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PROF ELIZABETH MAGOWAN
BSAS PRESIDENT

As the current president of the British Society of Animal Science it is an honour for me to welcome you to this unique event to showcase the 'Art of the possible in methane suppression to 2030'.

The British Society of Animal Science is a leading organisation within the UK and Ireland to provide a forum to disseminate state of the art science from a wide range of academic and industry stakeholders in support of the livestock sector. Today's event is a classic example of BSAS recognising the urgent need for industry and policy makers to interact with the academic community and equally the academic community to listen to the needs of industry and policy within the area of Methane Suppression.

Methane is a potent greenhouse gas with a global warming potential approximately 25 times that of carbon dioxide. Ruminants are the key source of methane emissions within the UK and especially Ireland.

Furthermore, they make up a significant proportion of the overall greenhouse profile from agricultural systems. As such the reduction of methane from ruminants is a key target to contribute to the achievement of Climate Act targets in both the UK and Ireland and beyond.

Today's event showcases the work of a range of BSAS members, who are globally leading in the area of scientific advances to reduce methane emissions from ruminants within a range of farming systems. Their work is pushing the boundaries in the area of feed additives, the biome of the rumen, the genetic make up of the microbiome and the host animal as well as the metrics to measure biogenic methane when compared with methane derived from fossil fuels. The event is complemented with partners from across the EU and beyond.

We are also delighted to welcome colleagues from industry as well as those working at the interface with national inventories in Denmark and New Zealand to share with us the practical application of this state-of-the-art science.

Today would not have been possible without our sponsors who are highlighted on page 2 within this booklet. We are extremely grateful to our sponsors for their generosity and support in delivery of this event.

I trust that todays proceedings will be of high value for your area of work and you come away with an enhanced knowledge of how this area of science is expected to develop in the years ahead to support the wider livestock sector and society

as a whole.

Elizabeth Magowan

BSAS President

Director, Agri-Food and Biosciences Institute, Northern Ireland.

Speaker biographies

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Prof Sharon Huws

Sharon Huws is a Professor in Animal Science and Microbiology within the School of Biological Sciences and the Institute for Global Food Security at Queens University Belfast. Prof Huws in responsible for the delivery of World-leading research and impact within the school. Her research focuses on enhancing sustainable livestock production within the remit of ensuring planetary and human health. She has won over £10M in funding in the past 5 years, published over 150 publications and led many global initiatives (e.g she coordinated the global 'Rumen Microbial Genomics' network which underpinned the mission of the Global Research Alliance for Methane Mitigation from 2013-2023; currently she is leading a global project with 16 partners across the World (RUMEN Gateway project) to build a major biobank of ruminant gastrointestinal tract microbes) Prof Huws is a Senior editor for the journal Microbiome and Editor-in-chief for the sister journal Animal Microbiome. She also sits on the Scottish Government's Academic Advisory Panel, which underpins the work of the Agricultural Reform Implementation Oversight Board.

Prof Huws was awarded the Sir John Hammond award for excellence in Animal Science from the British Society for Animal Science and the British Cattle Breeders Club in 2022.

Dr. David Yáñez-Ruiz

Dr. David Yáñez-Ruiz is a vet by training and senior scientist at Spanish Research Council (CSIC) in Granada. Previously he worked at Aberystwyth University (UK, 2003-2007) and at CSIRO/University of Queensland (Australia, 2019-2020) as visiting scientist. Dr. Yanez-Ruiz´s main research focus is the evaluation of different nutritional strategies to optimize rumen fermentation with a strong focus on additives development to reduce enteric methane emissions and interventions applied in the early life of ruminants. He has participated in the screening and development of different feed additives through collaboration with companies and worked in numerous EU funded projects (SMEthane, SOLID, iSAGE, MASTER, HoloRuminant, PATHWAYS, FutureFoods). Currently he coordinates the Horizon Europe project Re-Livestock (Facilitating innovations for resilient livestock farming systems), the flagship project on 'Guidelines to develop feed additives to reduce enteric methane emissions' and is chair of the Feed and Nutrition Network of the Global Research Alliance.

