Enteric Methane:

What are we doing?

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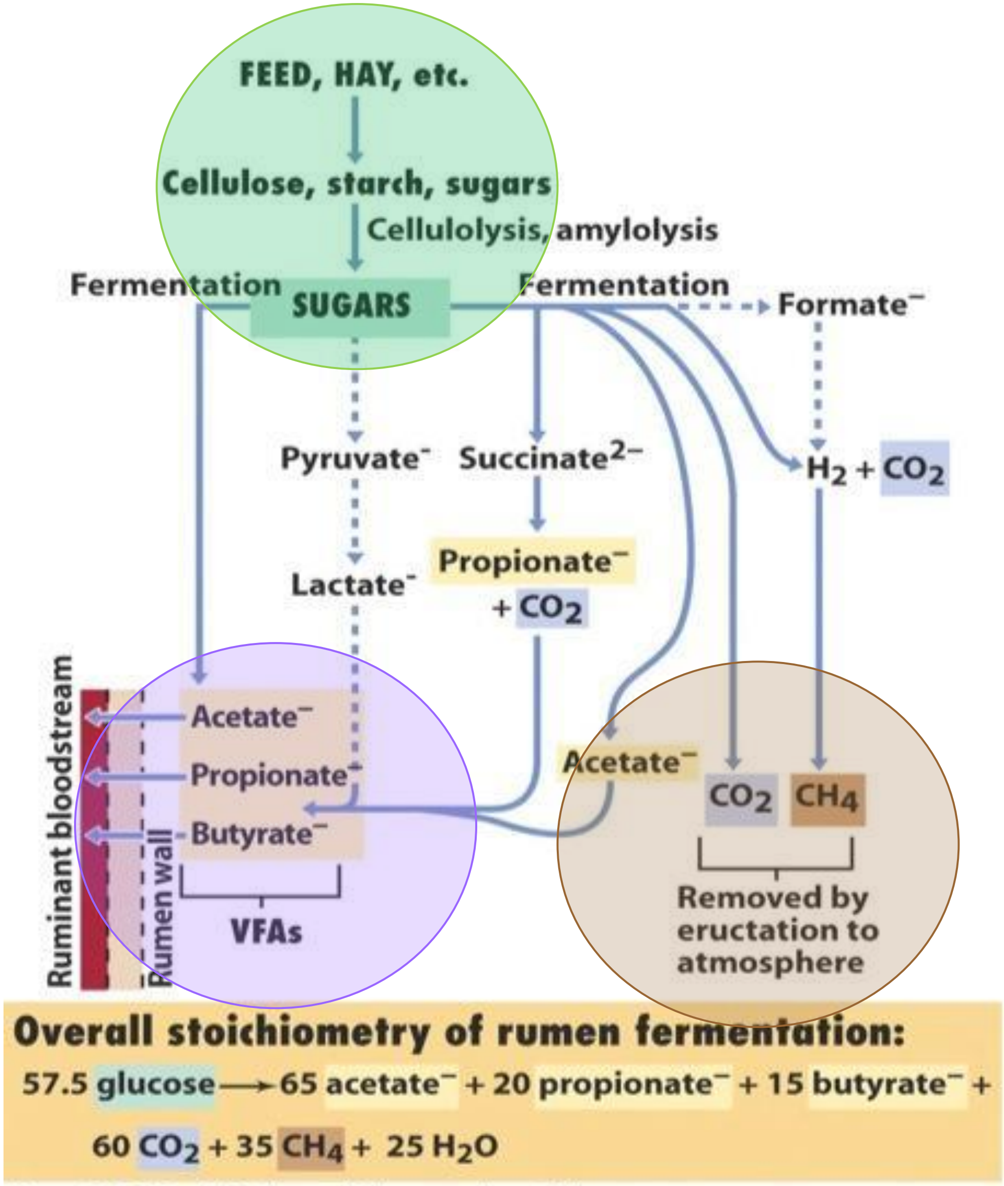
General Description of Rumen Fermentation and Methane Production

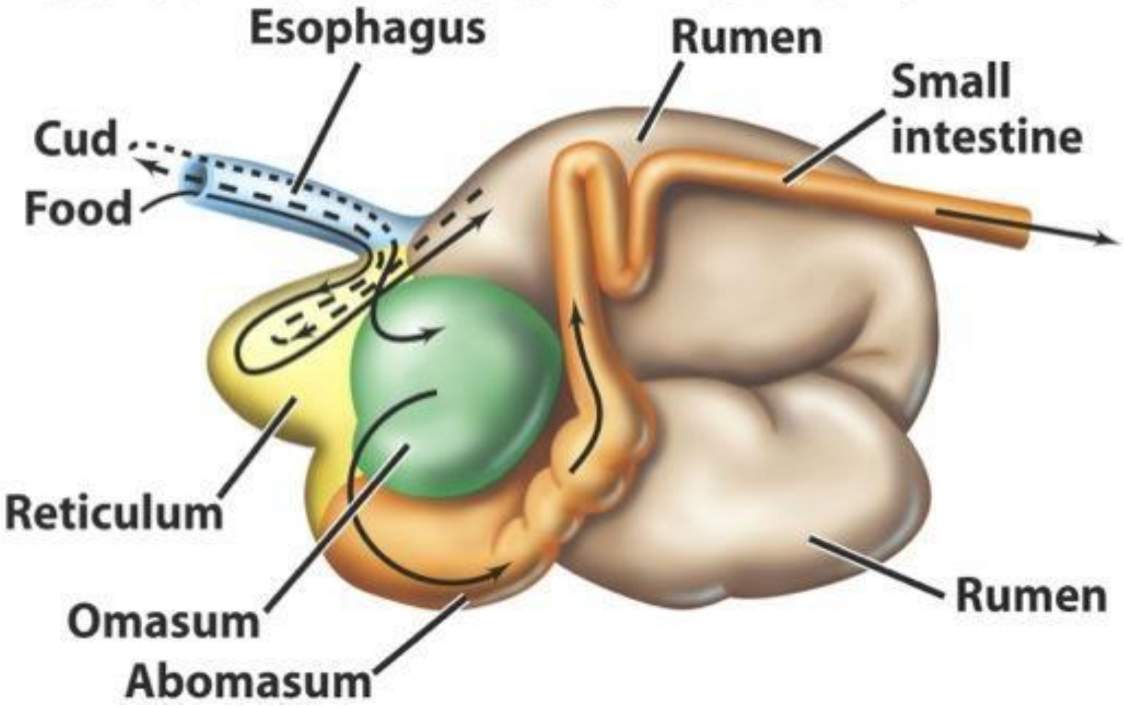


Overall stoichiometry of rumen fermentation:

$$57.5\ \text{glucose} \longrightarrow 65\ \text{acetate}^- + 20\ \text{propionate}^- + 15\ \text{butyrate}^- + 60\ CO_2 + 35\ CH_4 + 25\ H_2O$$

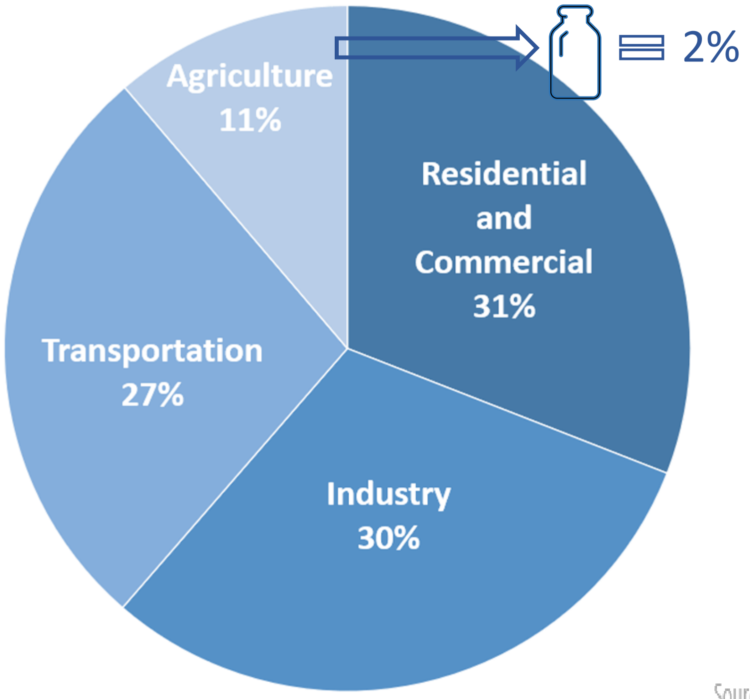
Figure 19-27 Brock Biology of Microorganisms 11/e
© 2006 Pearson Prentice Hall, Inc.

