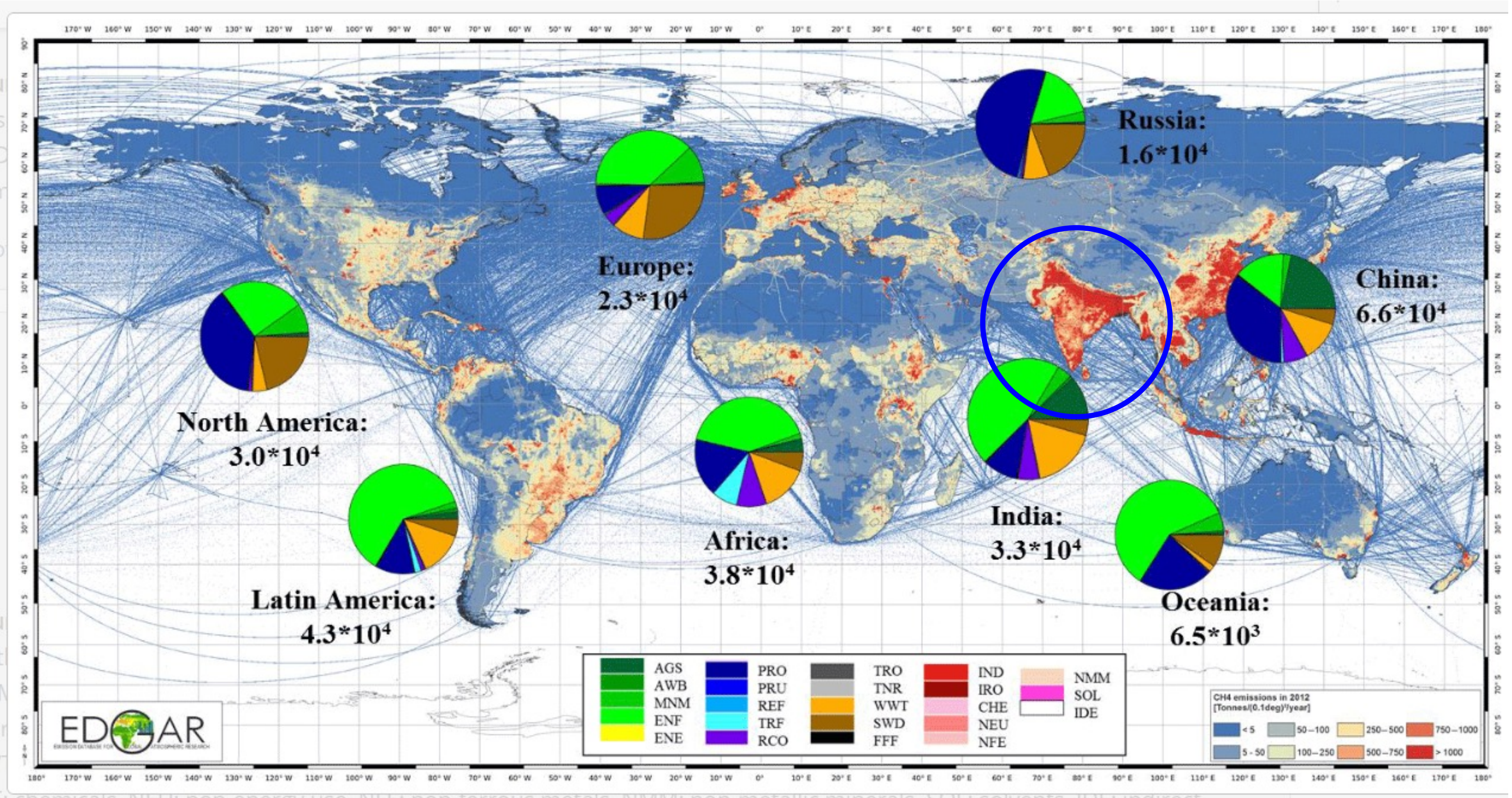
Hegde (2019)