Dr Taro Takahashi

Dr Taro Takahashi is Head of Precision Grazing Systems at Agri-Food and Biosciences Institute. Originally trained as a mathematical economist, his areas of expertise include grassland management, greenhouse gas emissions and life cycle assessment of agri-food supply chains.

Prior to joining AFBI in April 2023, he led the 'Metrics of sustainability' sub-work package for Soil to Nutrition, Rothamsted Research's BBSRC Institute Strategic Programme (2017-2023) to optimise the nutrient use efficiency of UK agriculture. He is a fellow of the Royal Society of Arts.

Prof Mike Coffey

Mike Coffey is a Professor of Animal and Veterinary Sciences, Livestock Breeding at the SRUC's Food Security Challenge Centre. His main area of interest is dairy cattle breeding and identification of appropriate selection goals that meet as many stakeholders' requirements as possible.

Mike teaches on the SRUC Agriculture degree course to Animal Science and Agriculture students as well as lecturing to practising Vets on the Diploma in Bovine Reproduction delivered at Liverpool University.

As part of the Agritech Centre, Agrimetrics, Mike led on the development of a CPD course, "Vetnomics", a course for the agri and vet industries practioners on genetic and genomic improvement in livestock.

He also presents to a number of varied audiences around the country including farmers on courses organised by Vet practices, RABDF and other extension services.

Dr. Ross Evans

Dr. Ross Evans is an employee of the Irish Cattle Breeding Federation (ICBF) since 2005. His role involves responsibility for the co-ordination of all genetics research, application to breeding programs in Ireland and dissemination to the wider industry. His previous roles involved the management of the ICBF genetics team in development and routine running of genetic and genomic evaluations across beef and dairy traits.

ICBF was formally set up in 1998, as an independent, non-profit, farmer-led organisation providing services to Irish farmers and industry. ICBF is charged with providing cattle breeding information services to the Irish dairy and beef industries. It exists to benefit farmers, our agri-food industry, and our wider communities through genetic gain.

Shareholders consist of farmers, milk recording, AI & herdbooks organisations. With sustainability now a global priority, ICBF's integrated database, with its metrics and scientific methodologies, have a key part to play in helping Irish agriculture rise to this challenge.

Prof. Sinéad M. Waters

Prof Waters is a Principal Research Officer in the Animal and Bioscience Research Department in Teagasc. She was also appointed Adjunct Professor at the Genetics and Biotechnology Laboratory, Plant and Agri-Biosciences Research Centre, The Ryan Institute, National University of Ireland Galway in 2018.

She leads a research programme in the application of genomics technologies to address key issues in agriculture, particularly in the role of the rumen microbiome in improving nutrient utilisation from feed and reducing greenhouse gas emissions, mainly methane, from ruminants and it's manipulation via animal breeding and dietary supplementation, leading a number of projects on the development and evaluation of feed additives to reduce enteric methane from ruminants. She has developed a strong national and international research profile (with over 140 peer-reviewed published research papers and >250 conference proceedings) and is Principal Investigator or lead Irish partner of many funded projects such as the US-Ireland Tripartite Research Fund, EU FACCE-JPI, ERA-GAS programme, EU Horizon 2020, Science Foundation Ireland and the Department of Agriculture, Food and the Marine Research Stimulus Fund.

She served co-chair of the Livestock Research Group of the Global Research Alliance for Agricultural Greenhouse Gas emissions (2018-2023) and an active member of the Rumen Microbial Genomics Network and represents Ireland on the Expert group on agricultural methane for the EU Commission (DG-AGRI). She has served on the council of the British Society of Animal Science (2010-2013) and is currently sits on their events committee. She has also supervised 18 PhD students successfully and currently supervises 5 as main supervisor. She serves on editorial boards of Journals Frontiers in Microbiology and Nature Scientific Reports and an expert reviewer for international funding agencies such as Genome Canada, FCT (Portuguese national funding agency for science, research and technology) and Poland's National Science Centre. She is the Irish lead and Workpackage 3 leader of the EU funded project 'HoloRuminant' which is coordinated by Dr Diego Morgavi (INRAE, Clermont Ferrand).

Prof Nicholas N Jonsson

Nicholas Jonsson is Professor of Animal Health and Production in the School of Biodiversity, One Health and Veterinary Medicine, at the University of Glasgow.