bacterial fermentation of glucose from feed Produces:
volatile fatty acids (VFAs):
acetic, propionic, and butyric acid
and gases:
carbon dioxide and **methane**



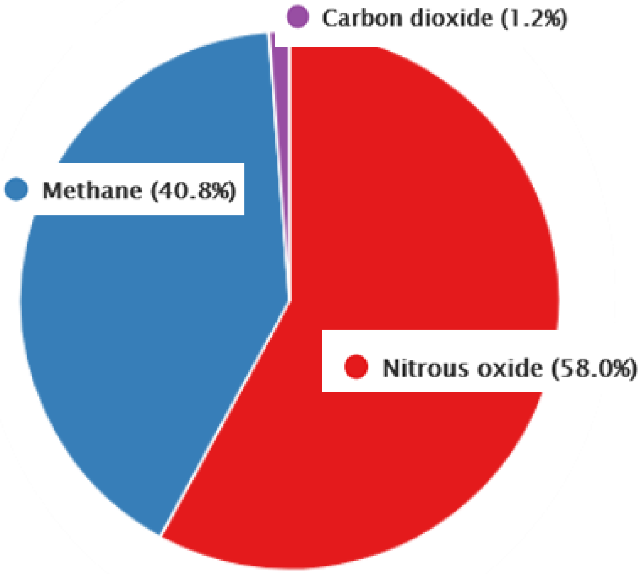
US Greenhouse Gas Emissions from Agriculture

Total U.S. Greenhouse Gas Emissions by Sector with Electricity Distributed

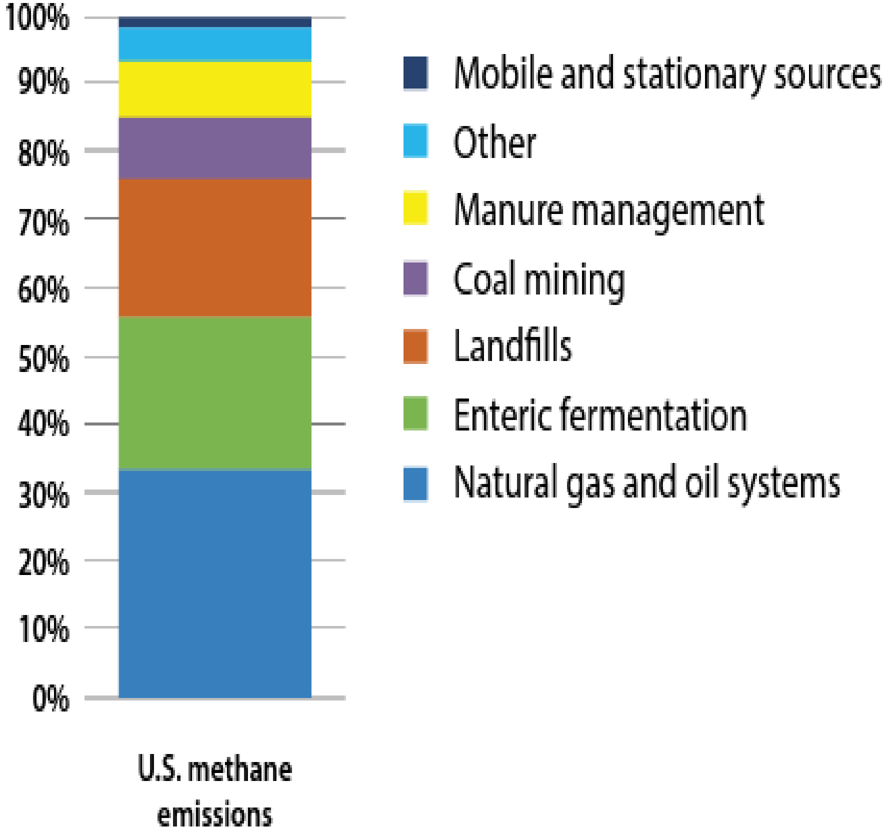


U.S. Environmental Protection Agency (2022). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020

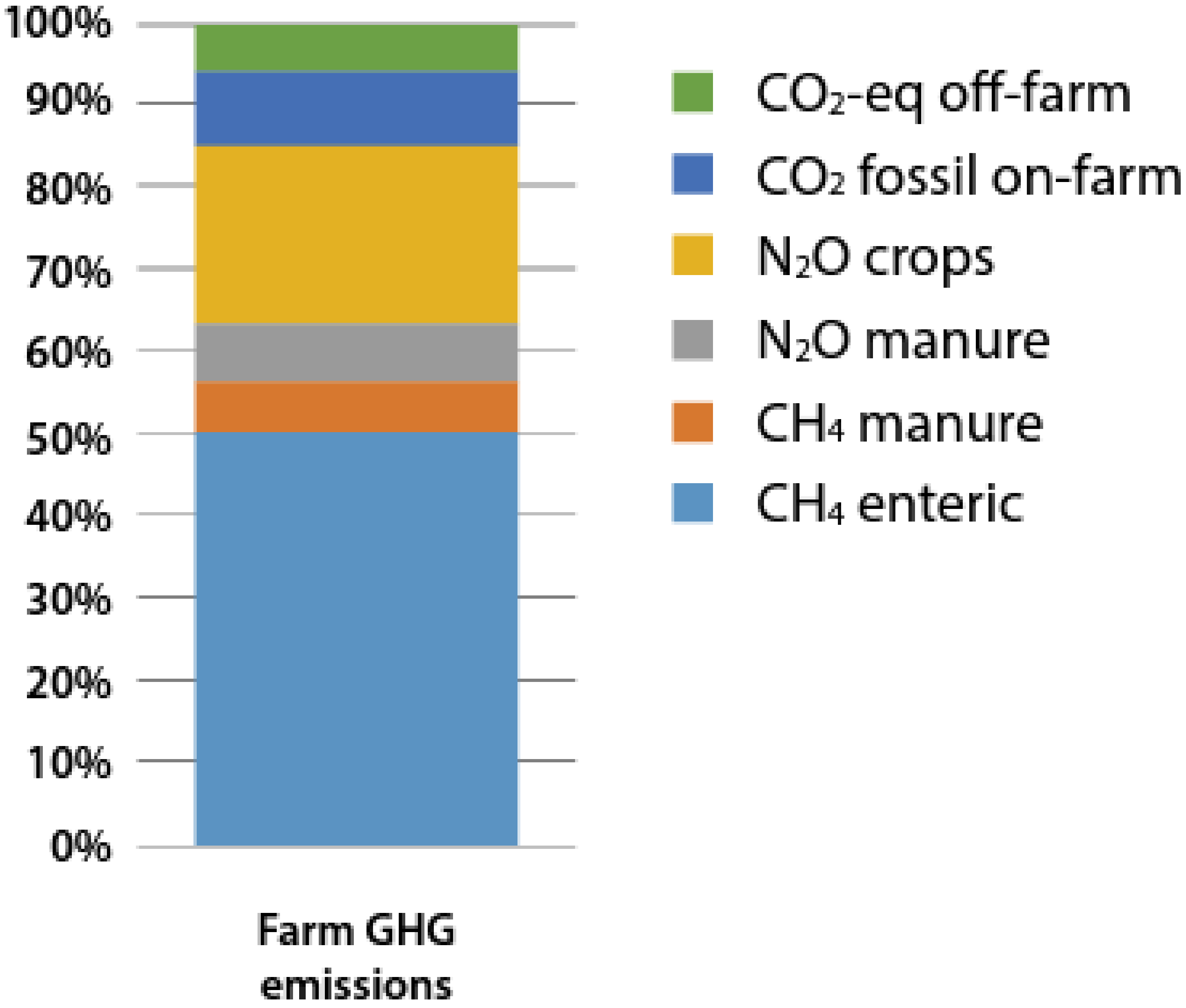
US GHG Emissions from Ag. Activities by Gas (2019)



Source: U.S. EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks



Farm Level **GHG** Emissions



sustainabledairy.org

Capper and Cady – 2007 to 2017

The industry is doing great things

All categories reduced by 15 to 31% except for transport which increased by 12%

That is amazing progress over 10 years!

