



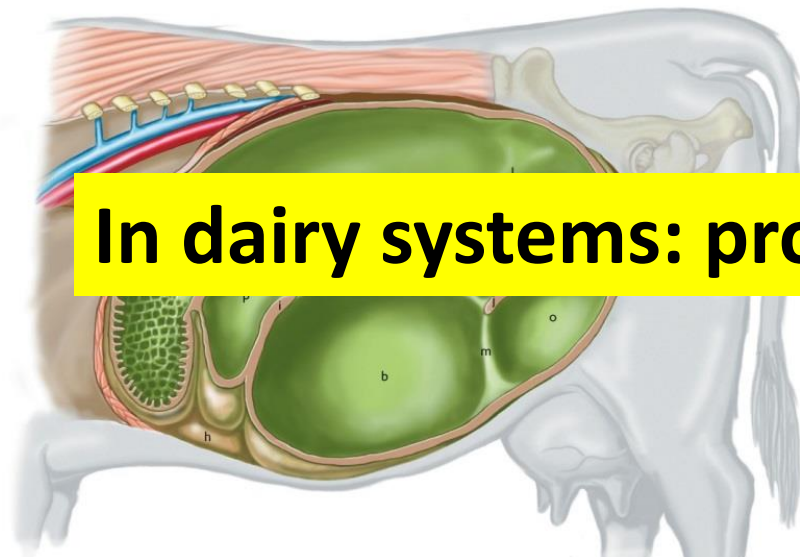
# Enteric methane emissions and mitigation

