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DOTTORATO IN AGRICOLTURA, AMBIENTE E BIOENERGIA
Agriculture, Environment and Bioenergy PhD Course

SUSTAINABILITY IN ANIMAL PRODUCTION

PRECISION FEEDING FOR A SUSTAINABLE ANIMAL HUSBANDRY

Prof. Luca Rapetti

Milano,
22 giugno 2020

Conclusions

- Both small-scale and medium/large scale livestock farms must coexist and be implemented in developing countries.
- Mixed small-scale farms are strategic for keeping people in rural areas and avoiding urbanism, but their efficiency must be improved.
- Mixed medium-scale farms (or a cooperative of mixed small-scale farms) are essential for increasing food production and supply, preserving the environment.
- Semi-intensive and intensive livestock production systems are essential for food supply and should not be demonized, but must minimize the environmental impact through genetics, nutrition&feeding, and management.

What is the precision feeding?

«Precision animal nutrition, or precision feeding, is an integrated information-based system to optimise the supply and demand of nutrients to animals for a target performance, profitability, product characteristics and environmental outcomes.»

"Precision animal nutrition is the application of principles, techniques and technologies that integrate biological and physical processes related to animal nutrition using remote monitoring, **modelling** and control tools that allow making precise, accurate and timely decisions"

Gonzalez et al., Animal (2018), 12:S2, pp s246–s261

What is the aim of precision feeding?

The aim is to make the right choices on nutrition-related decisions in order to:

- maintain the animals in a good **health** and **welfare** status
- allow animals to develop regular **reproductive cycles**
- allow animals to express their **genetic potential**
- allow animals to be highly **efficient** transformers

favoring a sustainable husbandry, in a social, economic and environmental perspective

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How to achieve the goals of Precision Feeding?

- managing in a proper way the variability of the nutritional status of animals over time and between animals
- achieving their optimal nutrition
- optimizing the economic return
- minimizing excretion

and consequently enhancing their health and welfare (Kyriazakis and Tolkamp, 2018).

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Maximizing production through overfeeding of nutrients has negative effects

- Increases feed costs
- Reduces profit
- Causes metabolic disorders
- Causes reproductive problems
- Increases environmental pollution (excess of N, P, NH3, N2O, …)

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Precision feeding has a multidisciplinary approach

- Animal nutrition
- Animal physiology
- Nutritional microbiology
- Immunology
- Genetics (including nutrigenomics and epigenetics)
- Chemistry and biochemistry (feed analysis)
- Mathematics and informatics (mathematical modelling)
- Technological sciences

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Nutrition models: the core of precision feeding

COMPLEX REAL SYSTEM

Diet

Flow of nutrients

Nutrient requirements and allowances

Mathematical model:
set of relationships aimed at describing the behaviour of a complex system in a more or less simplified way

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Ex-ante and ex-post key points for precision feeding management of dairy cows

Ex-ante

Guidelines

Particle size evaluation of feeds (peNDF)

Theoretic IOFC (Income over feed costs)

Chemical and biological analysis of feeds

Animal body weight, body condition score, stage of lactation …

Feed sampling

Precision feeding

Nutritive value of feeds

Nutrient requirements

Milk yield and quality

System of diet evaluation (models)

TMR and faecal sampling

Milk yield and quality

Dairy efficiency

Chemical and biological analysis of TMR and faeces

Urine sampling and pH evaluation

DM intake evaluation

Chewing activity evaluation

Particle size evaluation of TMR (peNDF)

Diet digestibility evaluation (using internal marker)

Effective IOFC (Income over feed costs)

Ex-post

Flow of nutrients and potential technologies to measure nutritional processes: NIRS

NIR analyzer mounted on the mixer wagon cutter

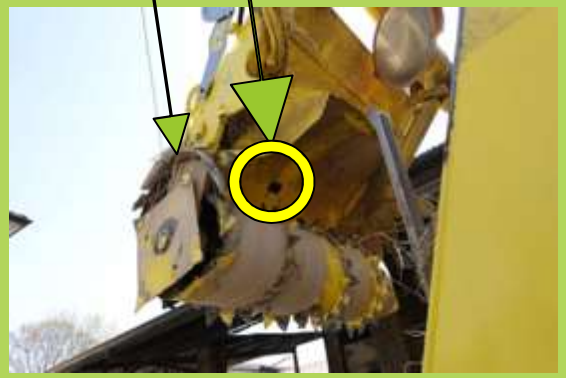
Available feed

amount

quality

Dry Matter Intake

NIRS



To determine the DM content of the ensiled feeds (mainly corn silage)

Portable NIR

- great potential
- accuracy according to the quality of calibration

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Transitory changes in dry matter (DM) and in the chemical composition of the total mixed ration (TMR)

- The composition of TMR in commercial farms differs from the composition defined in the diet formulation (Sova et al., 2014)

- The composition of the ration may vary from day to day following transitory changes in the DM content of the raw materials used and therefore in the DM content of the overall ration

- Greater DMI, milk production and production efficiency are generally associated with less variability in the energy content of the ration (Sova et al., 2014)

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Transitory changes in dry matter (DM) and in the chemical composition of the total mixed ration (TMR)

- Managing the ingredients of the ration by performing regular analysis of ensiled forages can improve the compositional regularity of the TMR by improving the performance of the herd (Stone, 2008; Mikus, 2012)

- The uncontrolled variability of the diet can also affect the health of the cow: the frequency of the dislocation of the abomasum, ketosis, subacute ruminal acidosis (SARA) and poor fertility would be partly associated with the fluctuations of nutrients and energy in the diet (Butler, 1998; Stone, 2004; Stone 2008)

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Flow of nutrients and potential technologies to measure nutritional processes: e-feeders

- **electronic feeders/drinkers**
  (ear tag trasponders)

Dry Matter Intake

Water Intake

The system documents the visit duration and feed intake by recording the animal identification number, initial and final times, and the difference between feed weight at start and end of each feed bin visit.

- Each animal has radiofrequency identification system (RFID) to assign the feed disappeared from the feeder to individuals.
- The RFID tags are widely used as the official animal identification system in many countries and, therefore, are the backbone of many technologies such as those to measure live weight (LW) and milk production

Flow of nutrients and potential technologies to measure nutritional processes: faecal NIRS

Faecal sampling

Dry Matter Intake

TMR sampling

Undigested

Digested

Faecal NIRS

TMR NIRS

Faecal uNDF, OM, NDF, Starch …

TMR uNDF, OM, NDF, Starch …

Digestible dry matter and other parameters (OM, NDF, N, Starch …)

Digestibility determination using uNDF as internal marker

- DM digestibility = (1 - $uNDF_{TMR}$ / $uNDF_{faeces}$) *100
- TTNDFD = (1 - $uNDF_{TMR}$ / $uNDF_{faeces}$ * NDF_{faeces} / NDF_{TMR}) *100
- STARCH digestibility = (1 - $uNDF_{TMR}$ / $uNDF_{faeces}$ * $STARCH_{faeces}$ / $STARCH_{TMR}$) *100
- N digestibility = (1 - $uNDF_{TMR}$ / $uNDF_{faeces}$ * N_{faeces} / N_{TMR}) *100

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Flow of nutrients and potential technologies to measure nutritional processes

the rumen degradable fraction of the feed produces waste, belched in the form of CH_4, CO_2 and NH_3, can be measured with **breath analysers** and **gas sensors** (Hegarty, 2013)

Rumen fermentation

Intra-ruminal devices have been developed to measure the pH and other characteristics of the rumen fluid (Mottram et al., 2008; Bishop-Hurley et al., 2016)

Energy expenditure and requirements for maintenance can be precisely measured using a combination of mask containing **gas analysers** (O_2 pulse: O_2 consumption for one heart pulse), **heart rate monitors** (Brosh, 2007) and **behavioural monitoring** of individual animals.