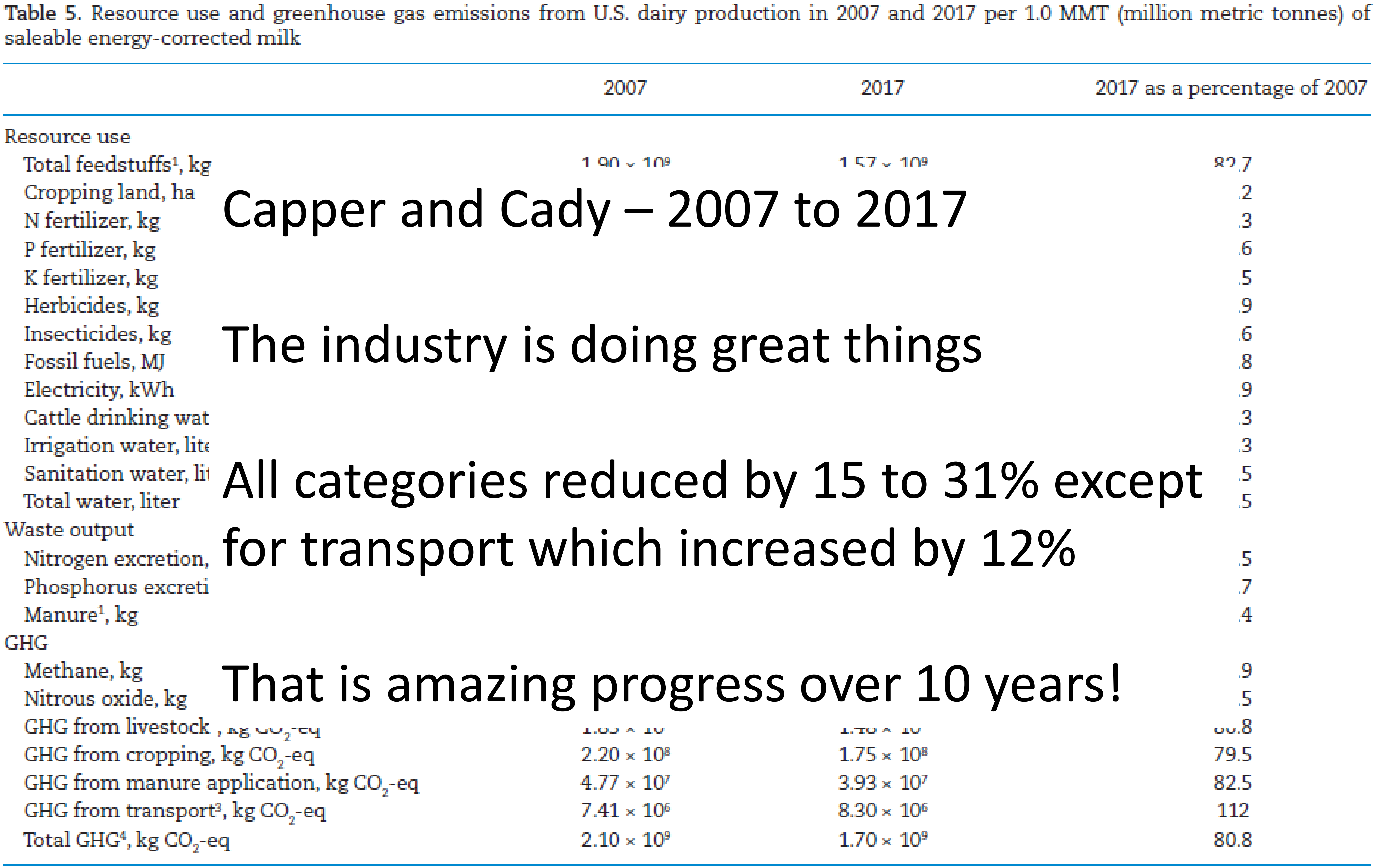
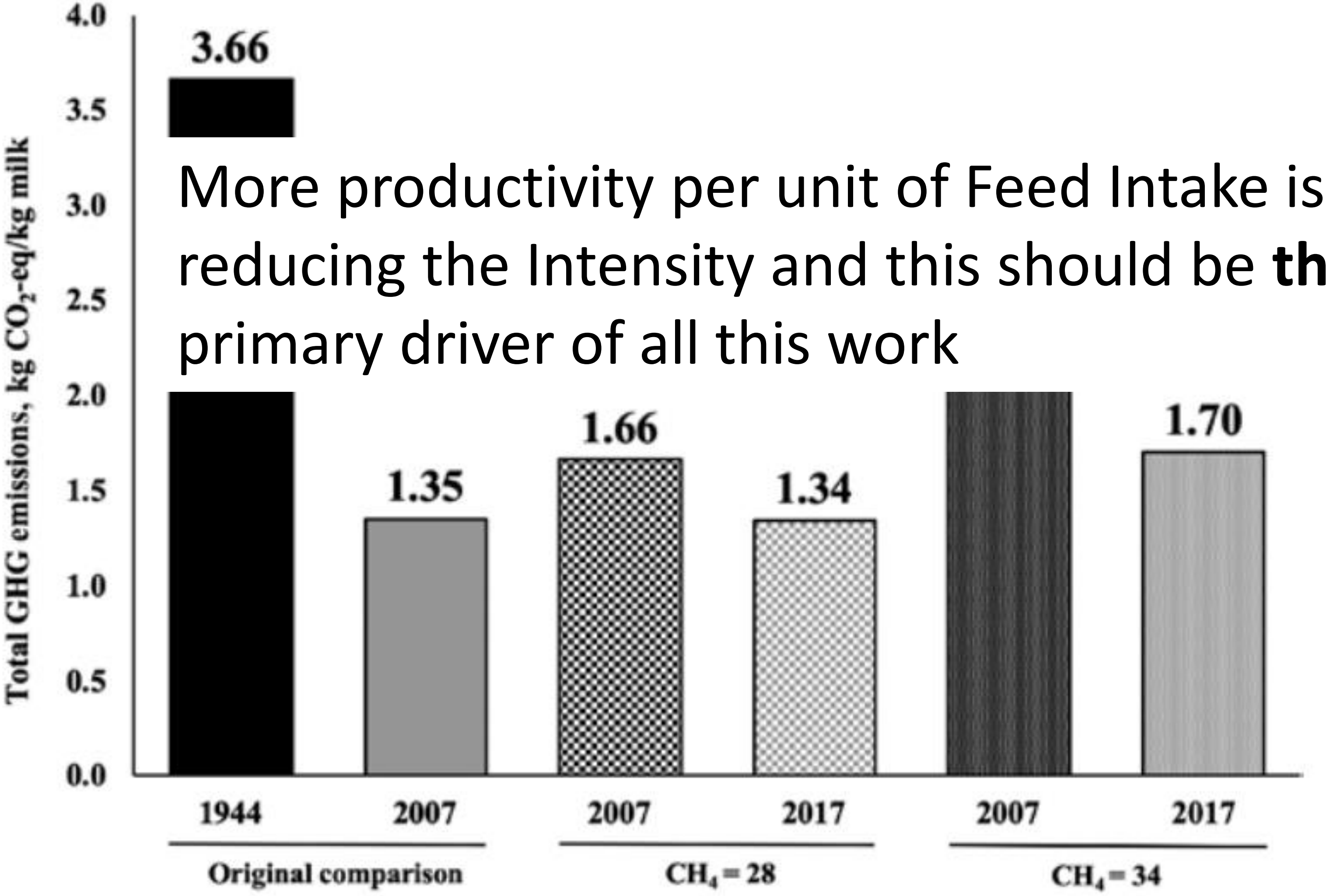