**Alex N. Hristov**

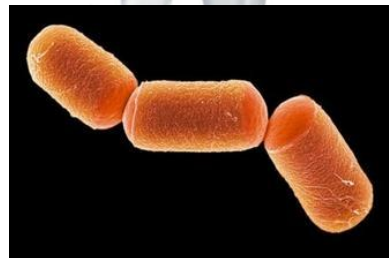
**The Pennsylvania State University**



# Sources of methane in a ruminant production system

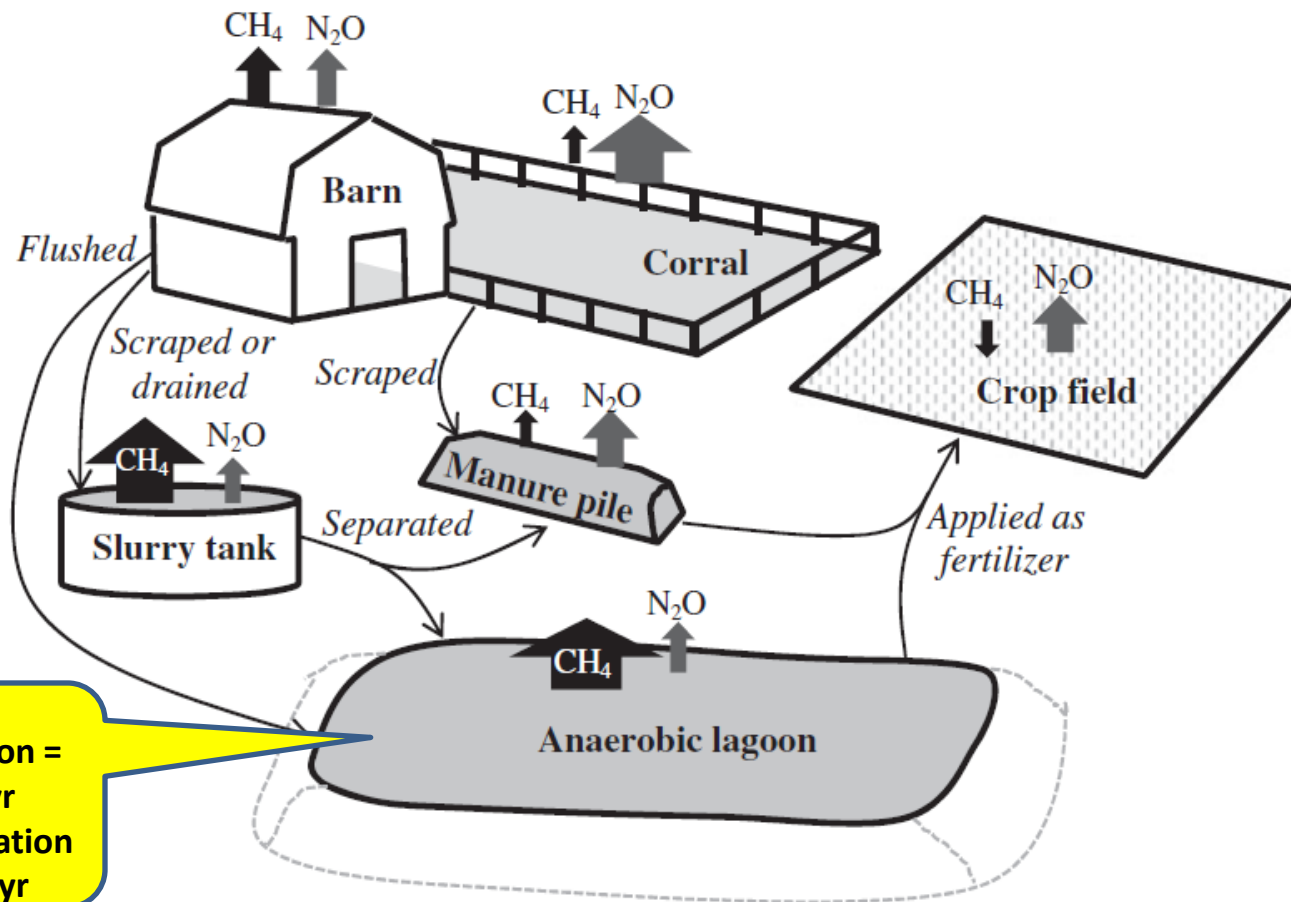


**In dairy systems: probably close to half/half**



*Methanobrevibacter*

# Sources of GHG on a dairy farm



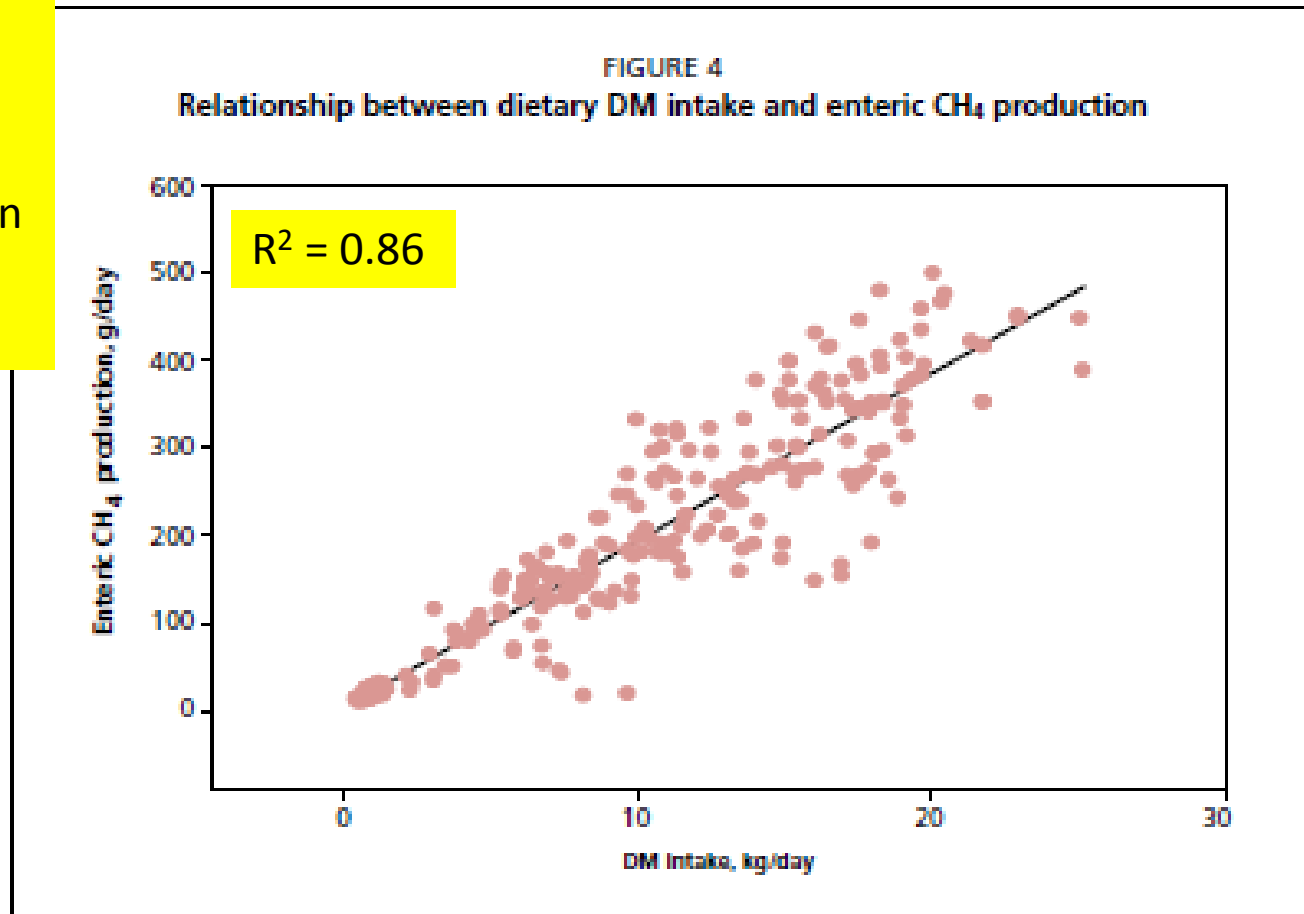


# Factors affecting enteric methane emission

**Driven by DMI**

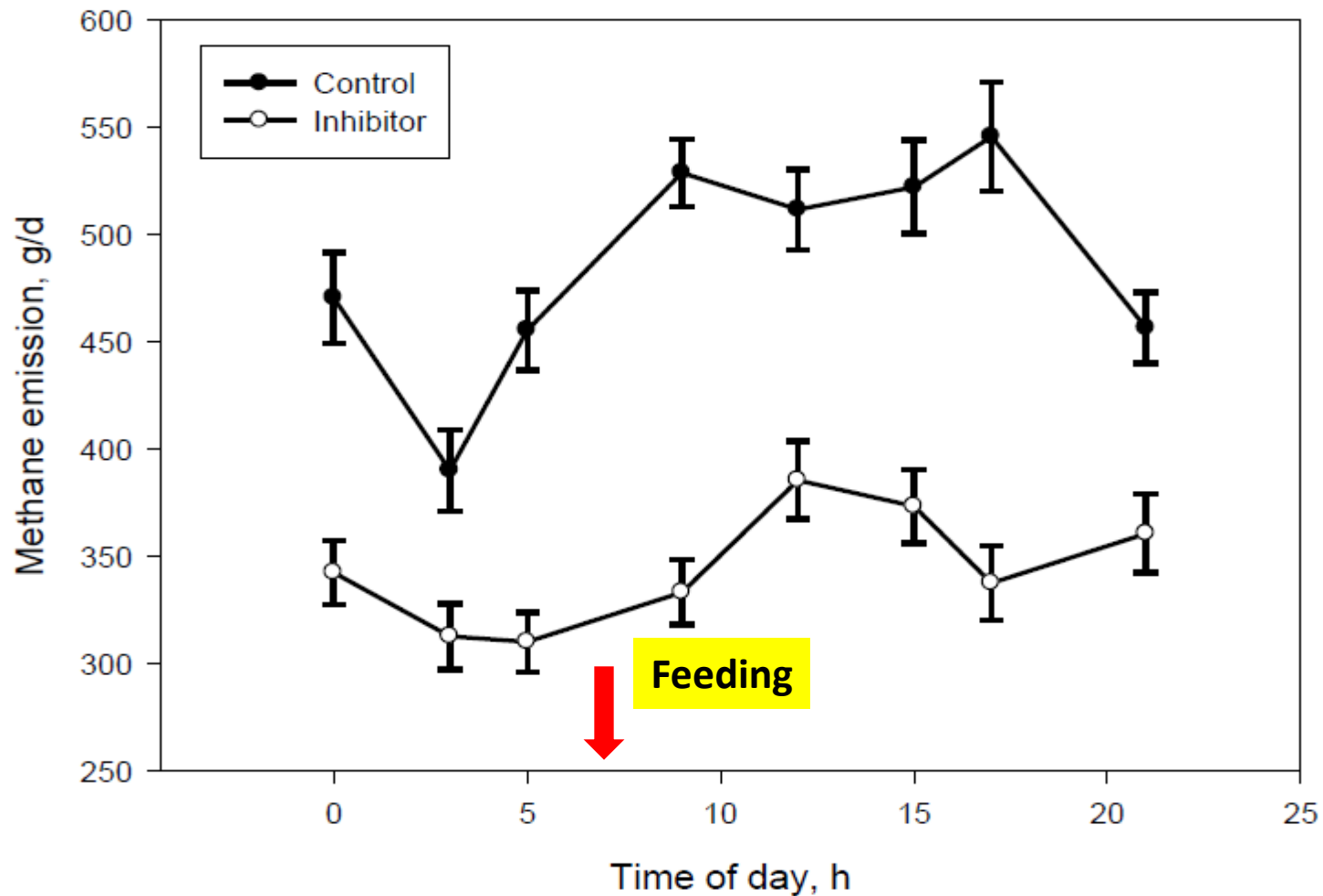
**Other factors:**

- Animal genetics
- Diet composition
  - fiber/starch
  - fat

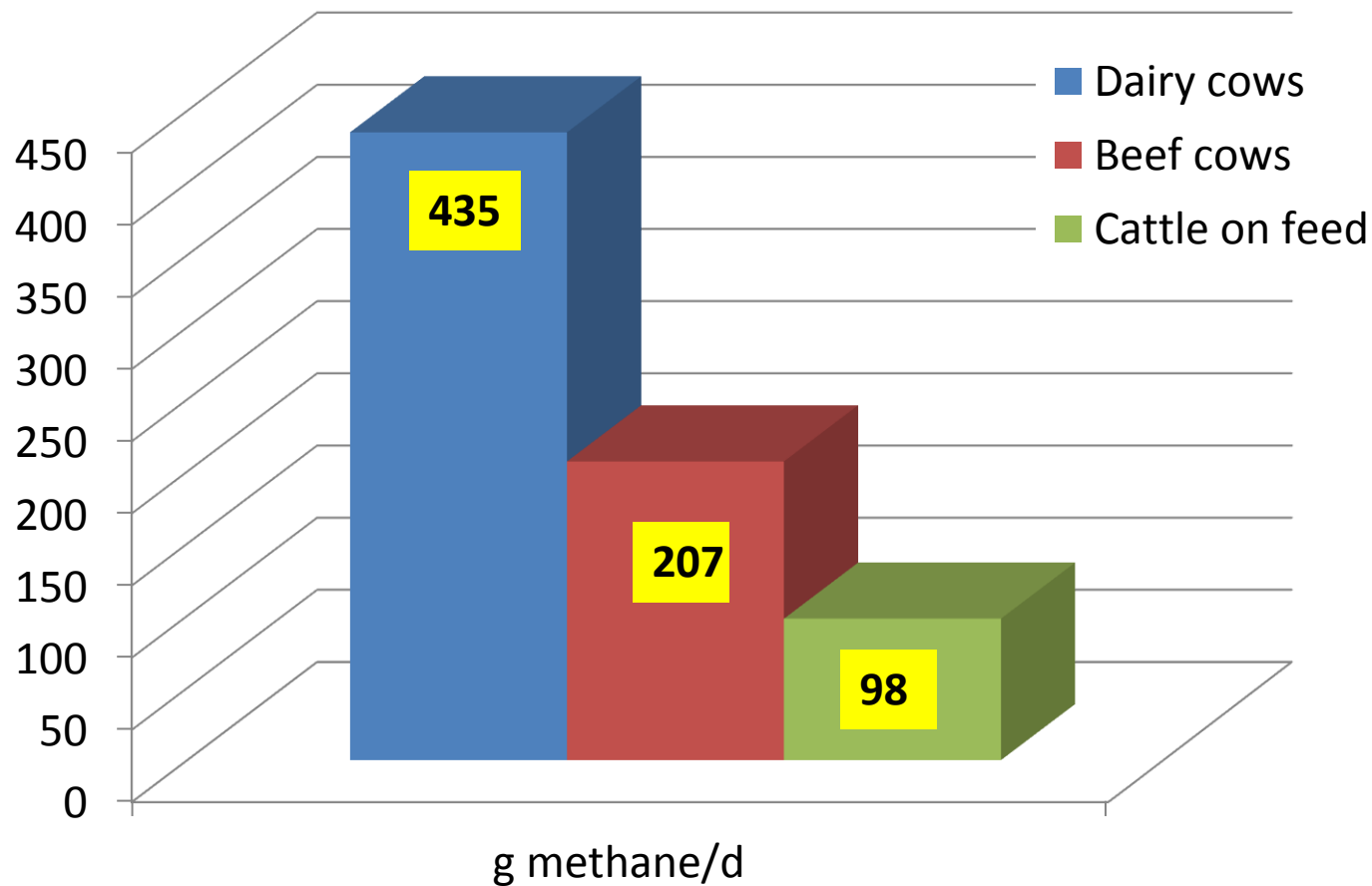




# Diurnal pattern of methane emissions in dairy cows

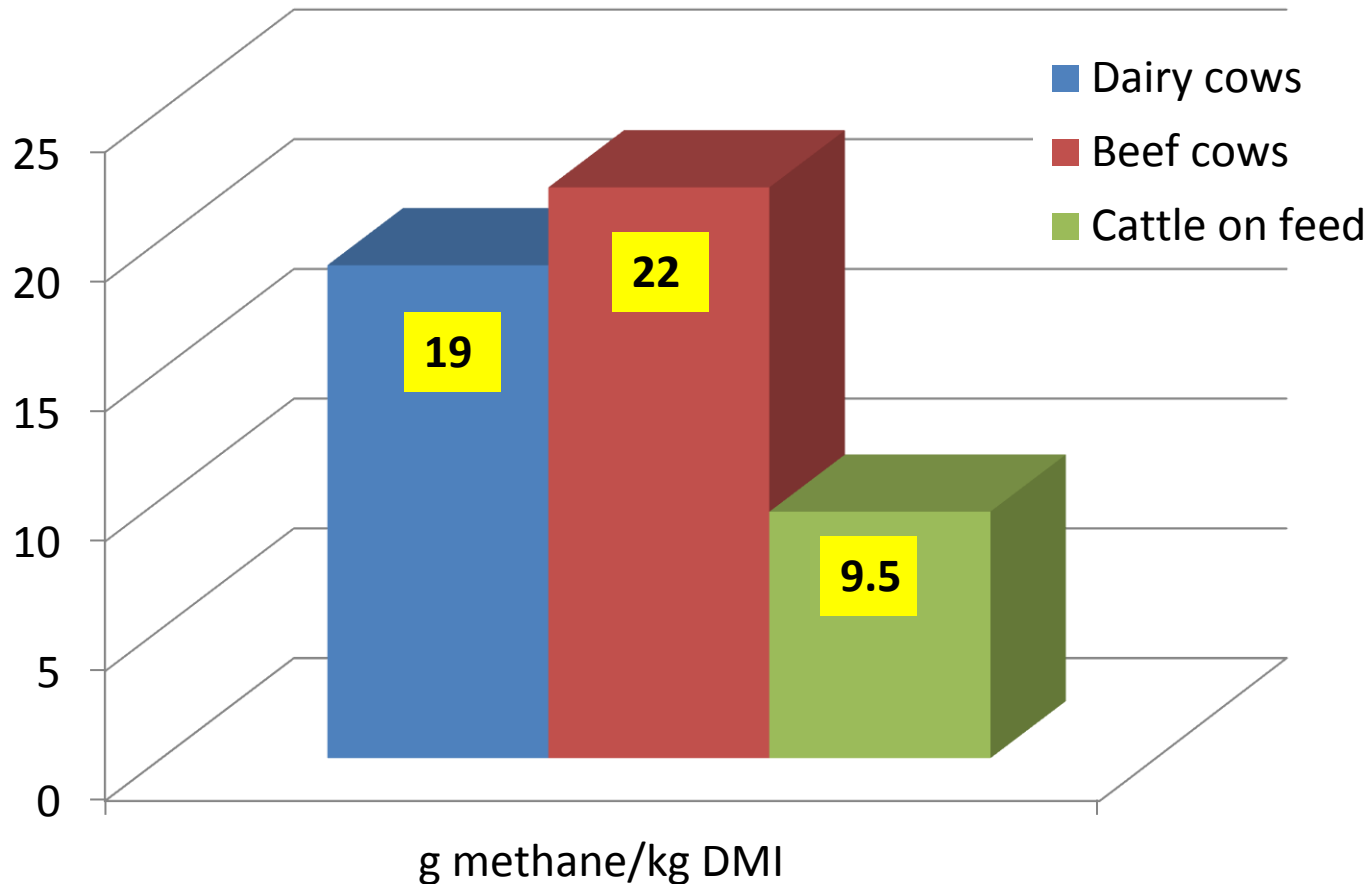