Energy Maintenance requirements

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Flow of nutrients and potential technologies to measure nutritional processes

Milk yield and quality

- Milk meters (weight or volume)

- Milk composition, MUN, concentration of ketone bodies, can provide useful information about energy and protein supply, roughage fraction in the diet, and metabolic imbalances in dairy cows.
- Progesterone concentration in milk helps farmers detect ovulation, pregnancy, and infertility.

- These systems for on-farm analysis of milk composition are based on infrared spectroscopy, optical methods, or biosensors.
- Their calibration and maintenance requirements have to be checked thoroughly before they can be regularly implemented on dairy farms.

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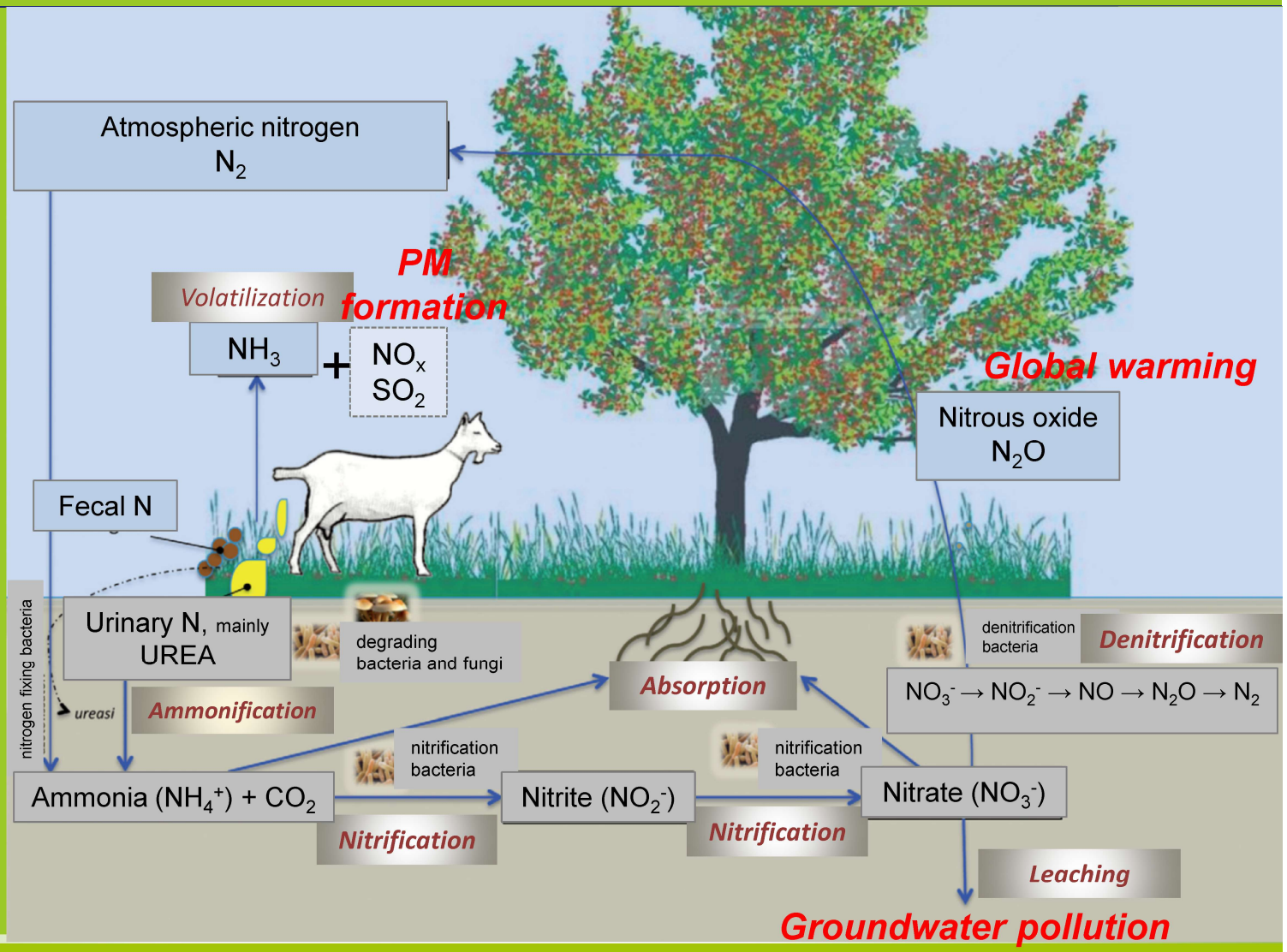
Environmental impact of N