Table 5. Resource use and greenhouse gas emissions from U.S. dairy production in 2007 and 2017 per 1.0 MMT (million metric tonnes) of saleable energy-corrected milk

	2007	2017	2017 as a percentage of 2007
Resource use			
Total feedstuffs[1], kg	1.90×10^9	1.57×10^9	82.7
Cropping land, ha	[illegible]	[illegible]	[illegible]
N fertilizer, kg	[illegible]	[illegible]	[illegible]
P fertilizer, kg	[illegible]	[illegible]	[illegible]
K fertilizer, kg	[illegible]	[illegible]	[illegible]
Herbicides, kg	[illegible]	[illegible]	[illegible]
Insecticides, kg	[illegible]	[illegible]	[illegible]
Fossil fuels, MJ	[illegible]	[illegible]	[illegible]
Electricity, kWh	[illegible]	[illegible]	[illegible]
Cattle drinking wat	[illegible]	[illegible]	[illegible]
Irrigation water, lit	[illegible]	[illegible]	[illegible]
Sanitation water, li	[illegible]	[illegible]	[illegible]
Total water, liter	[illegible]	[illegible]	[illegible]
Waste output			
Nitrogen excretion,	[illegible]	[illegible]	[illegible]
Phosphorus excreti	[illegible]	[illegible]	[illegible]
Manure[1], kg	[illegible]	[illegible]	[illegible]
GHG			
Methane, kg	[illegible]	[illegible]	[illegible]
Nitrous oxide, kg	[illegible]	[illegible]	[illegible]
GHG from livestock	[illegible]	[illegible]	[illegible]
GHG from cropping, kg CO_2-eq	2.20×10^8	1.75×10^8	79.5
GHG from manure application, kg CO_2-eq	4.77×10^7	3.93×10^7	82.5
GHG from transport[3], kg CO_2-eq	7.41×10^6	8.30×10^6	112
Total GHG[4], kg CO_2-eq	2.10×10^9	1.70×10^9	80.8

Capper and Cady, J. Anim. Sci. 2020

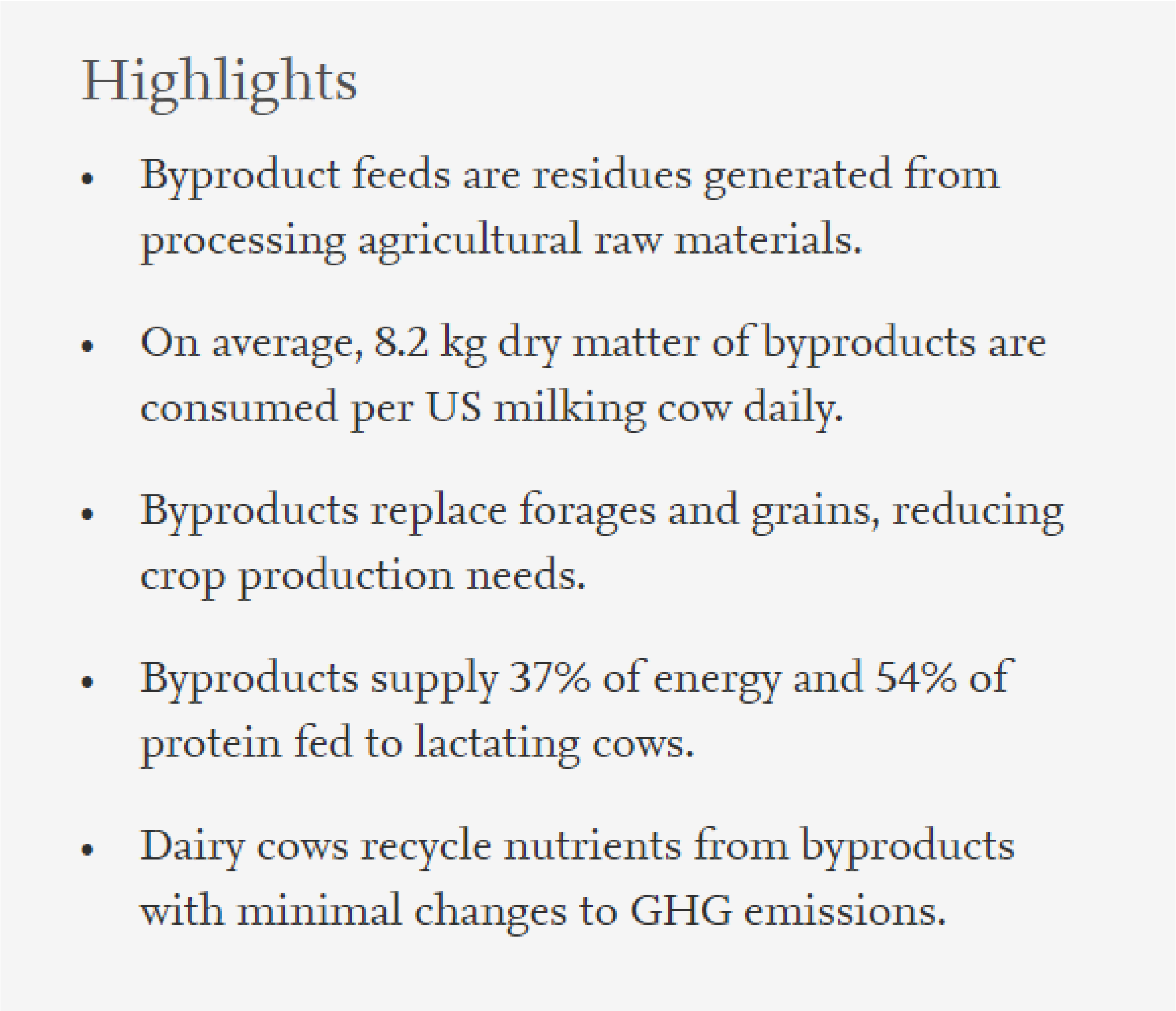


More productivity per unit of Feed Intake is reducing the Intensity and this should be **the** primary driver of all this work

Figure 2. Greenhouse gases (CO_2-eq) per kilogram of milk in original 1944 vs. 2007 comparison (Capper et al., 2009) compared to the current 2007 vs. 2017 comparison with global warming potential values for methane set at 28 (IPCC, 2006) and 34 (IPCC, 2013).

Capper and Cady, 2020

Nutritional contributions and non-CO_2 greenhouse gas emissions from human-inedible byproduct feeds consumed by dairy cows in the United States



Highlights

- Byproduct feeds are residues generated from processing agricultural raw materials.
- On average, 8.2 kg dry matter of byproducts are consumed per US milking cow daily.
- Byproducts replace forages and grains, reducing crop production needs.
- Byproducts supply 37% of energy and 54% of protein fed to lactating cows.
- Dairy cows recycle nutrients from byproducts with minimal changes to GHG emissions.