# Enteric methane emission rates by cattle categories

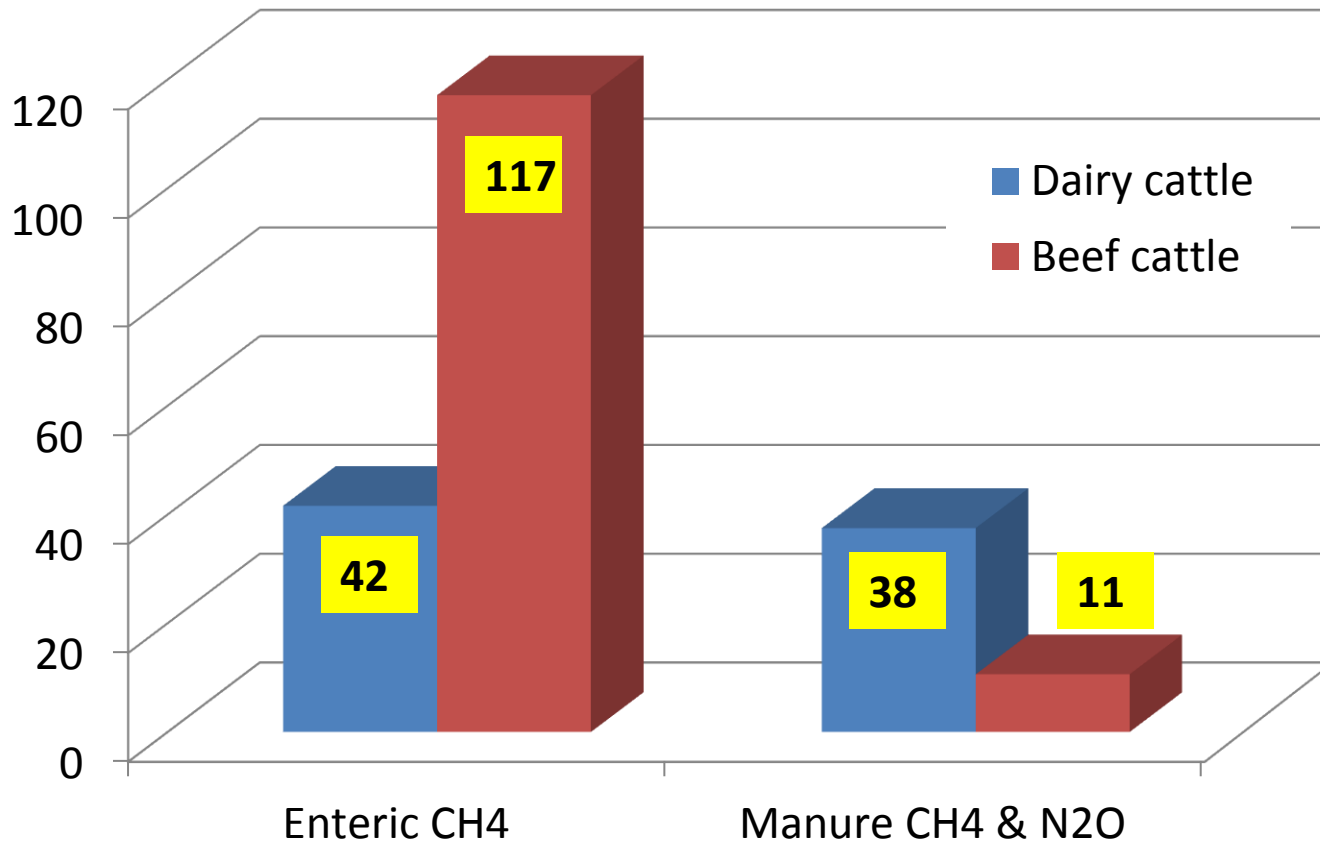




# Enteric methane **yield** by cattle category



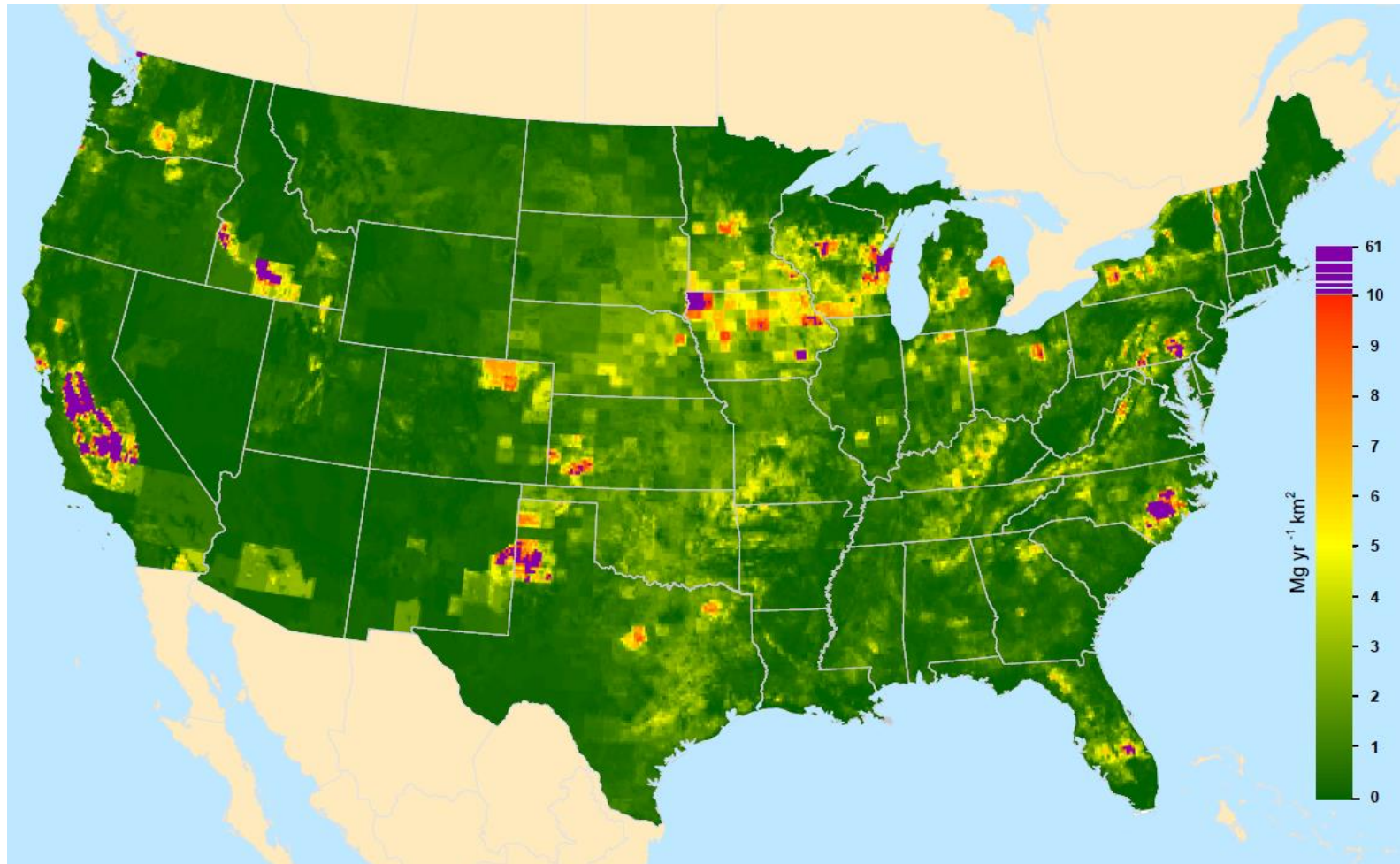
# Total GHG emissions from dairy and beef cattle in the US (MMT CO<sub>2</sub> eq)







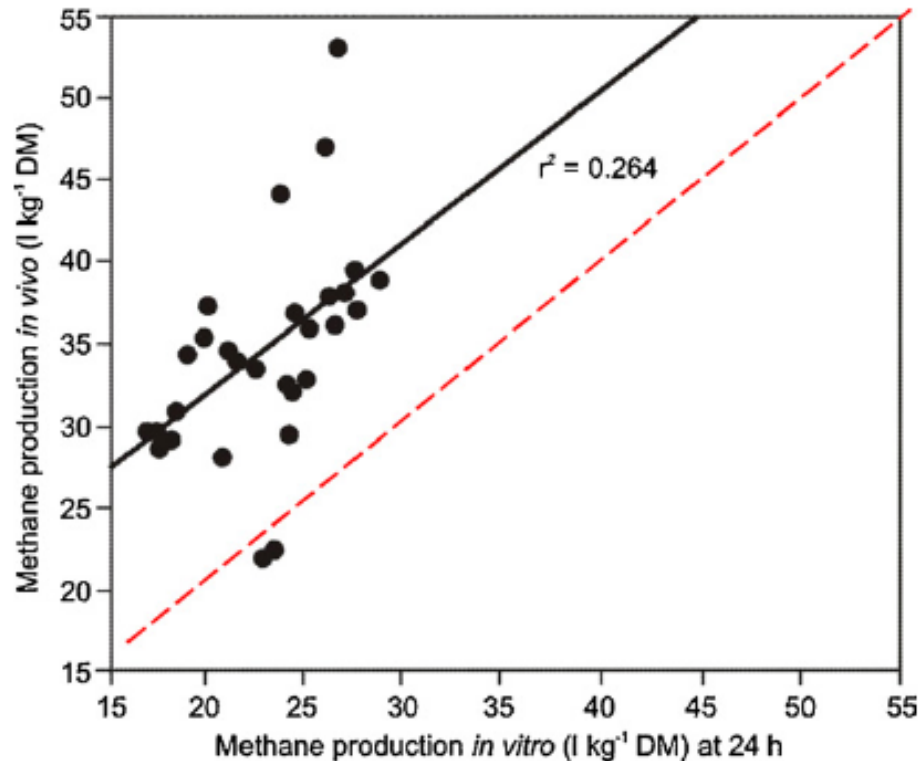
# Spatial distribution of livestock methane emissions in the US





# We have to measure enteric methane emissions in the animal: **poor relationship between in vitro and in vivo data**

*G. Flachowsky, P. Lebzien / Animal Feed Science and Technology 176 (2012) 70–77*