Nick worked as a farm animal veterinary practitioner in Australia for seven years before commencing an academic career in livestock production and health at Queensland Department of Primary Industries, then the University of Queensland in Australia and the University of Glasgow in the UK.

His research interests are in animal management, with emphasis on systems for efficient cattle production: ruminant gut function and pathology, the use of sensor technologies to optimize ruminant health and production, the genetics of adaptation in cattle, and sustainable strategies for parasite management.

Emma Nelson

Emma is the Senior Livestock Manager at Morrisons

From an organic beef farm in Hillsborough, Co. Down, Emma has 10 years experience in the agri food sector, spanning operational, commercial and agricultural roles.

Emma currently looks after ESG and livestock operations, across beef, pork and lamb, for Woodheads, Morrisons.

Prof Peter Lund

Prof. Peter Lund is leading the Ruminant Nutrition research group and professor in Sustainable Dairy Production within Department of Animal and Veterinary Sciences, Aarhus University. The professorship is in collaboration with Arla.

His research is centered around improved digestion of nutrients in dairy cows, and reduced environmental and climate impact of cattle production. Especially the interplay between rumen microbiome communities, nutrition, feed additives, and genetics is a key area of interest.

He provides advice to Danish Ministries regarding effect and implementation of methane mitigating feed additives, has supervised 15 PhD students, and published more than 140 peer review publications.

Prof David Kenny

Professor David Kenny is Head of the Teagasc Animal and Bioscience Research Department in Ireland. He has over twenty years of research experience in the biological control of a range of economically important traits to ruminant livestock production systems, including growth and reproductive efficiency, ruminal methanogenesis and the development and functionality of the rumen microbiome. His work is based on in-depth study and the application of state-of-the-art physiological and molecular approaches to these complex, multidimensional traits.

He has led a number of large multi-partner research projects and has supervised the studies of 19 Ph.D. and nine M.Sc. students to completion, as principal supervisor.

His research has resulted in the publication of over 200 full length internationally peer reviewed scientific manuscripts and book chapters to-date as well as industry targeted technical reports. He is the president of the Physiology Study Commission of the European Association of Animal Production, is Vice President and a trustee of the British Society of Animal Science (BSAS), and is a member of the management board of the international scientific journal, Animal.

He is co-ordinator of the recently awarded €5m Horizon Europe project, 'Towards sustainable livestock systems: European platform for evidence building and transitioning policy (STEP UP)'.

He was awarded the prestigious Hammond award by BSAS in 2018 in recognition of outstanding contribution to an improved understanding of how nutrition affects the complex underlying biology regulating economically important traits in cattle, including feed efficiency, rumen methane emissions and male and female reproduction.

He runs a beef and sheep farm in County Mayo, in the west of Ireland and is integrally involved, and is well known, within the beef cattle sector and wider agricultural industry in Ireland.

Professor Elizabeth Magowan

Prof Elizabeth Magowan is the Director of Sustainable Agri-Food Sciences at the Agri-Food and Biosciences Institute, and the current president of the British Association of Animal Science (BSAS)

Elizabeth's early research focused on optimising pig production performance through management and nutritional strategies whilst reducing environmental impact. Elizabeth worked extensively on industry/academic collaborative studies and presented her work across the UK and at international conferences as well as publications in journals.

Elizabeth was awarded the Sir John Hammond Award in 2017, from the British Society of Animal Science, in recognition of her scientific work in collaboration with industry.

Elizabeth has been responsible leading AFBI's membership of the UK Centre of Excellence for Livestock (CIEL) as well as undertaking the role of interim director of CIEL in its formative months. She also recently chaired UK wide consortiums of academics to deliver flagship reports for the Centre of Innovation and Excellence in Livestock on Livestock farming and net zero.

Elizabeth is also part of the driving force behind the AFBI-Queen's alliance which sees the sharing of academic and applied science resource, facilities and studentships to develop agri-food research in Northern Ireland and beyond.