De Ondarza and Tricarico, J. Cleaner Production, 2015

Approximately 30% of US dairy cattle diets are comprised of byproducts of the human food chain

Van Amburgh et al., 2019

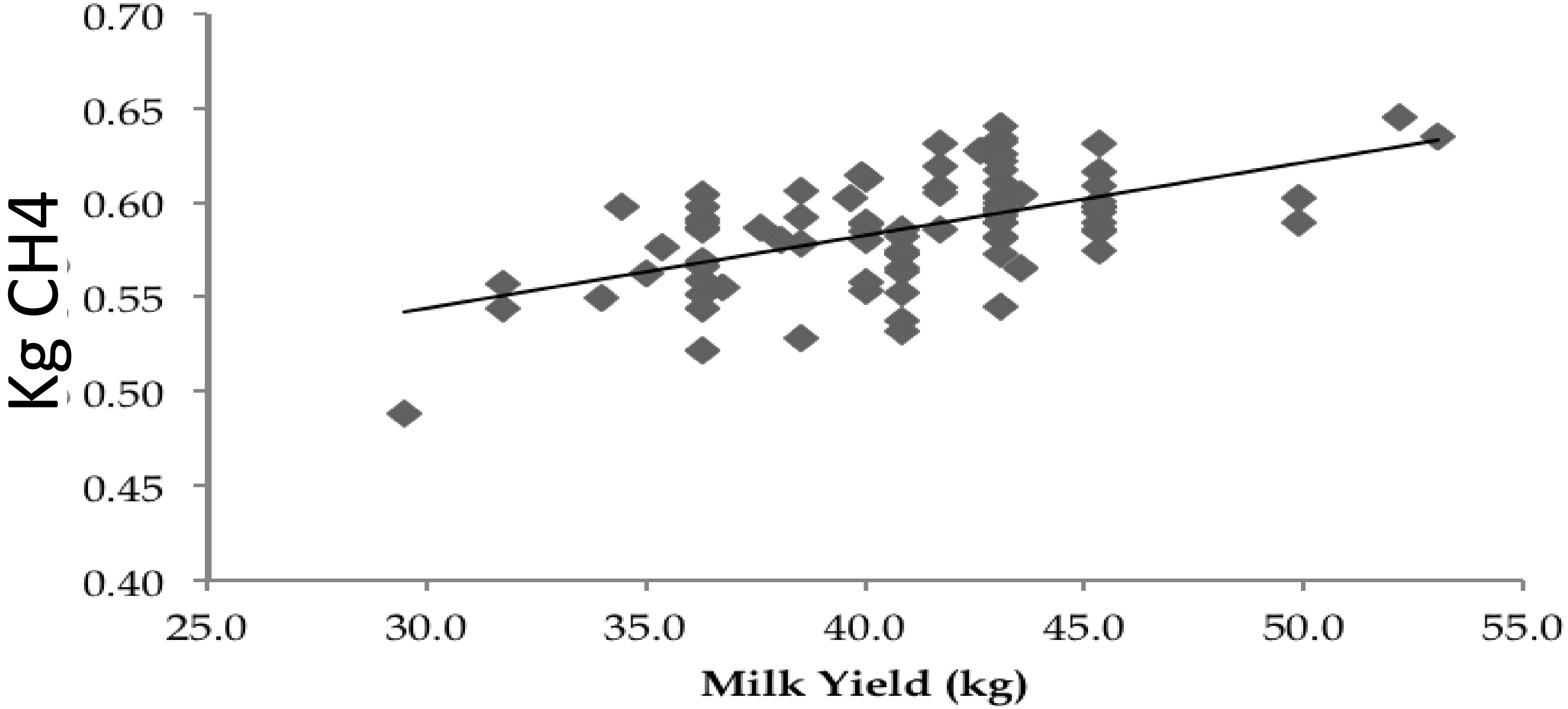
Cow/Farm Level Factors to Reduce Methane

There are three primary strategies

- Animal and Feed Management – feed processing, feeding level, forage quality, genetic selection
- Diet Formulation – use of byproducts, using more non-forage feeds, minerals and salts, oilseeds, tannins, urea
- Rumen Manipulation – additives, rumen modifiers, things to kill protozoa

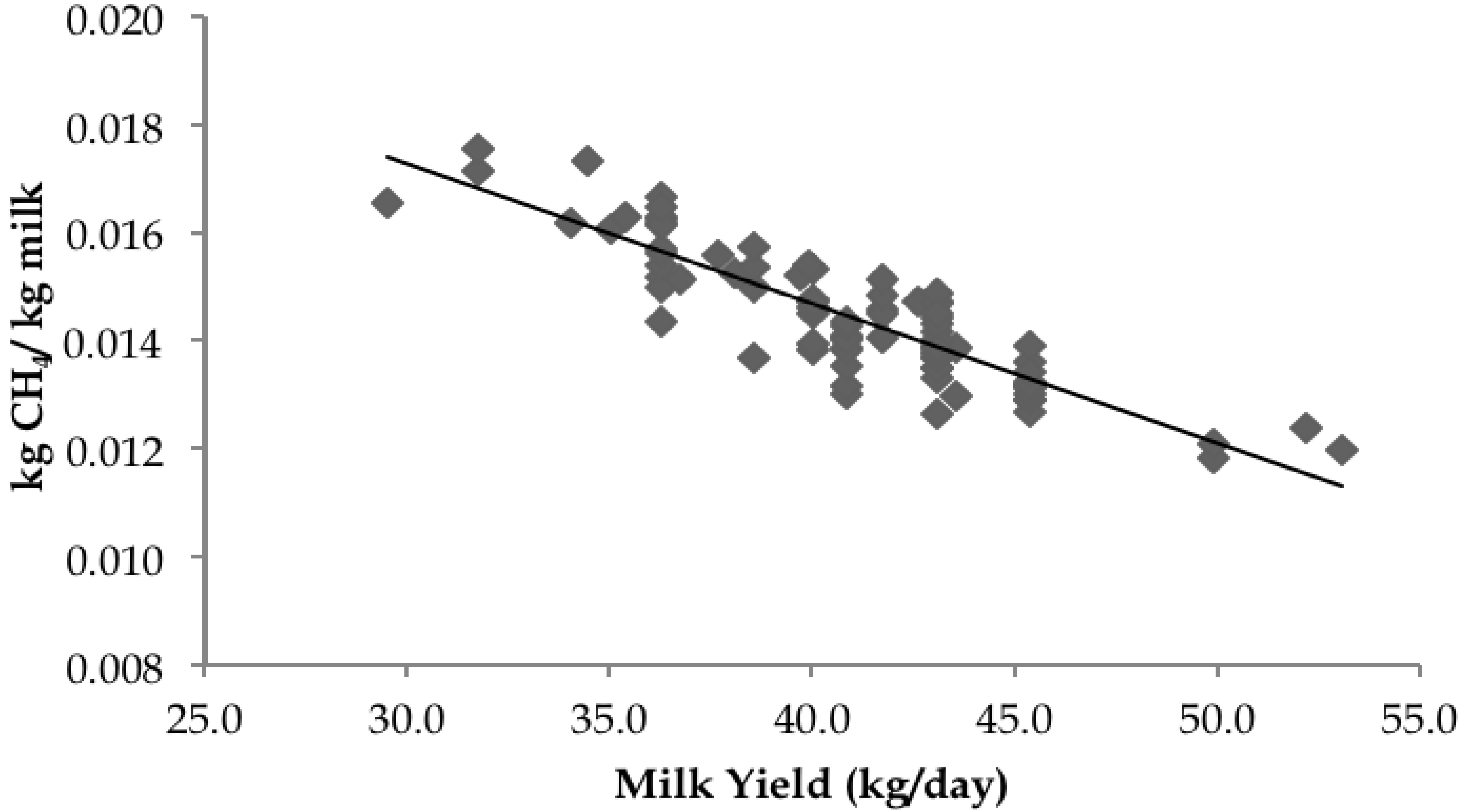
Part of the solution to pollution is dilution…

Predicted CH_4 emissions vs milk yield



CH_4 (kg/d) = 0.004 × milk yield (kg/d) + 0.43 ($R^2 = 0.75$; RMSE = 0.02 kg/d)

Predicted CH_4 emissions per kg of milk versus milk yield



kg CH_4/Kg milk = -0.0003 × milk yield (kg/d) + 0.03; (R^2 = 0.89; RMSE = 0.0005 kg CH_4/ kg milk.