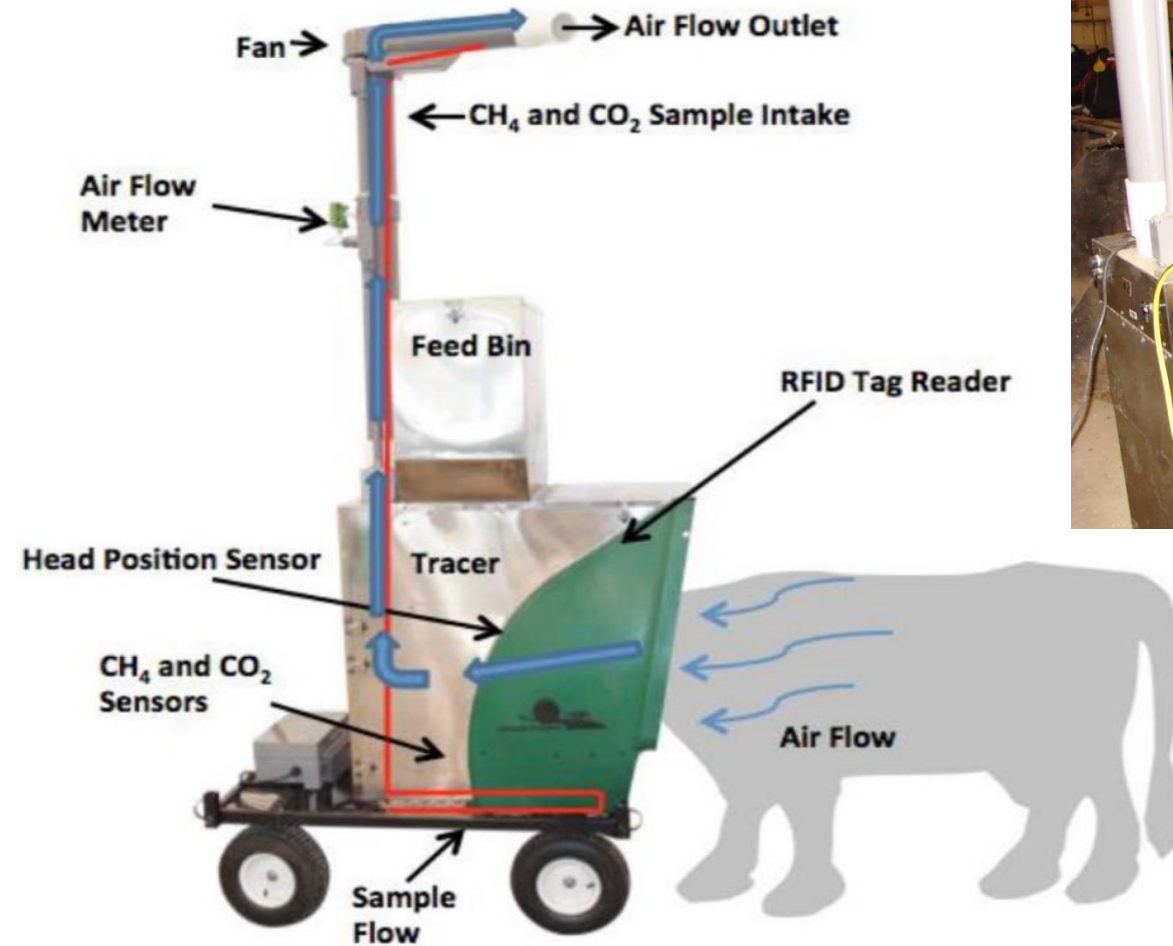




# Chamber Techniques



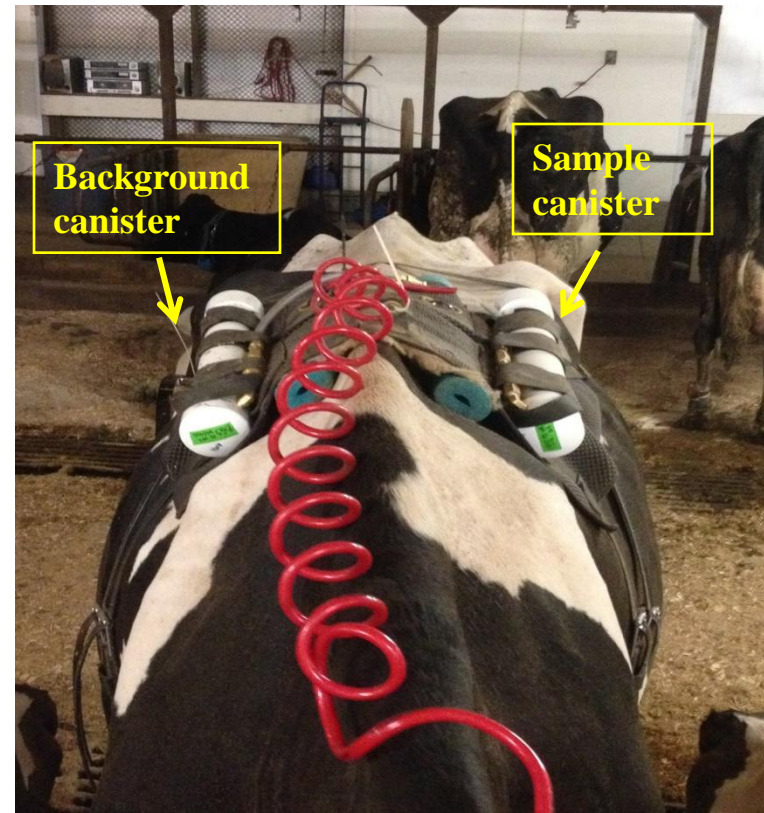
# The GreenFeed system







# The SF<sub>6</sub> technique





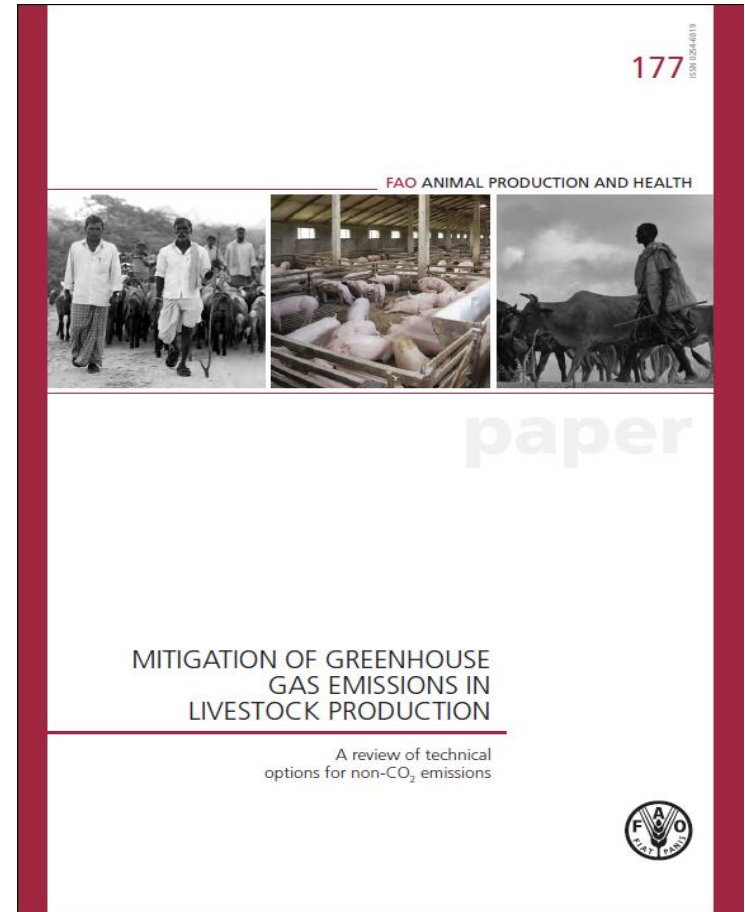
# Mitigation approaches

- **Nutritional approaches** – will be discussed in this presentation
- Genetic selection for low emitters
  - Low heritability; problems with measuring methane emission at the population scale; potentially selecting for lower DMI or poor fiber digestibility
  - Selection for feed efficiency
- Microbiome manipulation, vaccination
- Animal health
- Productivity gains



# GHG Mitigation Options for the Livestock Industries

**FAO, 2013**



**SPECIAL TOPICS — Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options**

A. N. Hristov, J. Oh, J. L. Firkins, J. Dijkstra, E. Kebreab, G. Waghorn, H. P. S. Makkar, A. T. Adesogan, W. Yang, C. Lee, P. J. Gerber, B. Henderson and J. M. Tricarico

*J ANIM SCI* 2013, 91:5045-5069.

doi: 10.2527/jas.2013-6583 originally published online September 17, 2013

**SPECIAL TOPICS — Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options**

F. Montes, R. Meinen, C. Dell, A. Rotz, A. N. Hristov, J. Oh, G. Waghorn, P. J. Gerber, B. Henderson, H. P. S. Makkar and J. Dijkstra

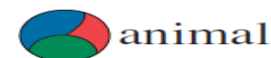
*J ANIM SCI* 2013, 91:5070-5094.

doi: 10.2527/jas.2013-6584 originally published online September 17, 2013

**SPECIAL TOPICS—Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options<sup>1</sup>**

A. N. Hristov,\*<sup>2</sup> T. Ott,\* J. Tricarico,† A. Rotz,‡  
G. Waghorn,§ A. Adesogan,# J. Dijkstra,|| F. Montes,¶ J. Oh,\* E. Kebreab,\*\*

*Animal* (2013), 7:s2, pp 220–234 © Food and Agriculture Organization of the United Nations 2013  
doi:10.1017/S1751731113000876



**Technical options for the mitigation of direct methane and nitrous oxide emissions from livestock: a review**

P. J. Gerber<sup>1+</sup>, A. N. Hristov<sup>2</sup>, B. Henderson<sup>1</sup>, H. Makkar<sup>1</sup>, J. Oh<sup>2</sup>, C. Lee<sup>2</sup>, R. Meinen<sup>2</sup>, F. Montes<sup>3</sup>, T. Ott<sup>2</sup>, J. Firkins<sup>4</sup>, A. Rotz<sup>5</sup>, C. Dell<sup>5</sup>, A. T. Adesogan<sup>6</sup>, W. Z. Yang<sup>7</sup>, J. M. Tricarico<sup>8</sup>, E. Kebreab<sup>9</sup>, G. Waghorn<sup>10</sup>, J. Dijkstra<sup>11</sup> and S. Oosting<sup>11</sup>



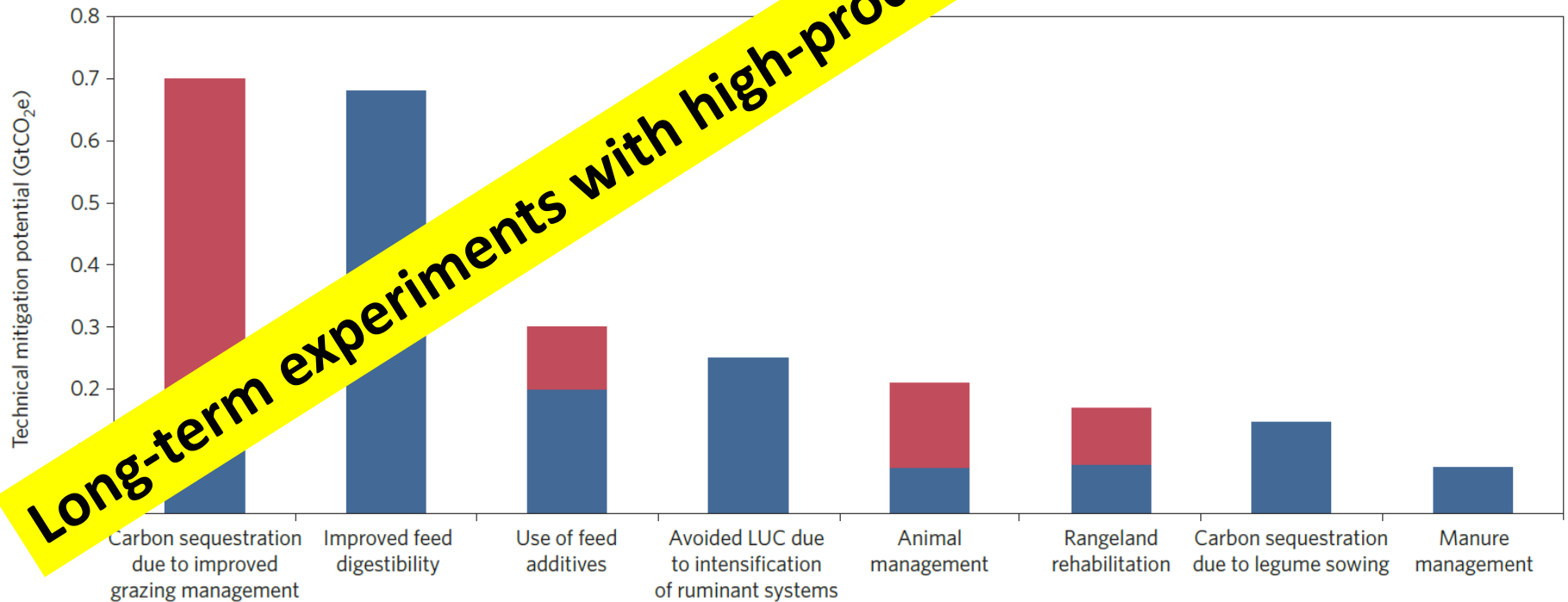


# Greenhouse gas mitigation potentials in the livestock sector

Mario Herrero<sup>1\*</sup>, Benjamin Henderson<sup>1</sup>, Petr Havlík<sup>2</sup>, Philip K. Thornton<sup>1,3</sup>, ... Conant<sup>4</sup>, Pete Smith<sup>5</sup>, Stefan Wirsenius<sup>1,6</sup>, Alexander N. Hristov<sup>7</sup>, Pierre Gerber<sup>8</sup>, ... Gill<sup>5</sup>, Klaus Butterbach-Bahl<sup>10,11</sup>, Hugo Valin<sup>2</sup>, Tara Garnett<sup>12</sup> and Elke S. ...