Abstracts

2

The rumen microbiome and methane production

PROFESSOR SHARON HUWS

SCHOOL OF BIOLOGICAL SCIENCES, INSTITUTE FOR GLOBAL FOOD SECURITY, QUEEN'S UNIVERSITY BELFAST (QUB)

Overview of the presentation

It is estimated that over 11.7 percent of humans do not have access to sufficient food and hence suffer from nutrient deficiencies and conditions such as anaemia and stunting. Moreover, it is predicted that the world's population will reach 10.4 billion in the 2080s. Ruminant products are high in protein and micronutrients, thus providing a valuable source of nutrients for human health, when consumed in a balanced manner. However, ruminant production is a major source of methane (CH_4), a greenhouse gas (GHG) that has between 27 and 30 times the global warming potential (GWP) of carbon dioxide (CO_2), with enteric fermentation from ruminants contributing to an estimated 11-20% of total GHG emissions as CH_4 (Huws et al., 2018). More recent data suggests that CH_4 may only have a half-life of approx. 12 years in the atmosphere (Allen et al., 2018), but irrespective of the accurate GWP of CH_4, it is still a GHG causing a climate challenge, with a balance required between ensuring human health and the health of our environment.

Ruminants evolved about 50 million years ago and were small (<5 kg) forest-dwelling omnivores, with approx. 200 living ruminant species in 6 families in existence today (Hackman & Spain, 2010). Their success is largely due to the possession of a specialized four-compartment forestomach, consisting of the reticulum, rumen, omasum, and abomasum, with the rumen, the primary fermentative chamber, allowing conversion of inedible protein to human edible protein (Figure 1). The fermentative capacity of the rumen is largely because it harbours a dynamic ecosystem comprising bacteria, protozoa, fungi, archaea, and bacteriophages; all of which focus on harvesting energy from the diet by conversion of complex carbohydrates into volatile fatty acids which are absorbed by the animal across the rumen epithelium as a source of energy (Figure 1). These microorganisms engage in diverse ecological interactions within the rumen microbiome, primarily benefiting the host animal by deriving energy from

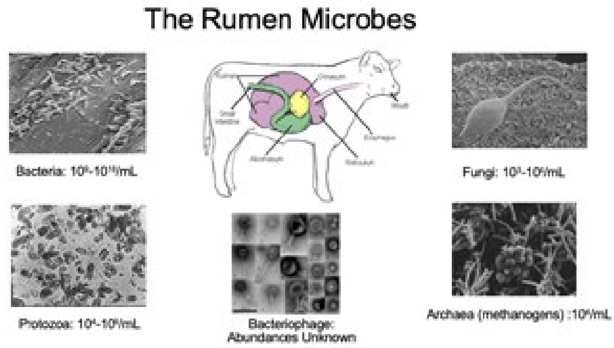

FIGURE 1.

plant material breakdown e.g mutualism, commensalism and competition, yet we still have poor understanding of the consequences of these interactions on ruminant productivity and GHG emissions. Likewise, a better understanding is required to fully understand the mechanisms of action of methane-mitigating dietary and breeding-based interventions, whilst evaluating any unintended consequences of such strategies.

In the last 20-30 years we have seen an explosion in data generation in terms of understanding rumen microbial diversity (using metataxonomic approaches based on marker amplicon sequencing) but such technologies are limited in terms of understanding what these microbes are doing i.e function. To understand function, more latterly technologies have progressed into understanding their function using technologies such as shotgun sequencing, metaproteomic s and metabolomics (so called 'multi-omic' approaches), which have enhanced understanding substantially, especially with respect to hydrogen flow in the rumen (Greening et al., 2019; Ungerfeld, 2020). However, these technologies are dependent of how good the databases which underpin them are and given that many microbes remain unexplored (so called rumen 'dark matter'), resulting in a lack of ability to understand their role, due to an inability to annotate genes/proteins/metabolites, this is one of the major barriers in progressing our understanding.

This paper will focus on the progress made globally on increasing our understanding of rumen microbial function in terms of the past, whilst looking to the future. In particular, the talk will focus on the progress made during the 'omic revolution and the role that novel culturomic approaches may play in the culture of so-called rumen 'dark matter', given the launch a new Global Research Alliance flagship project in this area (acronym: RUMEN Gateway).