MILKING IT

The largest organic dairy company says it wants to go beyond carbon neutral

March 4, 2020

By **Chase Purdy**
Food Reporter

REUTERS/KHAM

Cattle call.

https://qz.com/1812755/horizon-organic-dairy-says-it-wants-to-go-beyond-carbon-neutral/

What they list as options:

More efficient energy use
Soil health
Additives that reduce methane (seaweed)
“Organic” means more grass, which results in more carbon sequestration

Selection of cows/genetics that are more efficient at retaining C – less methane emissions

Cow/Farm Level Factors to Reduce Methane – mostly intensity

- Optimize milk production per unit of feed intake
- Don’t overcrowd dairy barns to the point it hurts production
- Raise only as many heifers as you need to replace your herd
- Extend lactations by up to 60 days on first lactation animals
- Feed higher digestibility forages (up to 24% reduction in intensity)
- Feed less forage – but this is a bad idea in high producing cows
- Feed Monensin/Rumensin to the lactating and close-up cows

Forage digestibility

- Cellulose digestion is responsible for the greatest amount of methane production (correlation + 0.58)
- The relationship between hemicellulose and methane production is negative (-0.57)
- Higher digestibility forages have lower cell wall content, meaning less cellulose and hemicellulose
- Higher digestibility forages have more non-cell wall components that are more highly digestible with low methane yield
- There is a tension between forage yield and digestibility due to land availability, number of cows per acre, and other factors
- Alfalfa vs grass – less methane with alfalfa but also less digestibility

Current Feed Additives That Reduce Enteric Methane

- Monensin/Rumensin – the reduction in enteric methane when feeding Rumensin is approximately 5% (NASEM, 2021, Marumo et al., 2023)
  - This needs further work on cows at lower feeding rates for longer periods of time
- Essential oil products like Agolin – Data to data suggest about an 11% reduction in intensity, but **no** significant effect on methane reduction
- Seaweed can reduce methane significantly (20% to 80%) through the active ingredient, bromoforms (bromine containing substances) – scaling is an issue and might offset methane reductions
  - Not fully approved and has the potential to be toxic and contaminate milk
- Lipids – some fatty acids can be toxic to protozoa who are large H+ producers and to some of the methanogens
- Nitrate (NO3−) can be used to reduce methane production by accepting H+ and making ammonia, but nitrates can be toxic and are difficult to manage dietarily at this point
- Tannins – soluble phenolic compounds which are generally anti-nutritional in nature and bind proteins – impact methanogens and protozoa

Symposium review: Effective nutritional strategies to mitigate enteric methane in dairy cattle

A.N. Hristov, A. Melgar, D. Wasson, C. Arndt

Journal of Dairy Science
Volume 105 Issue 10 Pages 8543-8557 (October 2022)
DOI: 10.3168/jds.2021-21398

Potential feed additives, ingredients and tannin containing feeds to reduce enteric methane

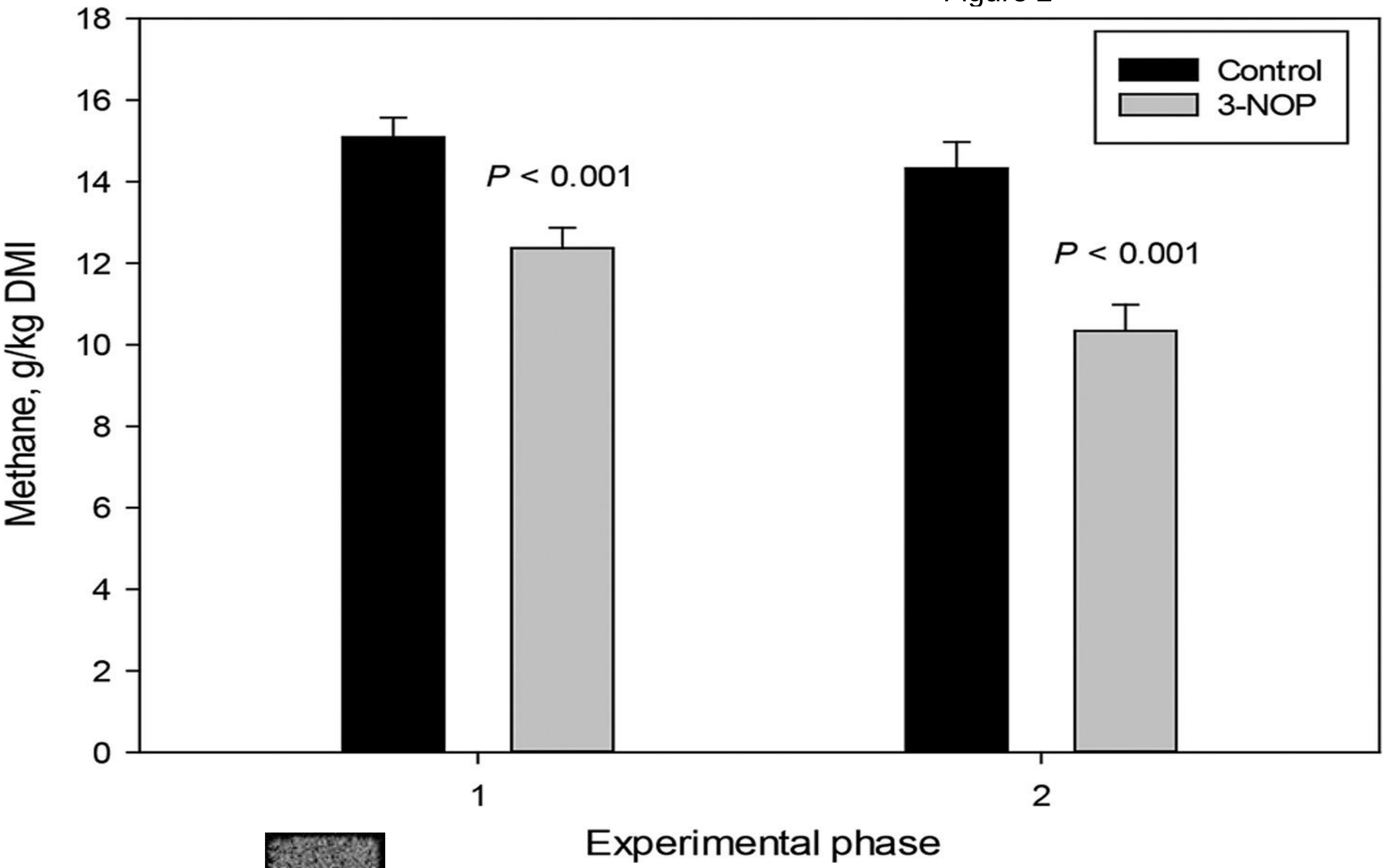
Mitigation strategy	n[2]	Mean effect[3]	95% CI[4]	*P*-value[5]	I^2 [6]
Daily CH_4, g/d					
Inhibitors	23	−35.2	(−40.4; −29.5)	<0.001	76.9
Electron sinks	54	−17.1	(−20.1; −14.0)	<0.001	70.6
Oils and fats[7]	63	−19.5	(−23.6; −15.2)	<0.001	96.0
Tanniferous forages	42	−11.6	(−16.1; −6.8)	<0.001	86.0

1 Adapted from Arndt et al. (2022).
2 n = number of treatment comparisons.
3 Decrease from control (%).
4 Lower and upper 95% CI (%).
5 *P*-value for the mitigation effect.
6 Heterogeneity statistic (%).
7 Similar effect was observed for oilseeds (n = 26, mean effect = −19.5%, 95% CI: −24.0%; −14.8%, $P < 0.001$).
8 Similar effect was observed for oilseeds (n = 18, mean effect = −14.3%, 95% CI: −19.9%; −8.2%, $P < 0.001$).
9 Similar effect was observed for oilseeds (n = 6, mean effect = −11.6%, 95% CI: −18.9%; −3.6%, $P = 0.02$).