NATURE CLIMATE CHANGE DOI: 10.1038/NCLIMATE2925

REVIEW ARTICLE



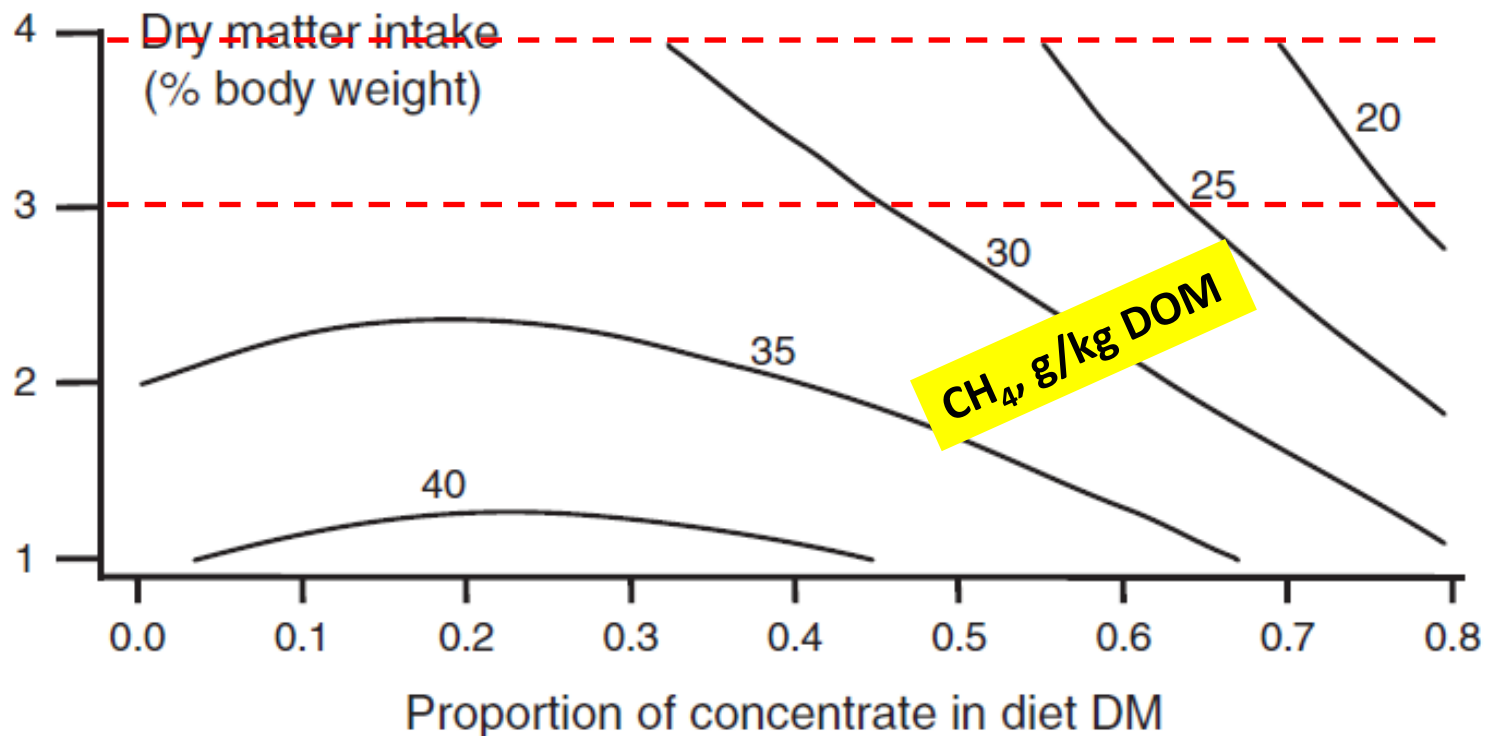


# Forage quality

- Increased forage digestibility is expected to increase animal production and decrease enteric  $\text{CH}_4$  production per unit of product (Ei)
- It appears, C4 grasses produce more  $\text{CH}_4$  than C3 grasses and introduction of legumes in warm climate may offer a potential mitigation opportunity, although low persistence and a need for long establishment periods are important agronomic constraints
- Enteric  $\text{CH}_4$  emission may be reduced when corn silage replaces grass silage
- Legume silages may also have an advantage over grass silage due to their lower fiber content and the additional benefit of replacing inorganic N fertilizer
- With all silages effective preservation will improve silage quality and reduce GHG emission intensity
- Forage with higher sugar content (high-sugar grasses or harvested in the afternoon) may reduce urinary N losses and consequently,  $\text{N}_2\text{O}$  emission from manure applied to soil, but more research is needed.
- The best mitigation option in this category is to increase forage digestibility in order to enhance digestible energy intake and animal productivity, thus reducing overall GHG emissions per unit of animal product



# Feed intake and concentrate inclusion effects on methane emission





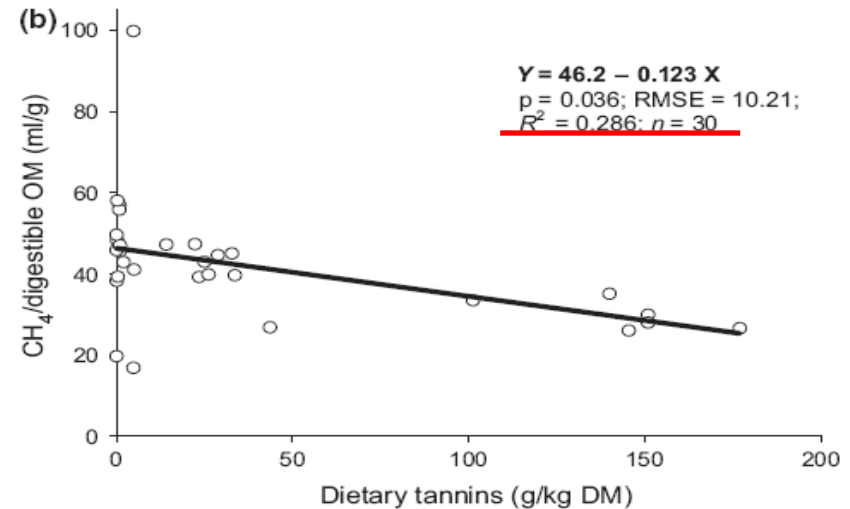
# Dietary lipids

- Lipids have a proven enteric CH<sub>4</sub>-mitigating effect:
  - However, may depress DMI
  - Which may actually increase feed efficiency (??)
- May decrease milk production and milk fat test
  - Potentially enhanced by combination with other rumen modifiers – monensin
  - A meta-analysis of 31 studies (with 105 treatments) in which lipid supplementation was the main effect:
    - DMI was reduced in 49% of the studies (by 5.6%)
    - 29 studies with dairy cows – milk production was reduced in 15% of the studies (by 9%)
    - **CH<sub>4</sub> production reduced in 81% of the studies (by 20%)**



# PBAC – tannins & saponins

- Tannins – meta-analysis of in vivo experiments (up to 40 exp.)
  - Negative slopes for OMD, CPD, NDFD, total VFA, propionate, butyrate, ammonia, bacteria, protozoa
  - Reduced enteric CH<sub>4</sub> emission
- Other issues: **LONG-TERM effects??**
  - Very variable results - type, concentration and astringency of the tannins
  - **Yields of temperate and tropical tanniferous legumes is usually less than that of corresponding grasses**
  - Anti-nutritional when dietary CP concentrations are limiting production
- Positive effects reported for **tea saponins....need confirmation.....**





# Essential oils

- Proven antimicrobial effects
  - in vitro, in vivo in monogastrics
- Large doses required in vivo
  - Higher doses are likely to affect negatively DMI and animal production
- So far, no consistent positive effects in vivo
- Adaptability, long-term effect??

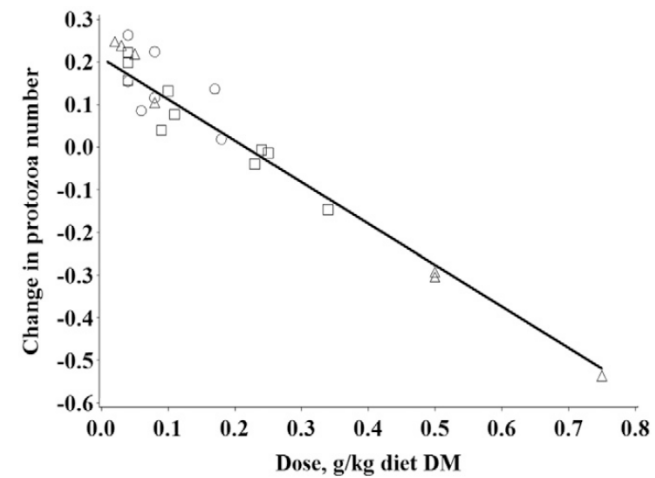


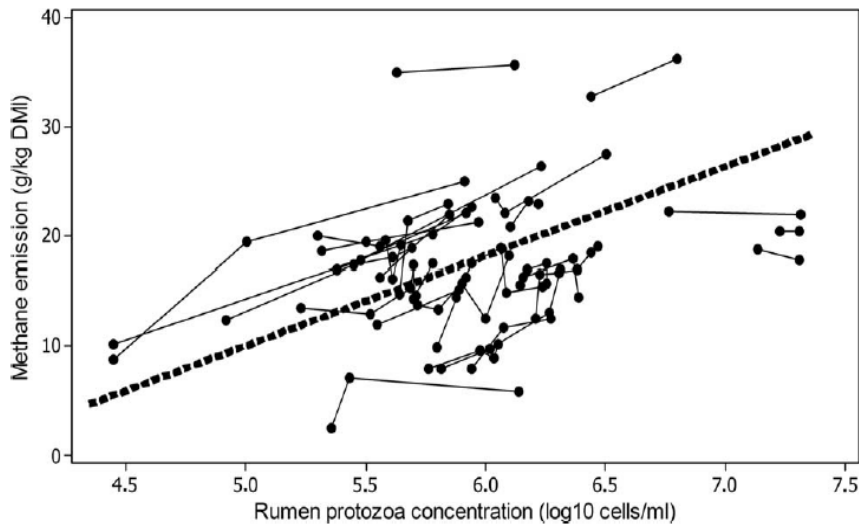
Figure 1. Effect of supplementation dose of essential oils and their bioactive compounds (EOBC; g/kg diet DM) on changes in protozoa numbers ( $\times 10^5/\text{mL}$ ) relative to control (no EOBC supplementation) in ruminants ( $\circ$ , beef cattle;  $\square$ , dairy cattle;  $\Delta$ , small ruminants). Equation is: Protozoa counts =  $0.210 (\pm 0.0418; P < 0.001) - \text{EOBC dose} \times 0.973 (\pm 0.1613; P < 0.001)$ ,  $n = 24$ , root mean square error = 0.1513.