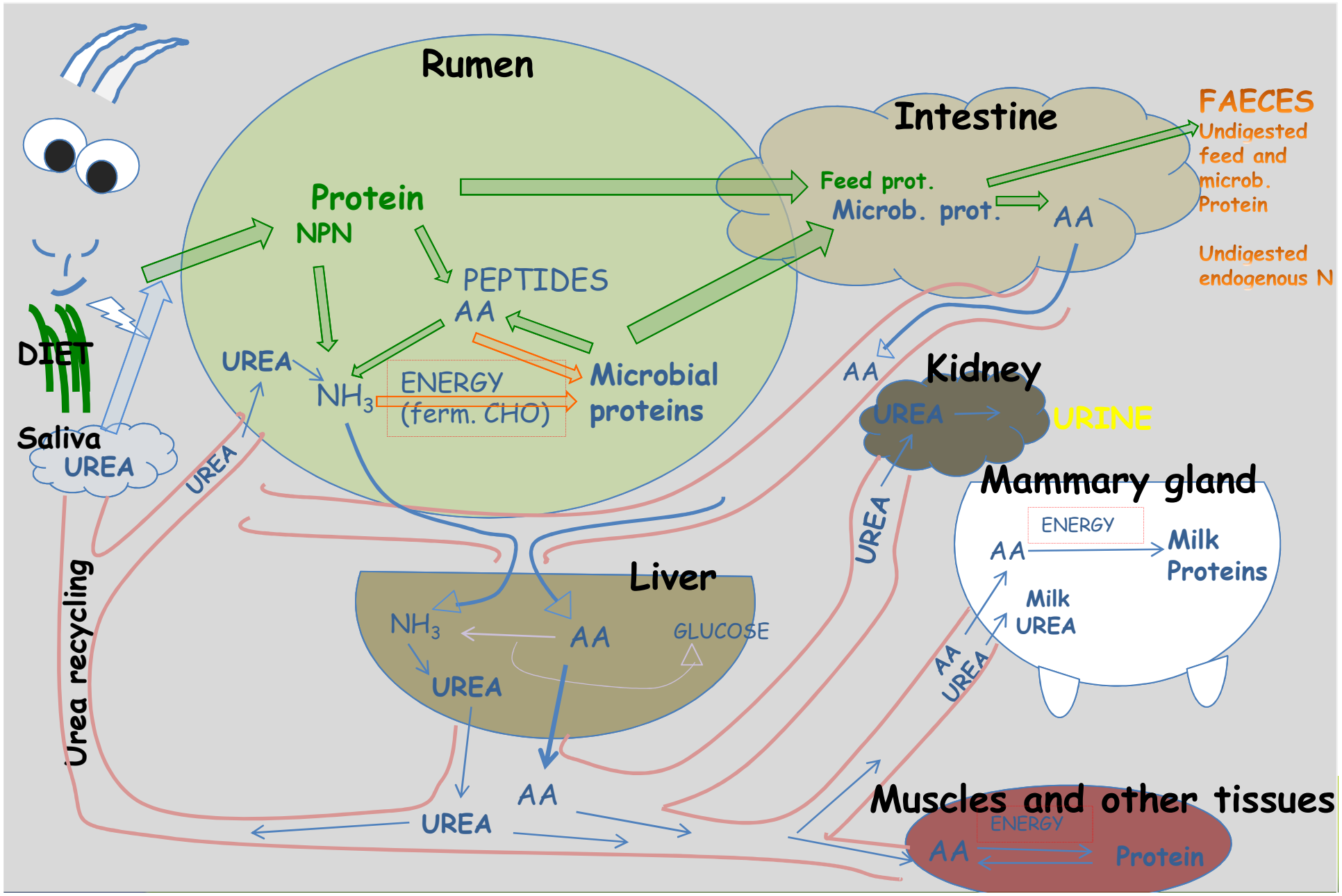
Urinary nitrogen excretion

↓

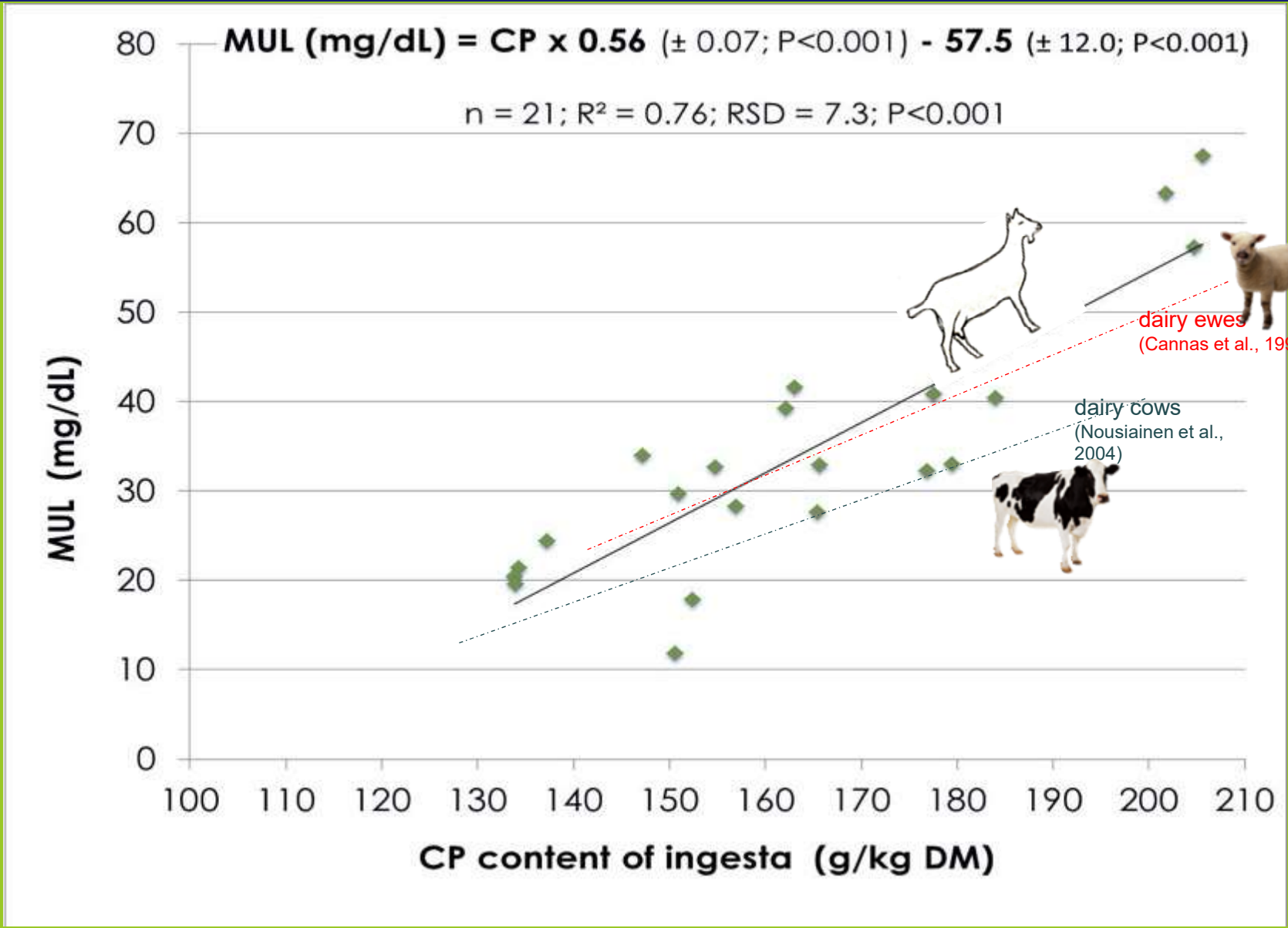
one of the most important factors affecting the **environmental impact** of farms



N metabolism in ruminants



Relationship between CP content of ingesta and milk urea level (MUL) (Rapetti et al., 2014)



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Estimation of urine N excretion based on MUL (Rapetti et al., 2014)

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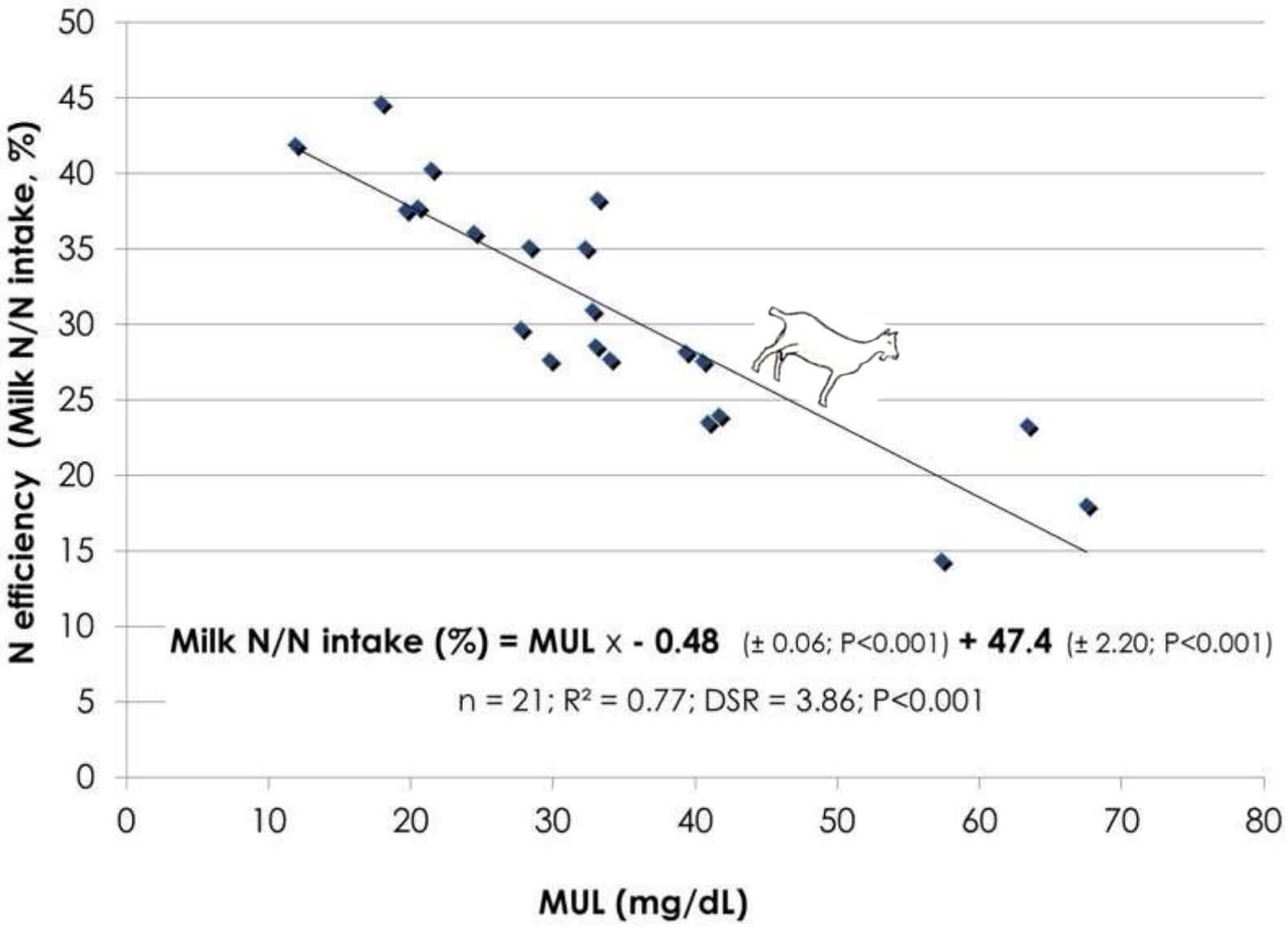
The efficiency of dietary N for milk protein decreases with increasing of MUL (Rapetti et al., 2014)