Hristov et al. J. Dairy Sci. 2022

3-NOP – trade name Bovaer from DSM - Not yet approved in the US

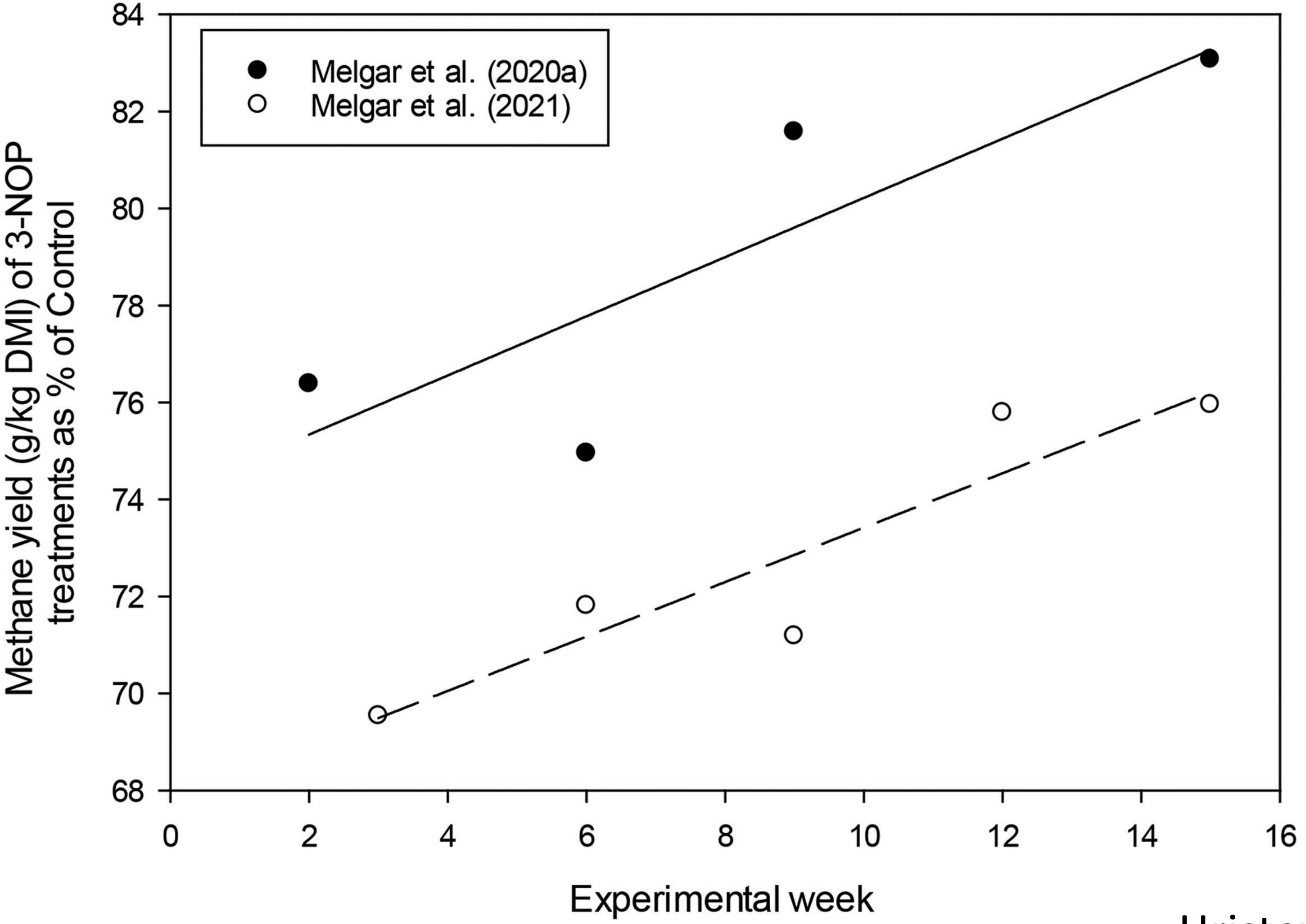
Figure 2



In experimental phase 1, treatment cows received 3-NOP at 60 mg/kg of DMI for 15 wk, and data shown in graph are from experimental wk 15. In phase 2, control cows from phase 1 received 3-NOP at 60 mg/kg of DMI for 3 wk, and methane emissions were measured during wk 3. Cows receiving 3-NOP in phase 1 were control cows in phase 2.

Journal of Dairy Science 2022 1058543-8557DOI: (10.3168/jds.2021-21398)

3-NOP/Bovaer



Hristov et al. J. Dairy Sci. 2022

Genetics and methane reduction

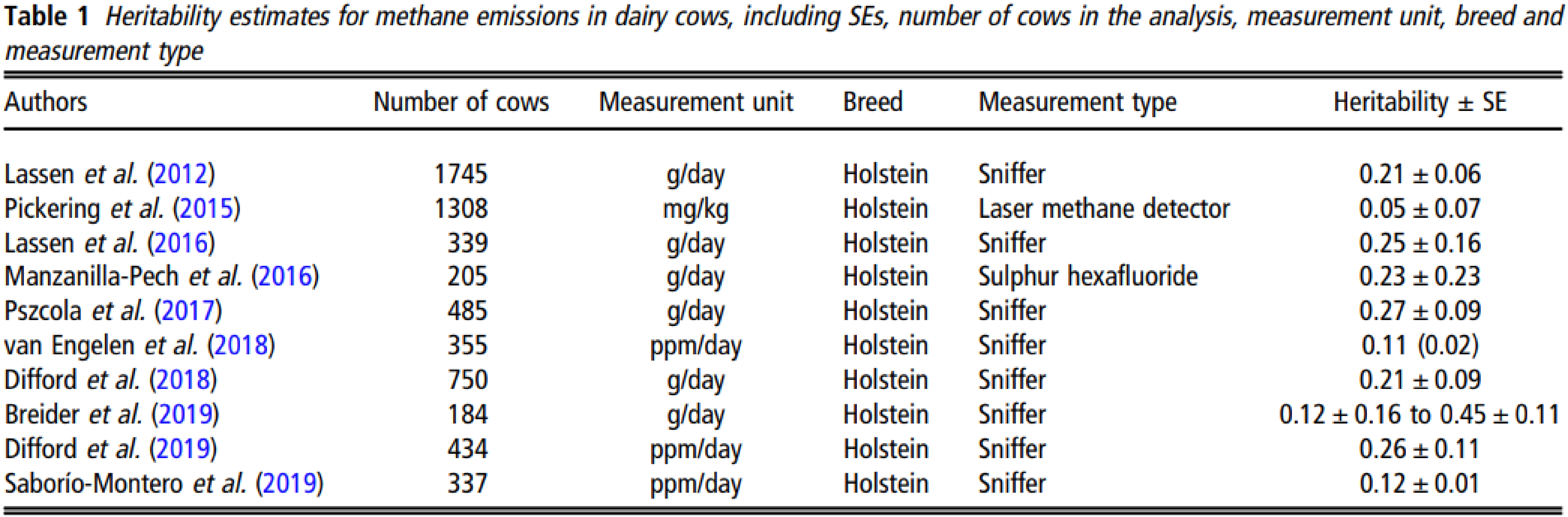


Table 1 *Heritability estimates for methane emissions in dairy cows, including SEs, number of cows in the analysis, measurement unit, breed and measurement type*