Khiaosa-ard and Q. Zebeli, 2014

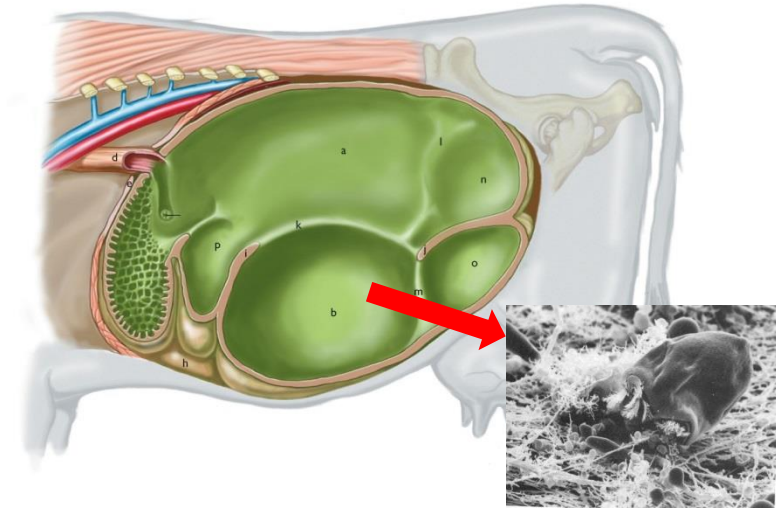


# Mitigation through rumen protozoa

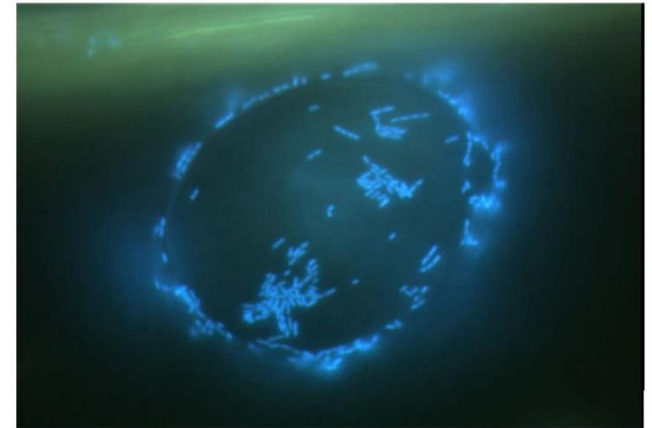
Guyader et al., 2014



**Figure 1** Relationship between methane emission and rumen protozoa concentration (raw data). The black dashed line represents the average within-experiment relationship (equation (2)).



Rumen protozoa are often colonized by methanogens, and the methanogens literally “suck” hydrogen from their “hydrogenosomes.”



© Rumen Microbiology and Its Role In Ruminant Nutrition. 2002.

(Courtesy S.H. Zinder)



# Nitrates – an example of a promising rumen modifier **with uncertain side effects..**

- Alternative electron sink.....**does reduce enteric  $\text{CH}_4$  emission**
- **Persistency of the effect (??)**
- **Toxicity of intermediate products**
  - The rumen ecosystem can adapt however, the adaptation **can be lost quickly**
- Do we need more NPN in the diet? **May be applicable to diets that need NPN**
  - If used in concentrate blocks – access has to be limited
- Nitrate in the basal diet?  $\text{NH}_3$  losses and manure  $\text{NH}_3/\text{N}_2\text{O}$ ;  
N production in the rumen

**About 16% reduction in a meta-analysis by Lee et al. (2015)**





# Nitrate may increase N<sub>2</sub>O emission and urinary nitrate excretion

Table 5. Emissions of CH<sub>4</sub> and N<sub>2</sub>O were calculated for the 24-h period on dry matter (DM) intake (see text). The percentage greenhouse gas on the individual treatments are identified in Table 2.

Diet	CH <sub>4</sub> emission	GHG mitigation	N <sub>2</sub> O emission	GHG mitigation, CH <sub>4</sub> + N <sub>2</sub> O
g NO <sub>3</sub> <sup>-</sup> kg <sup>-1</sup> DM	g CO <sub>2</sub> eq kg <sup>-1</sup> DM	%	g kg <sup>-1</sup> DM	%
<b>Period 4</b>				
0	974.3a (31.0)		0.4d (0.2)	
5	697.8b (15.7)	-28.4 (0.7)	3.7cd (0.1)	-28.0 (0.7)
14	733.6bc (39.4)	-24.5 (6.4)	14.1b (2.8)	-23.1 (6.2)
21	519.7d (34.3)	-46.5 (5.2)	67.2a (4.5)	-39.6 (5.0)
<b>Period 5</b>				
0	816.5a (60.0)		0.5c (0.2)	
5	689.8a (46.7)	-15.5 (0.5)	4.0c (1.3)	-15.0 (0.7)
14	791.8a (40.9)	-2.1 (12.2)	13.5b (2.4)	-0.5 (12.6)
21	658.5a (14.4)	-18.8 (7.7)	15.3a (0.9)	-16.9 (8.0)

**The mitigation effect of nitrates decreased by 12 to 18% due to N<sub>2</sub>O emissions**



# Other mitigation options

- **Ionophores:**
  - Ionophores, through their effect on feed efficiency, would likely have a moderate CH<sub>4</sub> mitigating effect in ruminants **fed high-grain or grain-forage diets**. In ruminants fed pasture this effect is less consistent.
- **Probiotics:**
  - **There is not sufficient evidence for direct enteric CH<sub>4</sub> mitigating effect of yeast and other microbes with probiotic mode of action.** Yeast products, however, appear to stabilize pH and promote rumen function, especially in dairy cattle, resulting in small but relatively consistent responses in animal production and feed efficiency, which might moderately decrease CH<sub>4</sub> emission per unit of product.
- **Manipulation of rumen archaea and bacteria:**
  - None of the existing technologies are ready for practical application, but vaccines could be applied to all ruminants, including those with little human contact, such as sheep and beef animals on pasture. **To be effective, the vaccines have to cover the entire methanogen community.** The extent of reductions in methanogenesis may only be 5-10 %, and **persistence of the effect is unknown.**