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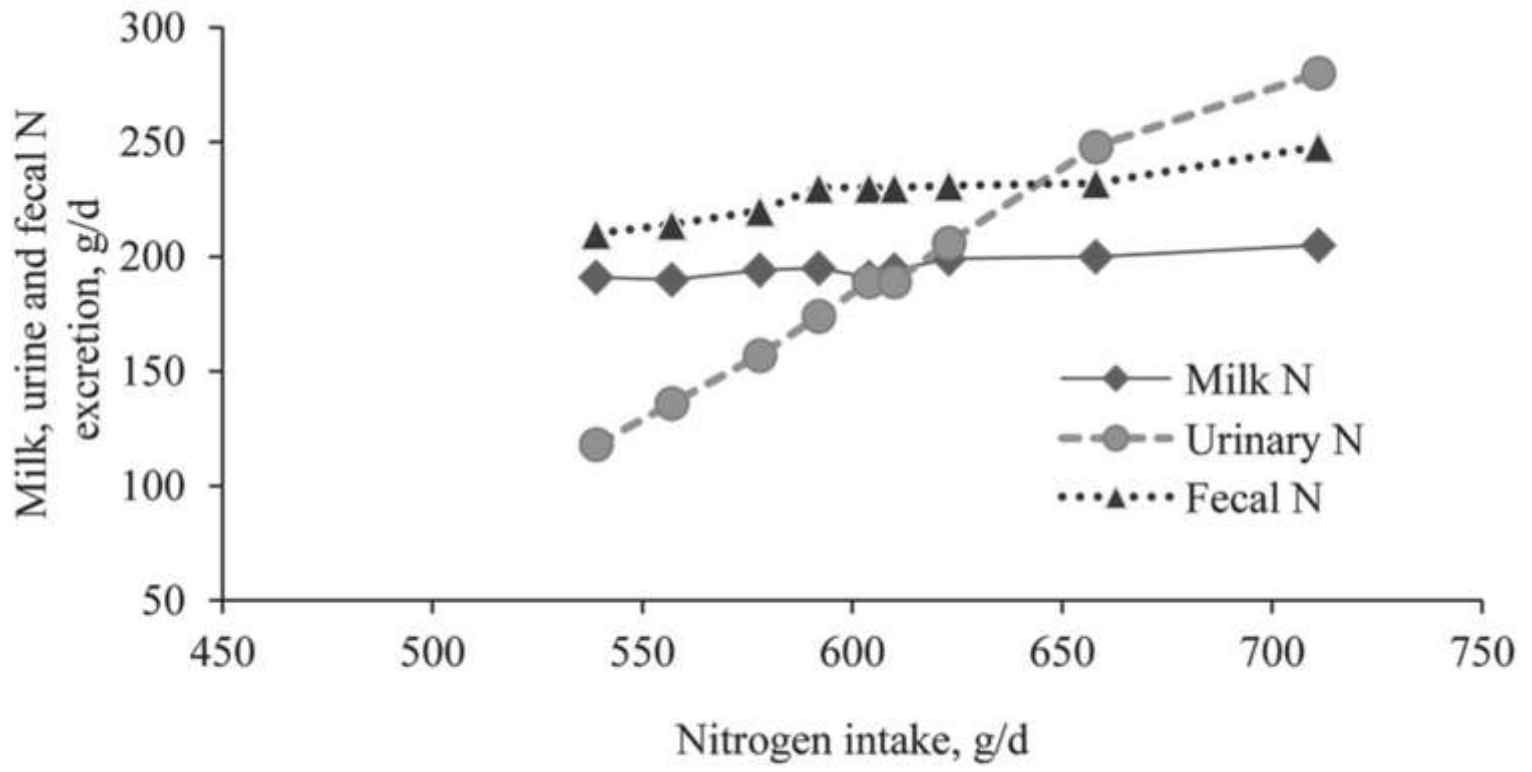
Nitrogen (N) excretion in milk, feces, and urine based on N intake in dairy cattle under controlled conditions of energy as first limiting.

J. Dairy Sci. 98:6361–6380
http://dx.doi.org/10.3168/jds.2015-9378



- Cattle from studies and treatments selected were producing approximately 40 kg of milk and consuming approximately 25 kg of DM per day with diets ranging from 14 to 19% CP.
- Data were taken from studies by Kauffman and St-Pierre (2001), Broderick (2003), Hristov and Ropp (2003), Groff and Wu (2005), Recktenwald (2007), and Recktenwald et al. (2014).

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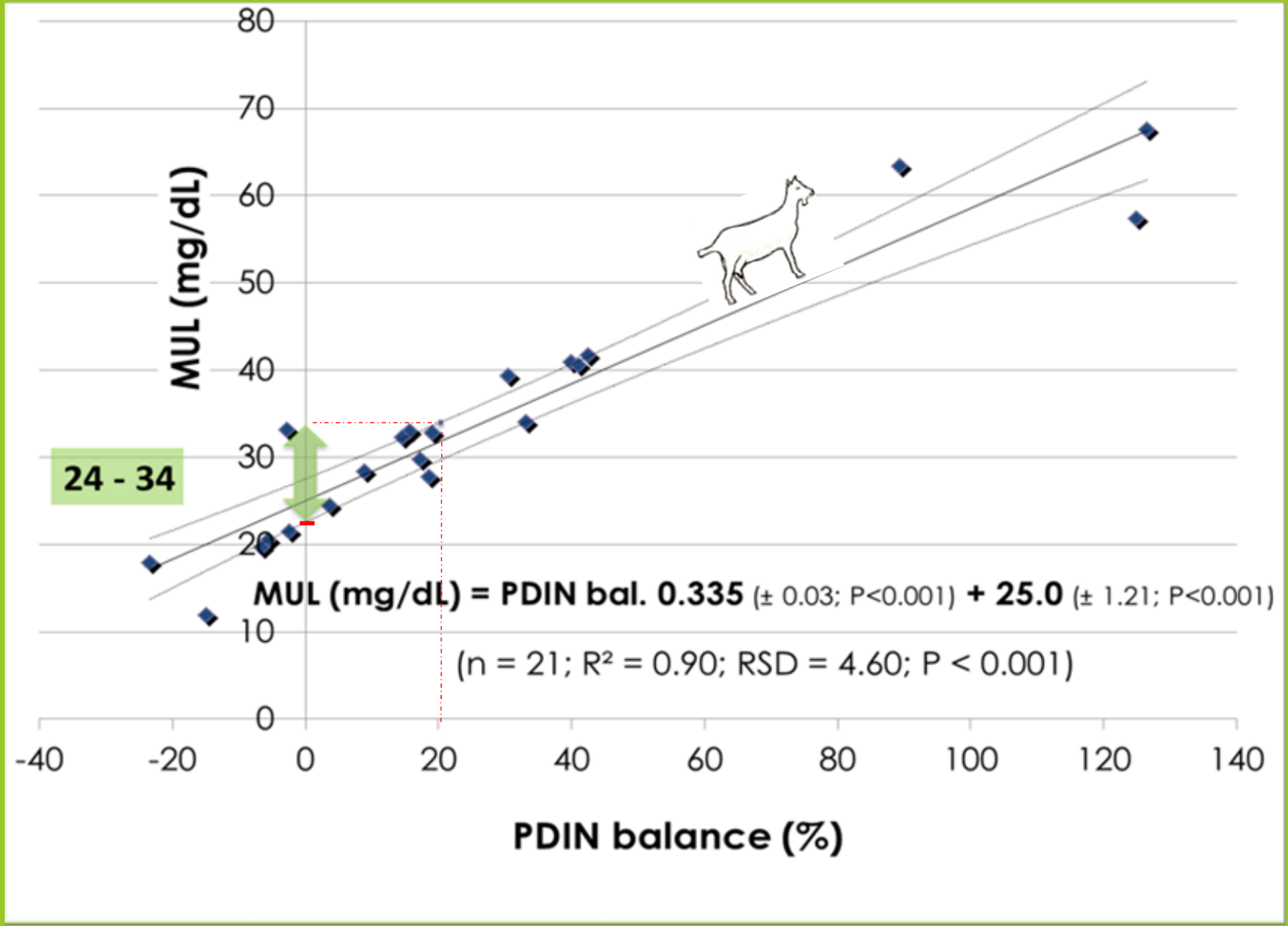
Relationship between daily PDIN balance (%) and MUL (Rapetti et al., 2014)