Regional total emissions and their profile by commodity

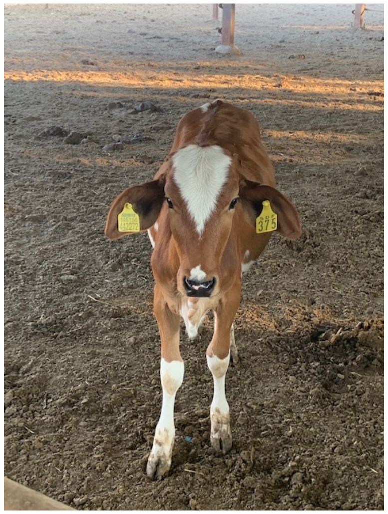


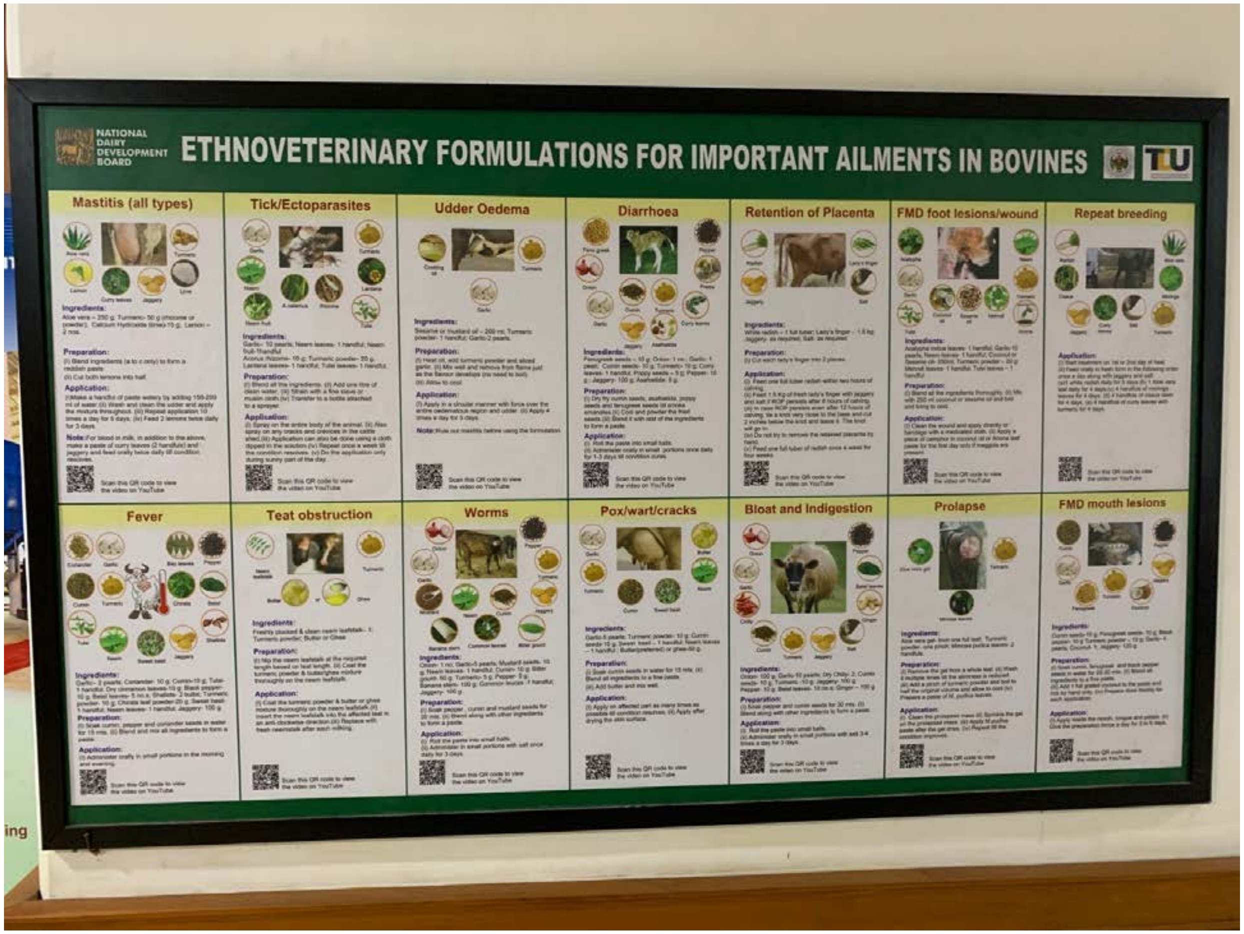
FAO, 2022 (GLEAM 2.0)

India has high methane emissions



Janssens-Maenhout et al. (2019)


375



NATIONAL DAIRY DEVELOPMENT BOARD

ETHNOVETERINARY FORMULATIONS FOR IMPORTANT AILMENTS IN BOVINES

Mastitis (all types)

Tick/Ectoparasites

Udder Oedema

Diarrhoea

Retention of Placenta

FMD foot lesions/wound

Repeat breeding

Fever

Teat obstruction

Worms

Pox/wart/cracks

Bloat and Indigestion

Prolapse

FMD mouth lesions

EDF
ENVIRONMENTAL
DEFENSE FUND®

Finding the ways that work

Cornell CALS

College of Agriculture
and Life Sciences

Cornell LIFE

Livestock
Innovations for
Food Security and
Environmental Health

Past 2 years:

- $2+ million from NYS, NY Ag and Markets, Cargill, and Balchem Corporation to build infrastructure for feed additive testing
- 4 respiration chambers for complete enteric and manure gas exchange
- 3+ GreenFeed units
- Cornell dairy upgrades for large-scale production trials
- Analytical equipment
- Staff support
- New strategic plan and faculty hires
- Communication campaign

No one person can solve this challenge

- **Lab manager:** Dr. Nirosh Seneviratne
- **Admin coordinator:** Lindsay Sprague
- **Postdocs:** Patrick Zang, Pinar Uzun, Ananda Fontoura
- **Grad students:** Becca Culbertson, Awais Javaid, Miranda Farricker, Fabian Oviedo, Tanya France, Charlie You, Olivia Wen, Andrew Richards (intern)

- **Current openings:**
  - 3 graduate student positions
  - 2 postdoc positions

Transparency is key

- National Science Foundation Integrative Organismal Systems (2022)
- Foundation for Food and Agriculture Research Foundation Seeding Solutions (2019)
- USDA NIFA AFRI Foundational Program (2013, 2016, 2019, 2021)
- Foundation for Food and Agriculture Research Foundation Graduate Fellowship (2018)
- National Science Foundation Fellowship Program (2017)
- USDA Northeast Sustainable Agriculture Research and Education Program (2013, 2018, 2019)
- Northeast Agribusiness & Feed Alliance

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Mitigation of enteric methane emissions: How can we speed up progress?

J. W. McFadden[1], P. K. Rosenstein[2], and A. N. Davis[3]

[1]Associate Professor of Dairy Cattle Biology; Northeast Agribusiness and Feed Alliance Faculty Fellow
Cornell Atkinson Center for Sustainability Faculty Fellow; Department of Animal Science

Questions?

[2] Environmental Defense Fund, [3]SUNY Cortland
McFadden@Cornell.edu; 🐦 @RuminateOnThis

Cornell CALS College of Agriculture and Life Sciences