Authors	Number of cows	Measurement unit	Breed	Measurement type	Heritability ± SE
Lassen *et al.* (2012)	1745	g/day	Holstein	Sniffer	0.21 ± 0.06
Pickering *et al.* (2015)	1308	mg/kg	Holstein	Laser methane detector	0.05 ± 0.07
Lassen *et al.* (2016)	339	g/day	Holstein	Sniffer	0.25 ± 0.16
Manzanilla-Pech *et al.* (2016)	205	g/day	Holstein	Sulphur hexafluoride	0.23 ± 0.23
Pszcola *et al.* (2017)	485	g/day	Holstein	Sniffer	0.27 ± 0.09
van Engelen *et al.* (2018)	355	ppm/day	Holstein	Sniffer	0.11 (0.02)
Difford *et al.* (2018)	750	g/day	Holstein	Sniffer	0.21 ± 0.09
Breider *et al.* (2019)	184	g/day	Holstein	Sniffer	0.12 ± 0.16 to 0.45 ± 0.11
Difford *et al.* (2019)	434	ppm/day	Holstein	Sniffer	0.26 ± 0.11
Saborío-Montero *et al.* (2019)	337	ppm/day	Holstein	Sniffer	0.12 ± 0.01

Lassen and Difford, 2020

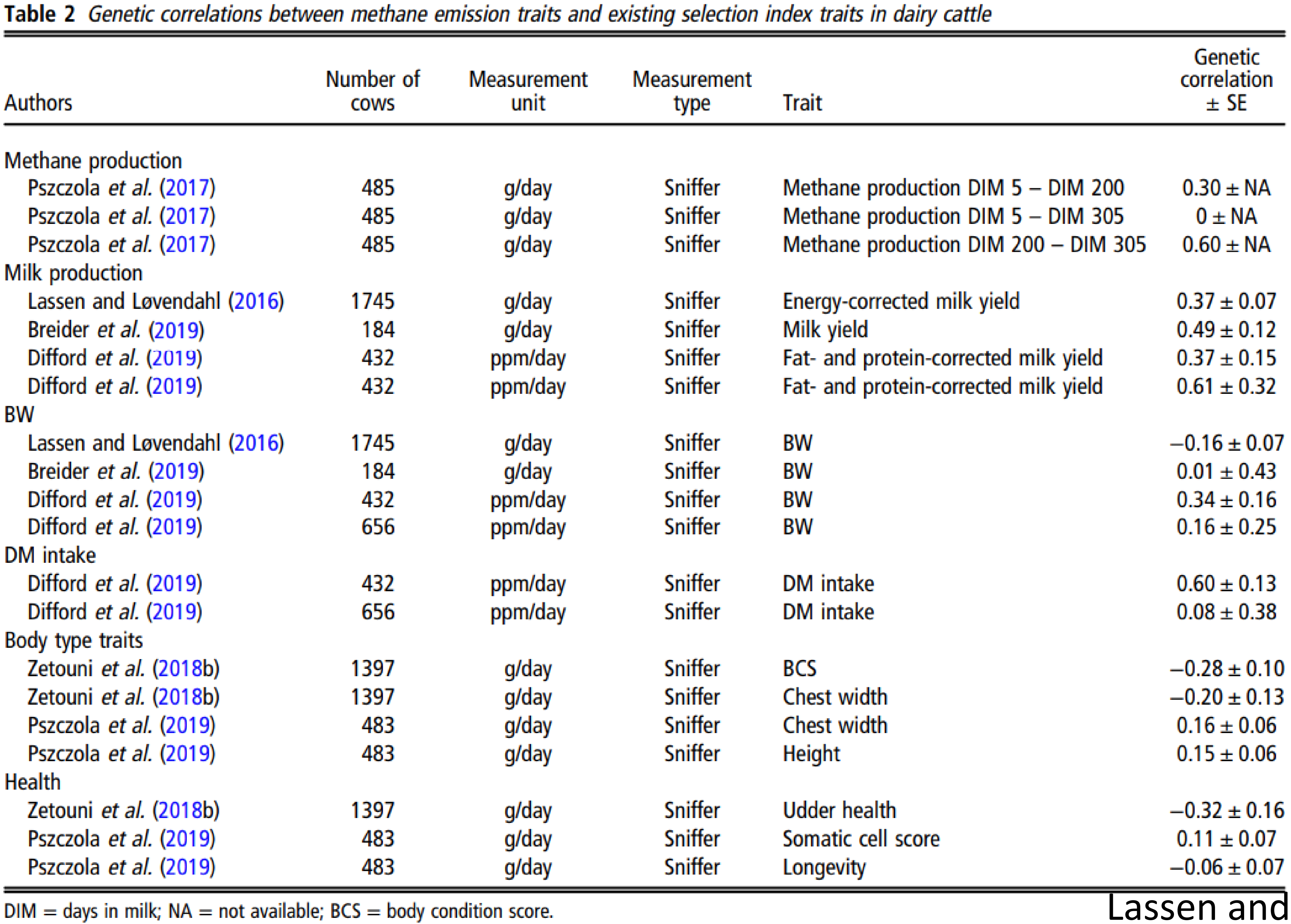


Table 2 *Genetic correlations between methane emission traits and existing selection index traits in dairy cattle*

Authors	Number of cows	Measurement unit	Measurement type	Trait	Genetic correlation ± SE
Methane production					
Pszczola *et al.* (2017)	485	g/day	Sniffer	Methane production DIM 5 – DIM 200	0.30 ± NA
Pszczola *et al.* (2017)	485	g/day	Sniffer	Methane production DIM 5 – DIM 305	0 ± NA
Pszczola *et al.* (2017)	485	g/day	Sniffer	Methane production DIM 200 – DIM 305	0.60 ± NA
Milk production					
Lassen and Løvendahl (2016)	1745	g/day	Sniffer	Energy-corrected milk yield	0.37 ± 0.07
Breider *et al.* (2019)	184	g/day	Sniffer	Milk yield	0.49 ± 0.12
Difford *et al.* (2019)	432	ppm/day	Sniffer	Fat- and protein-corrected milk yield	0.37 ± 0.15
Difford *et al.* (2019)	432	ppm/day	Sniffer	Fat- and protein-corrected milk yield	0.61 ± 0.32
BW					
Lassen and Løvendahl (2016)	1745	g/day	Sniffer	BW	−0.16 ± 0.07
Breider *et al.* (2019)	184	g/day	Sniffer	BW	0.01 ± 0.43
Difford *et al.* (2019)	432	ppm/day	Sniffer	BW	0.34 ± 0.16
Difford *et al.* (2019)	656	ppm/day	Sniffer	BW	0.16 ± 0.25
DM intake					
Difford *et al.* (2019)	432	ppm/day	Sniffer	DM intake	0.60 ± 0.13
Difford *et al.* (2019)	656	ppm/day	Sniffer	DM intake	0.08 ± 0.38
Body type traits					
Zetouni *et al.* (2018b)	1397	g/day	Sniffer	BCS	−0.28 ± 0.10
Zetouni *et al.* (2018b)	1397	g/day	Sniffer	Chest width	−0.20 ± 0.13
Pszczola *et al.* (2019)	483	g/day	Sniffer	Chest width	0.16 ± 0.06
Pszczola *et al.* (2019)	483	g/day	Sniffer	Height	0.15 ± 0.06
Health					
Zetouni *et al.* (2018b)	1397	g/day	Sniffer	Udder health	−0.32 ± 0.16
Pszczola *et al.* (2019)	483	g/day	Sniffer	Somatic cell score	0.11 ± 0.07
Pszczola *et al.* (2019)	483	g/day	Sniffer	Longevity	−0.06 ± 0.07

DIM = days in milk; NA = not available; BCS = body condition score.

Lassen and Difford, 2020

How Can the Supply Chain Help?

- An idea for nutrition companies/suppliers:
- Record and report the amount of C, N, P, and K sold to the dairy or business every year so they can document what was supplied to them
- This helps in at least two ways:
  - Provides documents about the tons of nutrients coming onto the farm
  - Provides opportunity to understand how efficient the nutrients are being used

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Thoughts?

Questions?

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