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Precision feeding for a more efficient N utilization

Precision feeding may improve protein feeding of lactating ruminants thanks to the ability of the models to predict the metabolizable protein (MP or PDI) supply (or AA supply) and requirements which allows the user to refine diet formulation to improve the productive efficiency.

Diet formulation refinement

↘ Dietary CP → ↘ MUL → ↘ UN excretion

↓ **ns** Milk Yield

↓ ↗ Dietary N efficiency

Effect of Precision Feeding management on N excretion and production (a case study)

Applied Animal Science 35:101–113
https://doi.org/10.15232/aas.2018-01783

ARPAS

INVITED REVIEW: *Sustainability and Integrated Systems*

INVITED REVIEW: Modifications to the Cornell Net Carbohydrate and Protein System related to environmental issues—Capability to evaluate nitrogen and phosphorus excretion and enteric carbon dioxide and methane emissions at the animal level*

M. E. Van Amburgh,[1]† K. L. Russomanno,[2] R. A. Higgs,[3] and L. E. Chase,[1] PAS
[1]Department of Animal Science, Cornell University, Ithaca, NY 14853; [2]Medstar Georgetown University Hospital, Washington, DC 20002; and [3]OnSide Ltd., Canterbury, New Zealand 8022

- This project was conducted in New York to evaluate the effect of implementing precision feeding management (**PFM**) on nutrient excretion on 8 dairy farms.
- The study lasted for 3 yr
- 2 to 4 visits per yr to obtain forage samples, animal production information, and updated ration information
- Manure N excretion was calculated as the difference between N intake and the quantity of N contained in the milk produced
- Forage samples were evaluated for a standard feed analysis by near-infrared reflectance spectroscopy (NIRS) procedures. The last year forage analysis included a 30-h NDF digestibility determination by NIRS

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Effect of Precision Feeding management on N excretion and production (a case study)

Herd	Initial CP (%)	Final CP (%)	Initial manure N excretion (g/cow per d)	Final manure N excretion (g/cow per d)	Manure N excretion change (%)	Manure N excretion change (kg/herd per yr)
A	16.0	14.9	358	323	−9.7	−383
B	16.3	14.9	319	282	−11.5	−730
C	20.5	16.0	510	362	−29.0	−4,755
D	17.1	16.0	385	344	−10.6	−1,138
E	19.0	16.2	465	370	−20.4	−6,520
F	17.4	16.5	456	423	−7.2	−5,241
G	16.7	15.7	424	345	−18.6	−16,296
H	16.9	16.2	422	400	−5.2	−2,128

- Overall, a 9.2% decrease in average dietary CP levels occurred during the study due to formulating diets with a smaller safety margin above requirements, along with adjustments in forage and feeding management practices.
- Manure N excretion decreased 5.2 to 29%, which corresponds to the overall decrease in diet CP.
- An average decrease in total yearly herd manure N excretion of 14.1% was observed, indicating that the herds improved the efficiency of N use and captured more of the intake N in milk.
- Although dietary CP was decreased, the average milk protein yield increased by 8.7% among the herds, demonstrating improvement in protein utilization as the dietary CP was decreased.
- Income over total feed costs increased by $147/cow per year

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Effect of Precision Feeding management on N excretion and production (a case study)

- The results of this field study demonstrated that implementing a PFM plan using a model (in this case the CNCPS) for diet formulation lowered manure N excretion while improving profitability when measured as change in income over feed costs.

- Regular laboratory analysis of samples taken on-farm remains the recommended approach to characterizing the components in a ration.

- This approach moves dairy production in a positive direction toward meeting societal expectations of a lower environmental impact of food production because less nutrients were excreted into the environment.

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Estimation of fecal and urinary nitrogen excretion with the CNCPS model in comparison with the results of a nitrogen balance trial determined in lactating cow

Item	Pirondini et al., 2015	CNCPS vs 6.5	Difference
Live weight (kg)	626		
Dry matter intake (kg/d)	22,8		
Diet crude protein (%)	14,7		
Milk yield (kg/d)	27,0		
Milk crude protein (%)	3,77		
Milk Urea Nitrogen[1] (mg/dL)	10,1	**8,9**	-1,2
Nitrogen balance			
Ingested N (g/d)	533		
Faecal N (g/d)	207	**210**	3
Urinary N (g/d)	168	**163**	-5
Manure N (g/d)	375	**373**	-2
Milk N (g/d)	160		
Retained N (g/d)	-2	0	2

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Precision Feeding management on N excretion and production: the case of Italian heavy pigs

- Husbandry of heavy pig for ham production (DPO) is quite different from that of other countries
- The differences are related to the slaughter weight (160-175 vs 110-120 kg) and to rationing of the animals
- Some models exist for the light pigs
- A mathematical model for feeding Italian heavy pigs is missing
- In practice, farmers rely in part on experience but it is very common the overfeeding, especially as regards the contribution of essential amino acids, determining excess in urinary N excretion