# Monensin & methane meta-analysis

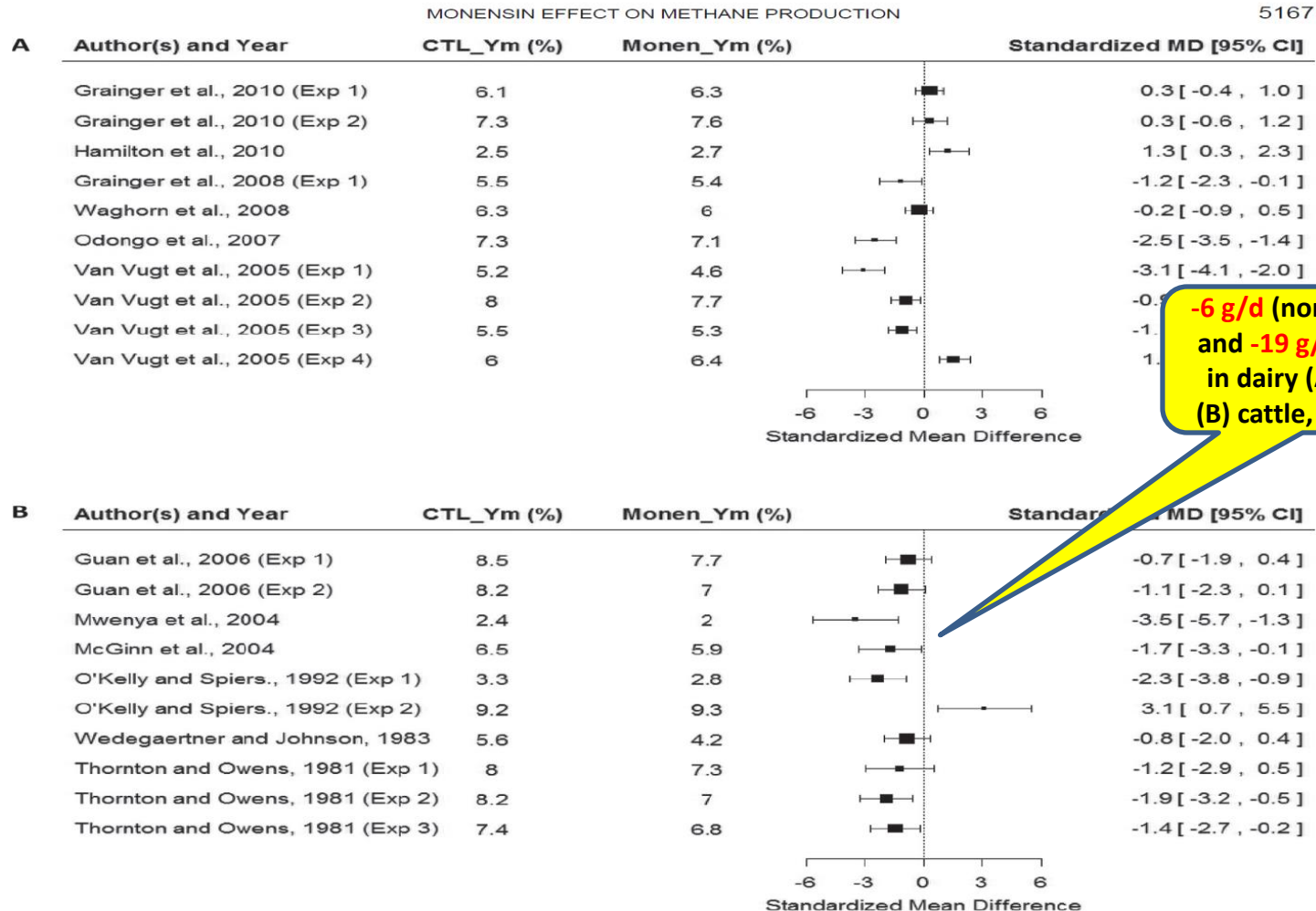


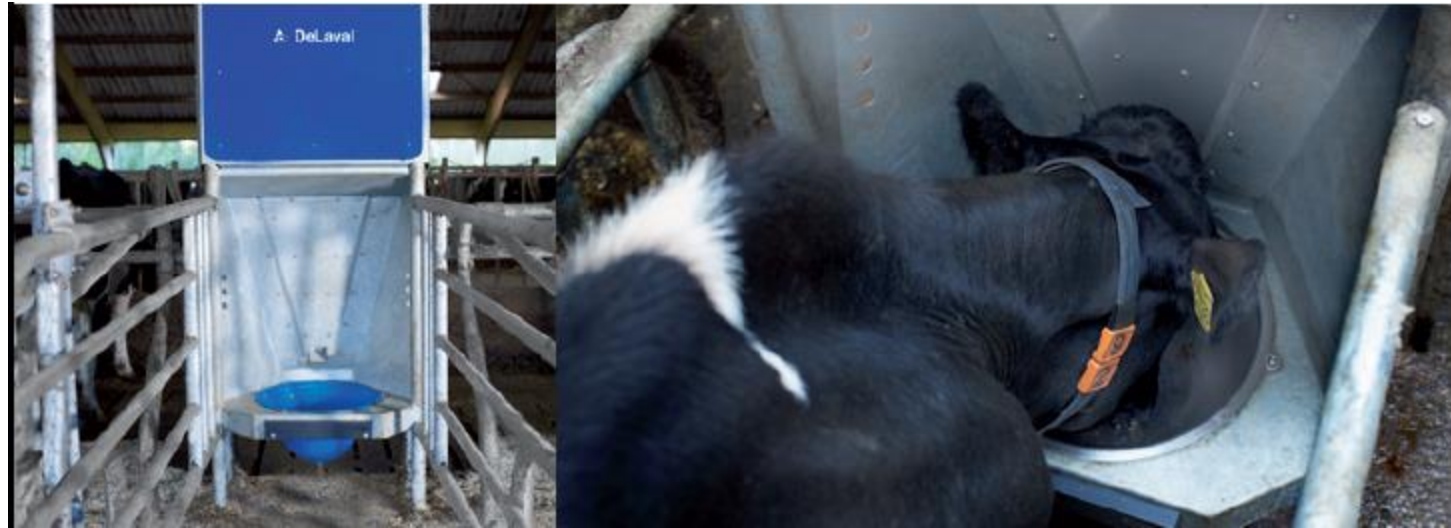
Figure 2. Forest plot showing mean dietary gross energy lost via CH<sub>4</sub> (Y<sub>m</sub>, %) in control (CTL\_Ym) and monensin treatment (Monen\_Ym) groups along with standardized mean difference (MD) and its 95% CI for dairy cow (A) and beef steer (B) studies. The dotted line represents a 0 standardized mean difference.



# Precision feeding

- The original term “**precision agriculture**” was coined in relation to plant nutrition, namely “a series of technologies that allow the application of water, nutrients and pesticides only to the places and at the times they are required, thereby optimizing the use of inputs”
- **In animal nutrition**, precision feeding may have different dimensions, but from a practical standpoint and farm sustainability perspective it refers to **matching animal requirements with dietary nutrient supply**

# Precision feeding technologies in animal nutrition

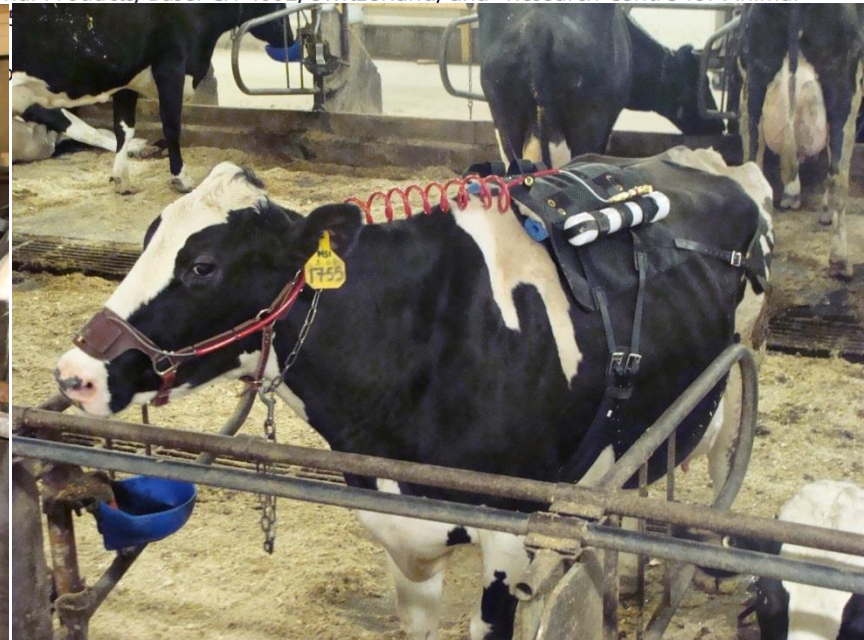




# An inhibitor persistently decreased enteric methane emission from dairy cows with no negative effect on milk production

Alexander N. Hristov<sup>a,1</sup>, Joonpyo Oh<sup>a</sup>, Fabio Giallongo<sup>a</sup>, Tyler W. Frederick<sup>a</sup>, Michael T. Harper<sup>a</sup>, Holley L. Weeks<sup>a</sup>, Antonio F. Branco<sup>b</sup>, Peter J. Moate<sup>c</sup>, Matthew H. Deighton<sup>c</sup>, S. Richard O. Williams<sup>c</sup>, Maik Kindermann<sup>d</sup>, and Stephane Duval<sup>e</sup>

<sup>a</sup>Department of Animal Science, The Pennsylvania State University, University Park, PA 16802; <sup>b</sup>Departamento de Zootecnia, Universidade Estadual de Maringá, PR 87020-900, Brazil; <sup>c</sup>Agriculture Research Division, Department of Economic Development Jobs Transport and Resources, Ellinbank Centre, Ellinbank 3821, Victoria, Australia; <sup>d</sup>Animal Nutrition and Health, DSM Nutritional Products, Basel CH-4002, Switzerland; and <sup>e</sup>Research Centre for Animal



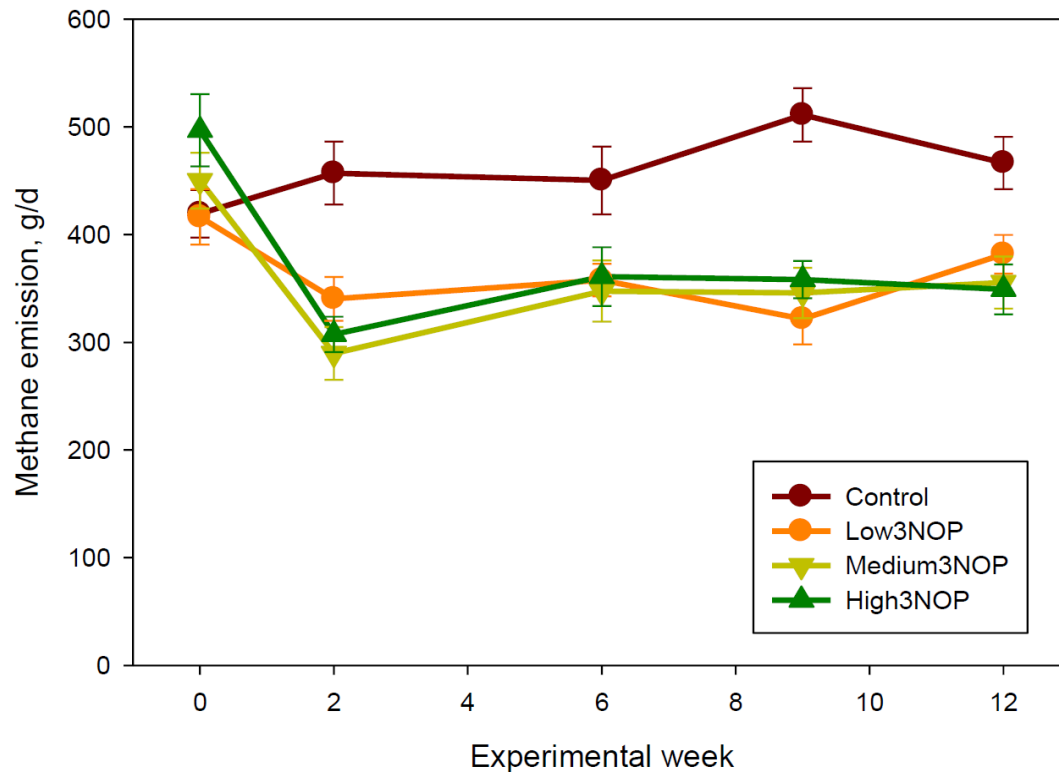
AGRICULTURAL  
SCIENCES

60 mg/kg feed dry matter, decreased methane emissions from high-producing dairy cows by 30% and increased body weight gain without negatively affecting feed intake or milk production and composition. The inhibitory effect persisted over 12 wk of treatment, thus offering an effective methane mitigation practice for the livestock industries.

an effect in sheep (12). The nutrient requirements of high-producing dairy cows are much greater than those of nonlactating or low-producing cows (13) and hence any reduction in feed intake caused by a methane mitigation compound or practice would likely

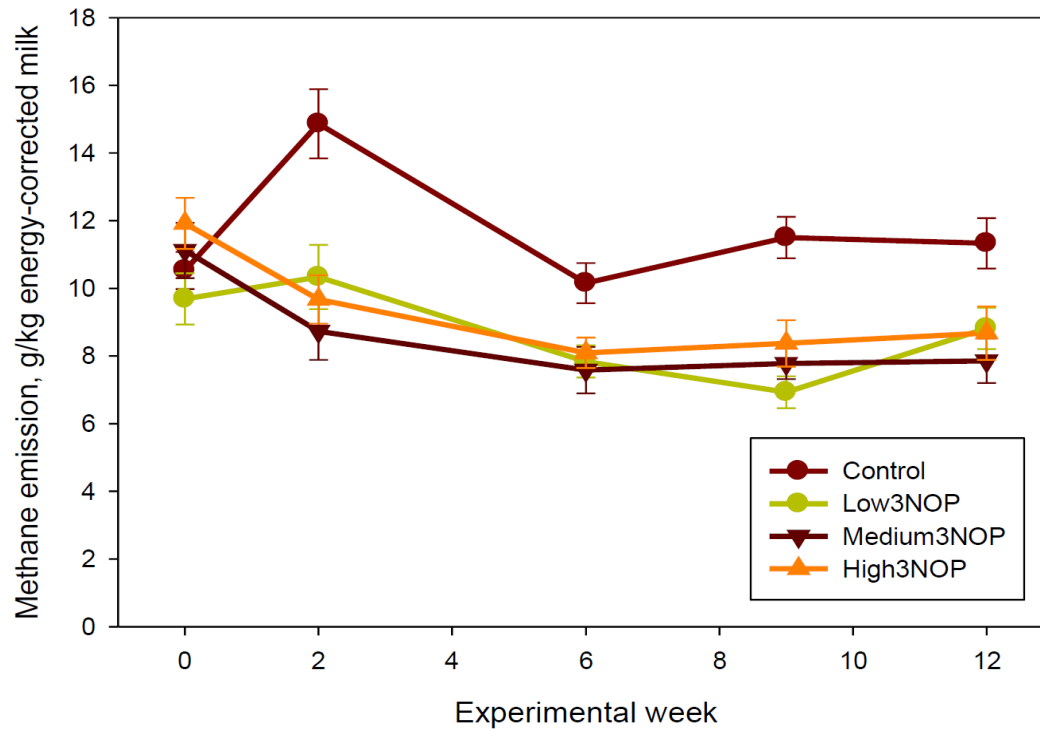
# Effect of 3NOP on methane emission

**29% lower;** Means: 481, 363, 333, and 329 g/cow/d; SEM = 15.9;  $P_L < 0.001$



# Effect on methane emission **intensity**

**31% lower;** Means: 12.0, 8.7, 7.9, and 8.3 g/kg ECM; SEM = 0.48;  $P_L < 0.001$







# Production data

**Table 1. Effect of 3-nitrooxypropanol on feed dry matter intake, lactation performance, and body weight change of Holstein dairy cows**