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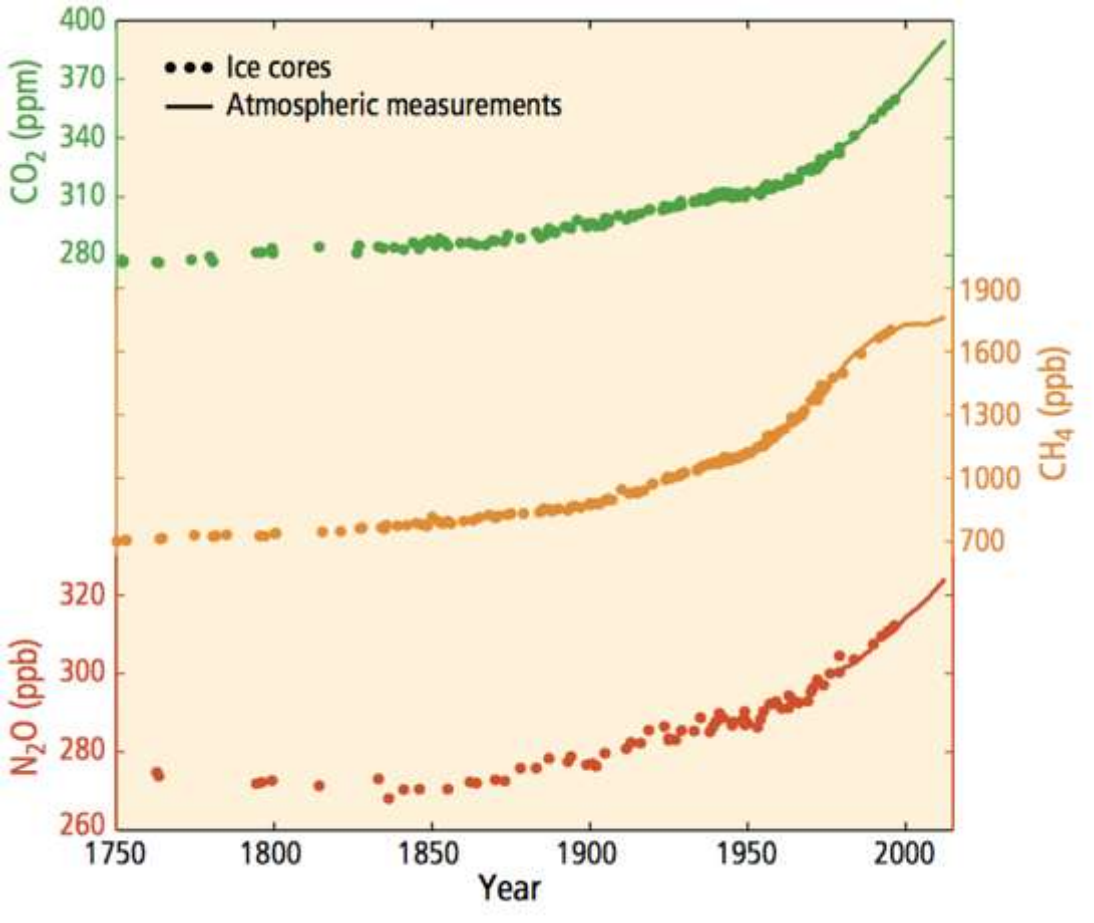
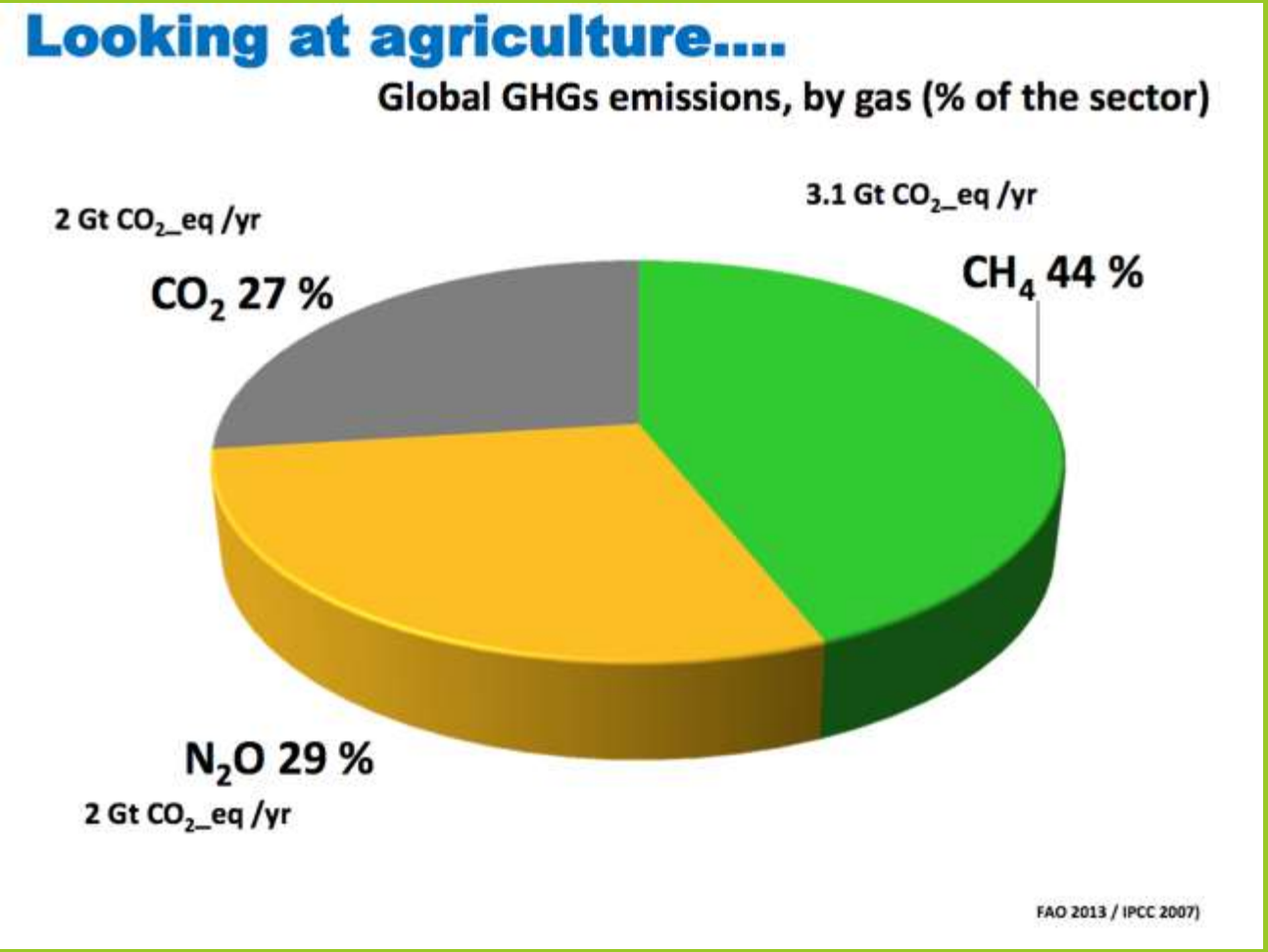
Globally averaged greenhouse gas concentrations (IPCC, 2014)

Observed changes in atmospheric greenhouse gas concentrations. Atmospheric concentrations of carbon dioxide (CO2, green), methane (CH4, orange), and nitrous oxide (N2O, red). Data from ice cores (symbols) and direct atmospheric measurements (lines) are overlaid. (IPCC, 2014).



CH4 and N2O have global warming potentials that are 25 and 298 times that of CO2 (on weight basis), respectively; therefore they contain 25 and 298 CO2-equivalents.

Methane plays an important role in contributing to the GHGs emissions of agriculture sector



The enteric methane

http://www.fao.org/in-action/enteric-methane/background/what-is-enteric-methane/en/

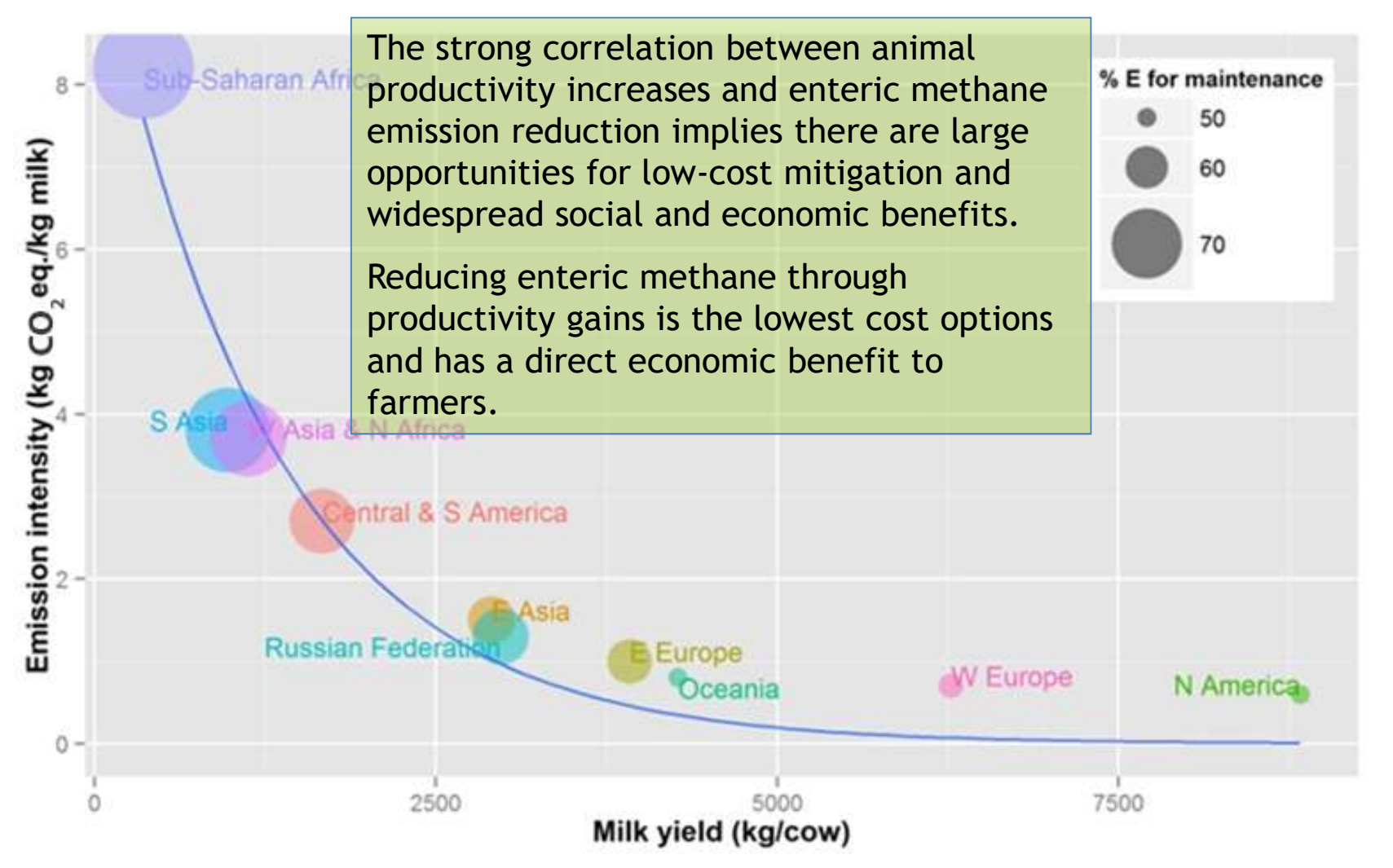
- Naturally occurring methane is generated by anaerobic fermentation, where bacteria break down organic matter producing hydrogen (H2), carbon dioxide (CO2) and methane (CH4). This process naturally occurs in the digestive system of domesticated and wild ruminants, natural wetlands, and rice patties.

- In ruminants, methane is produced mostly by enteric fermentation where microbes decompose and ferment plant materials, such as celluloses, fiber, starches, and sugars, in their digestive tract or rumen. Enteric methane is one by-product of this digestive process and is expelled by the animal through burping. While other by-products (acetate, propionate and butyrate) are absorbed by the animal and used as energy precursors to produce milk, meat and wool.

- Enteric methane production is directly related to the level of intake, the type and quality of feed, the amount of energy consumed, animal size, growth rate, level of production, and environmental temperature. Between 2 to 12% of a ruminant's energy intake is typically lost through the enteric fermentation process.

- … there are opportunities to substantially reduce emissions per unit of product, i.e. emission intensity. These opportunities generally consist of improving the efficiency of production via the implementation of known practices or technologies that result in greater yields per animal and per unit of feed.

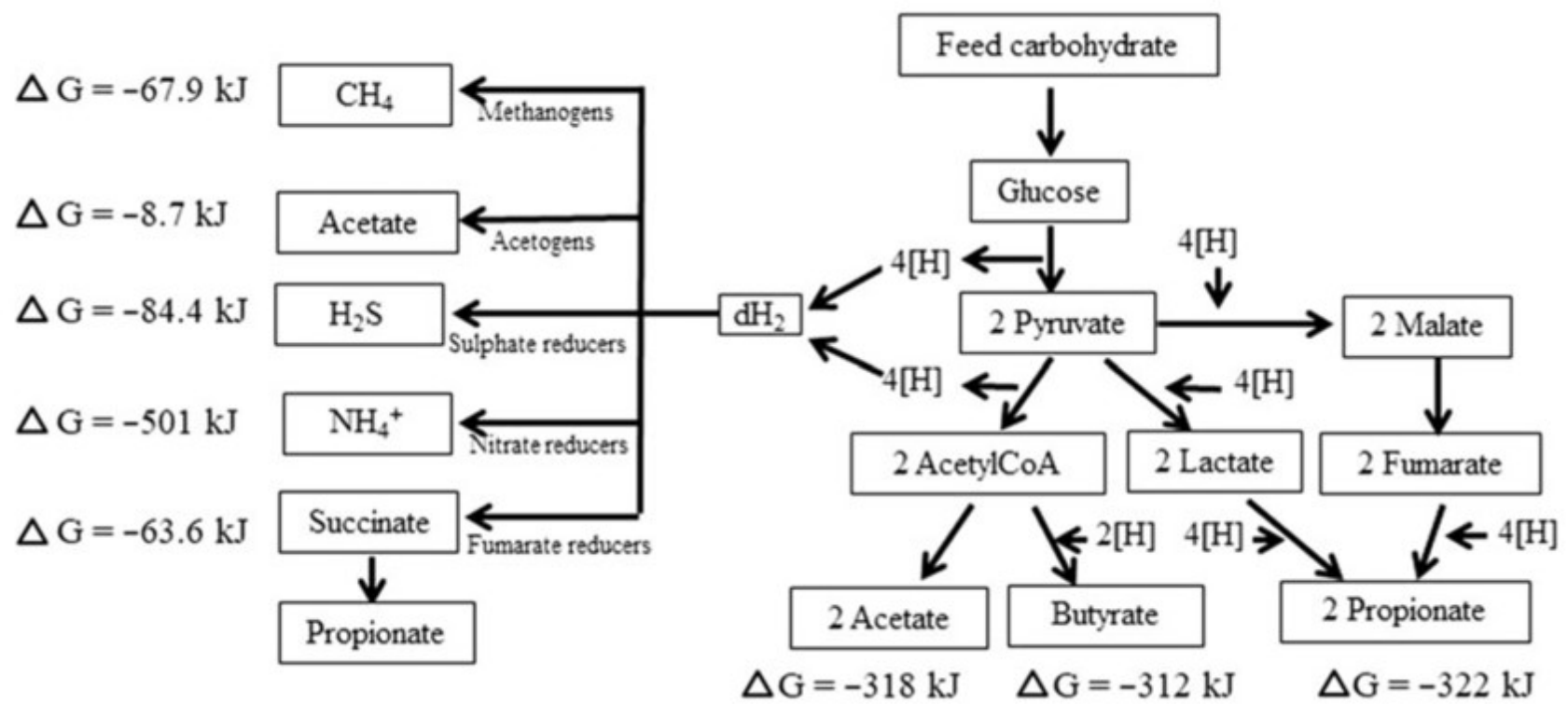
Relationship between emission intensity and milk productivity (http://www.fao.org/in-action/enteric-methane/background/what-is-enteric-methane/en/)



The strong correlation between animal productivity increases and enteric methane emission reduction implies there are large opportunities for low-cost mitigation and widespread social and economic benefits.

Reducing enteric methane through productivity gains is the lowest cost options and has a direct economic benefit to farmers.