Item	Treatment <sup>1</sup>				SEM <sup>4</sup>	C vs. Trt.	P-value <sup>2,3</sup>	
	Control	Low3NOP	Medium3NOP	High3NOP			L	Q
Dry matter intake, kg/d	28.0	28.0	27.7	27.5	0.45	0.58	0.38	0.69
Milk yield, kg/d	46.1	46.4	45.9	43.6	1.21	0.59	0.21	0.19
ECM yield, <sup>5</sup> kg/d	44.9	45.2	46.2	43.9	1.59	0.91	0.84	0.44
Feed efficiency, <sup>6</sup> kg/kg	1.64	1.65	1.67	1.62	0.033	0.94	0.80	0.41
Milk fat, %	4.08	3.98	4.02	4.25	0.123	0.98	0.43	0.15
Milk fat yield, kg/d	1.85	1.81	1.87	1.85	0.086	0.98	0.90	0.85
Milk protein, %	3.06	3.14	3.12	3.13	0.033	0.07	0.14	0.31
Milk protein yield, kg/d	1.37	1.46	1.45	1.33	0.042	0.42	0.75	0.02
Milk lactose, %	4.78	4.79	4.81	4.77	0.026	0.69	0.95	0.32
Milk lactose yield, kg/d	2.16	2.22	2.25	2.04	0.069	0.90	0.43	0.05
Body weight, kg	664	672	672	664	5.0	0.38	0.83	0.13
Body weight change, <sup>7</sup> g/d	210	353	451	330	71.2	0.05	0.09	0.16

<sup>1</sup>Control = 0 mg/kg of 3NOP, Low3NOP = 40 mg/kg of 3NOP, Medium3NOP = 60 mg/kg 3NOP, and High3NOP = 80 mg/kg 3NOP (dietary dry matter basis). Data, except body weight change, are presented as covariate-adjusted means.

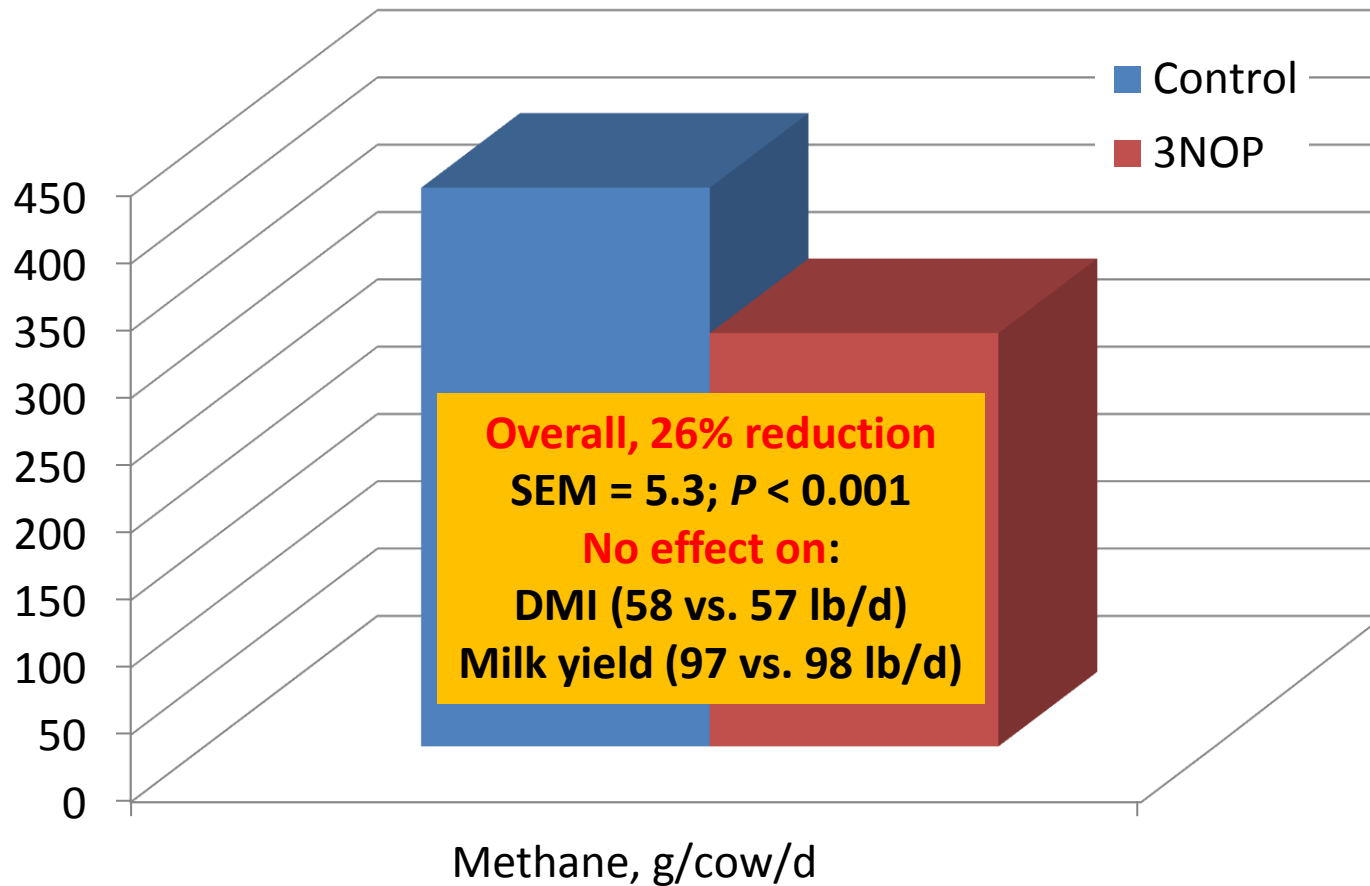
<sup>2</sup>Contrasts: C vs. Trt., Control vs. all 3NOP treatments; L, linear effect of treatment; Q, quadratic effect of treatment.

<sup>3</sup>Treatment × experimental week interactions for dry matter intake, milk yield, feed efficiency, and body weight:  $P = 0.05, 0.97, < 0.001,$  and  $0.93,$  respectively; milk composition and ECM yield data  $P \geq 0.17.$



# Overall mitigation effect of 3NOP

**(Penn State data from over 700 cow-observations)**





# Seaweed

- In 2015 a Canadian study reported up to 18% methane reduction by stormtoss seaweeds in vitro
- An Australian study found 99% methane reduction with 2% (feed DM)

*Asparagopsis*  
*taxiformis* in vitro

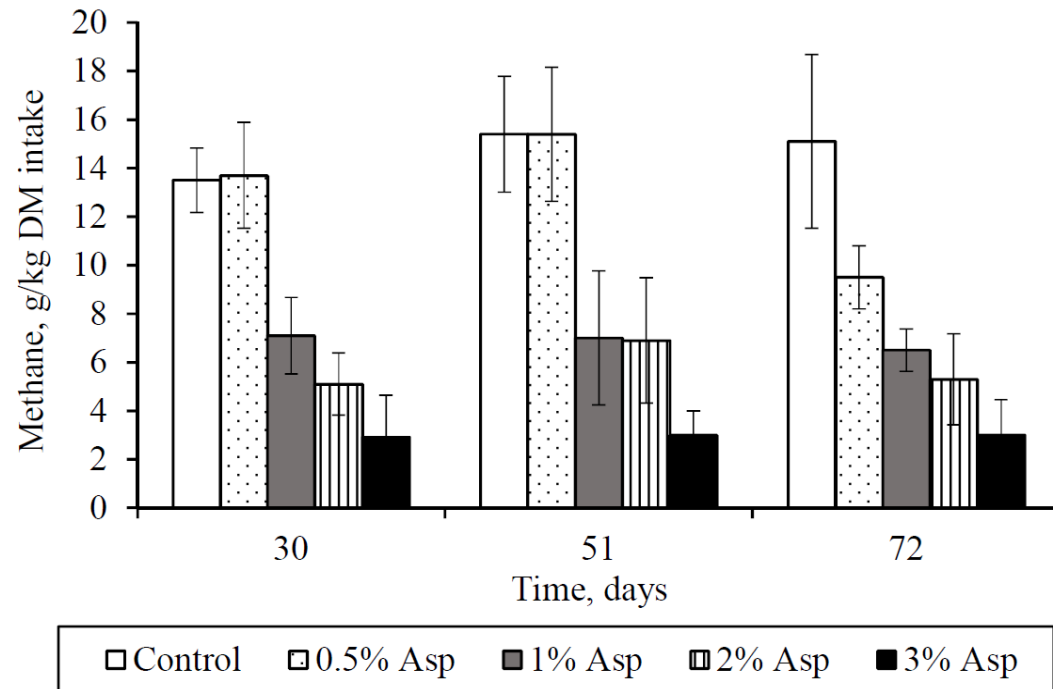


*Asparagopsis taxiformis*



# *Asparagopsis taxiformis*

- The bioactives from *Asparagopsis* have been identified as **bromoform and dibromochloromethane**
- Mechanism similar to that of bromochloromethane (BCM)
  - reacts with reduced vitamin B<sub>12</sub> inhibiting cobamide-dependent methyl groups leading to methanogenesis, thus inhibiting methane production
- A study with sheep (restricted feeding @ 1.5% of BW)
- **Sharp reduction in methane emission**
- Effects on DMI, fiber digestibility, and animal productivity are **unclear at this point**





# Take-home message

- **Discrepancies in top-down vs. bottom-up methane emission inventories**
- There are several established methods for measuring enteric and manure methane emissions
- **We have a pretty good idea of enteric emissions from livestock, but we may be underestimating manure emissions – large uncertainties with both**
- There are a variety of mitigation techniques available to the livestock industries
- Mitigation techniques targeting enteric CH<sub>4</sub> emissions may be difficult to implement and yield a limited effect
  - Assessment techniques can affect experimental outcomes
  - The ultimate verification for a rumen modifier (**for dairy cows**) is a **long-term, continuous design experiment**
- Improving **forage digestibility and feed efficiency and use of effective feed additives** are among the most realistic and applicable short-term mitigation practices for intensive dairy production systems
- Other nutritional approaches may also be promising
- Manipulating the host and microbial genetics may be promising mitigation options in the future
- **Approval and use of 3NOP could lead to a substantial reduction of greenhouse gas emissions from the ruminant livestock sector**





**QUESTIONS?**