Scheme of the major pathways of rumen fermentation including generation and incorporation of metabolic hydrogen ([H]) and dihydrogen (H2) (adapted from Beauchemin et al., 2020. Animal, 14:S1, pp s2–s16)



Assessment of select strategies for enteric methane mitigation in the short or medium term (adapted from Beauchemin et al., 2020. Animal, 14:S1, pp s2-s16)

Strategy	CH4 reduction potential		Expected availability	Feasibility of implementing on-farms	Limitations
	Intensity				
	g/d	g/kg product			
Management					
Increasing animal productivity (through nutrition, genetics, health and management)	Uncertain	Low	Immediate	Greatest potential for production systems that are not already optimized	Adoption limited by knowledg transfer, economics, percepti limitation of resources and ot
Breeding					
Animal selection for low-CH_4 production	Low	Low	Unknown, possibly within 10 years	Can be incorporated into multiple trait selection index	Need robust ways of measuri CH_4 of large numbers of indiv animals. Relationships betwe CH_4 production and economi important traits are unknown to know long-term persistenc different diets and effects on animal health
Animal selection for feed efficiency and residual feed intake	Low	Low	Immediate	Can be incorporated into multiple trait selection index	Existence of genotype × environment interactions nee be determined. Relationship t productivity-related traits at pasture unknown. Lack of information on the biological regulation of the trait

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Strategy	CH4 reduction potential: Intensity g/d	CH4 reduction potential: Intensity g/kg product	Expected availability	Feasibility of implementing on-farms	Limitations
Nutrition					
Lipids	Medium	Medium	Immediate	Feasible for ruminants fed diets, but difficult to implement for grazing ruminants	Can be expensive. Potential negative effects on fibre digestibility. Need more information on fat × diet interactions. Effects on meat and milk quality need further study
Concentrates	Low to medium	Low to medium	Immediate	Feasible, but limited scope for further increase in grain feeding	Decrease in enteric CH4 does not always reduce total greenhouse gas emissions. Can increase risk of acidosis. Concentrates can be fed to other livestock and consumed by people
Improved forage quality	Highly variable	Low	Immediate	Feasible, but highly dependent upon weather and other environmental factors	Adoption limited by knowledge transfer and potential trade-off between yield and quality. Absolute emissions may increase, but improved animal performance decreases intensity

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Strategy	CH4 reduction potential		Expected availability	Feasibility of implementing on-farms	Limitations
	Amount	Intensity			
	g/d	g/kg product			
Algae	Medium to high	Medium to high	Unknown, experimental	Few algae species contain active compounds. Need to dry material, which may require energy	Safety concerns related to bromoforms. Will need approval from regulatory authorities in most countries. Life cycle assessment needed to account for upstream emissions
Nitrate	Low to medium	Low to medium	Available, but requires approval by regulatory officials in some countries	Useful in low-protein diets. Can be used in place of urea, maximum of 2% of dietary DM. Can be used in blocks for grazing ruminants	Risk of toxicity to non-adapted animals. Potential increase in N excretion if N requirements of animals are exceeded. Not approved in some countries
Tannins	Low to medium	Low to medium	Immediate	Extracts can be added to diets. Tannin-containing forages can be incorporated into pastures	Much of the research has been conducted in vitro. Need more information of effectiveness of different source and types of tannins for CH4 reduction. Need information on whether digestibility and performance is negatively affected

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Effect of dietary starch concentration and fish oil supplementation on milk yield and composition, diet digestibility, and methane emissions in lactating dairy cows

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- The aim of the study was to evaluate the effects of diets with different starch concentrations (23 vs 28% DM) and fish oil (FO, 0,8% on DM) supplementation on lactation performance, in vivo total-tract nutrient digestibility, N balance, and methane (CH4) emissions in lactating dairy cows.
- Increasing the concentrate proportion of the diet (especially increasing starch) generally decreases CH4 emissions.
- Fish oil is characterized by a high concentration of long-chain unsaturated fatty acids, which have been shown to decrease methanogenesis (Fievez et al., 2003).

  This CH4-suppressing effect may relate to:

  - the degree of unsaturation of these FA as they undergo biohydrogenation in the rumen
  - their effects on specific rumen microorganisms (e.g., cellulolytic bact. and protozoa).

We observed a trend for lower CH4 emission (g/d) and intensity (g/kg of milk) with the high-starch diets compared with the low-starch diets: 396 versus 415 g/d on average, respectively, and 14.1 versus 14.9 g/kg of milk, respectively.

Table 5. Total-tract digestibility (%) of the experimental diets

	Diet[1]					*P*-value		
Item	LS	HS	LSO	HSO	SE	Starch	Oil	Starch × Oil
DM	67.9	64.9	69.4	68.1	0.80	0.02	0.02	0.25
OM	69.6	66.4	71.1	69.7	0.80	0.02	0.02	0.24
CP	61.0	57.8	62.7	60.4	1.21	0.04	0.09	0.66
Ether extract	55.0	52.3	67.3	66.9	2.37	0.47	<0.01	0.60
NDF[2]	47.3	36.5	49.6	42.6	1.67	<0.01	0.03	0.22
Starch	96.3	96.7	95.9	96.8	0.38	0.10	0.60	0.48
Gross energy	67.3	63.9	69.4	67.7	0.89	0.02	0.01	0.32

[1]LS = low starch; HS = high starch; LSO = low starch supplemented with fish oil; HSO = high starch supplemented with fish oil.
[2]NDF corrected for insoluble ash and with the addition of α-amylase.

Table 7. Methane production from the cows fed the experimental diets

	Diet[1]					*P*-value		
Item	LS	HS	LSO	HSO	SE	Starch	Oil	Starch × Oil
CH_4 (g/d)	415	392	415	400	10.6	0.08	0.67	0.67
CH_4 (g/kg of DMI)	18.3	17.4	17.9	18.3	0.58	0.54	0.63	0.23
CH_4 (g/kg of milk)	15.4	14.1	14.3	14.1	0.45	0.09	0.21	0.20
CH_4 (g/kg of ECM[2])	13.5	12.4	12.6	13.2	0.30	0.17	0.95	0.02
CH_4 (% of gross energy intake)	5.64	5.33	5.46	5.55	0.18	0.48	0.88	0.23
CH_4 (g/kg of NDF intake[3])	53.4	55.7	52.2	58.9	2.07	0.05	0.58	0.26
CH_4 (g/kg of dNDF intake[4])	109	156	106	140	10.8	0.01	0.32	0.51

[1]LS = low starch; HS = high starch; LSO = low starch supplemented with fish oil; HSO = high starch supplemented with fish oil.
[2]ECM (3.5% fat and 3.2% protein) according to Tyrrell and Reid (1965).
[3]NDF corrected for insoluble ash and with the addition of α-amylase.
[4]dNDF = digestible NDF.

Conclusions

- Precision feeding can contribute to improve the sustainability of farms through direct (e.g. reducing N excretion) and indirect (e.g. allowing higher milk yield) actions

- Technology can be of great help by providing more precise and short-term information to be used as input in diet evaluation models.

- Precision feeding means higher accuracy in the evaluation of the actual animal requirements and also higher accuracy in the evaluation of the effective diet nutrient allowances

- Keep in mind that precision feeding does not necessarily aim to obtain maximum production but should aim at the right balance between production, animal welfare, economic return, environmental and social impact.

Conclusions

- The effort and the path to follow for a farming system able to provide quality food in adequate quantities, with full respect for sustainability, must have a holistic vision, with a broad cultural horizon but, at the same time, must be able to observe the smaller details of the phenomena (details often make the difference)

- This requires great collaboration between specialists from different sectors.

- Discuss the different ideas resulting from the knowledge of agronomists, geneticists, nutritionists, engineers etc. it is fundamental to look for practical and applicable solutions that determine real benefits and not ephemeral chimeras.