Acknowledgments

The speaker acknowledges the close research collaboration with the Agri-Food Biosciences Institute (AFBI) through the AFBI-QUB alliance alongside project specific collaboration with a number of research institutions globally as part of the RUMEN Gateway consortium. The speaker also thanks the Global Methane Hub, Schmidt futures, The European Union Commission, UKRI, DEFRA, DAERA and many industrial partners for funding the research.

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Overview of the state of the art in methane mitigation

DAVID R. YÁÑEZ-RUIZ,

SPANISH RESEARCH COUNCIL, CSIC, GRANADA, SPAIN

Take home messages

Several solutions have been investigated to reduce enteric methane emissions. However, to date, most are still far from being ready for practical implementation. Some feed additives/ supplements with 10-30 % reduction efficacy are ready for commercial use while others need more research. Vaccination and breeding for low emissions offer potential in the medium-long term.

Overview of the presentation

Globally, around 32 percent of global human-induced methane (CH_4) emissions come from livestock, mainly from enteric fermentation and manure management systems. Methane is produced as a by-product of the digestive process of ruminants and during the anaerobic fermentation of animal manure by methanogenic Archaea. Given its short lifespan and strong warm potential, lower CH_4 concentrations would rapidly reduce the rate of warming making CH_4 mitigation one of the most promising ways of limiting climate change in the near term. This work will present a general overview of the main interventions to reduce enteric CH_4 emissions available to date, with a main focus on dietary interventions using feed additives.

Mitigation strategies to reduce enteric CH_4 emissions can be classified into three main categories: animal and feed management, diet formulation or rumen manipulation.
An optimized management of the herd (i.e. reduce unproductive periods of animals) and improved quality of the diet, mostly the forage/ grass, are well-known strategies to reduce CH_4 emissions intensity. A recent metanalysis (Arnd et al., 2022) identified that the main interventions to reduce methane production is by direct impacting methanogenic Archaea in the rumen. This can be achieved by using feed additives or vaccination. Also, there is potential to reduce CH_4 emissions from livestock by selecting for higher feed conversion efficiency, or breeding for low CH_4 emitting animals that exploits natural animal variation in CH_4 emissions.

Feed additives

The inclusion of feed additives in livestock rearing systems or supplements is a routine global nutritional management practice. Therefore, the existing commercial feed additive marketing and delivery pathways would be able to deliver rapid market penetration of feed additives specifically developed to reduce enteric CH_4 emissions. However, despite the strong research effort in the last decades, the number of feed additives with consistent CH_4 mitigation efficacy and commercially available is very limited.
Two different products (3-Nitrooxypropanol, Bovaer®) and Asparagopsis (red algae) have routinely delivered over 25-30% mitigation of enteric CH_4, while dietary nitrate is the third most effective additive and can safely deliver around 10% reduction. The efficacy, stage of development/registration and the constraints associated to their wider implementation will be discussed. Other feed additives cannot deliver more than 5-10 % mitigation. Some other inhibitors are now going through initial stages of development and will be presented. The potential of combining feed additives with different modes of action is currently investigated in the Horizon Europe Re-Livestock project and initial results will be discussed.

Vaccination

The possibility of applying vaccines that target methanogenic archaea to mitigate CH_4 production from enteric fermentation in ruminants has been repeatedly suggested and investigated in the last decades. The advantage of this approach is that some of the obstacles associated with using feed additives (i.e. grazing systems) can be avoided. However, it is complicated to evaluate the real effectiveness of this strategy. Few studies have directly assessed the complete approach, i.e., from immunization development to enteric animal CH_4 emission measurement. Furthermore, the great variety in methods is an obstacle in comparison of results from different studies in an appropriate and repeatable way. However, the strategy has been considered promising by many authors, and more research is needed to reach a rigorous conclusion on its feasibility, practical implementation, and sustainability.

Various steps should be considered for future studies, such as antigenic capacity, archaeal recognition/tolerance by the host immune systems, Igs in saliva (IgG transfer and IgA production), action and stability of Igs in the rumen, booster protocols, long-term efficacy, etc…

Animal breeding

Animal breeding that exploits natural variation in CH_4 emissions has been shown to be a mitigation solution that is cost-effective, permanent, and cumulative. Results have been used to simulate the potential of breeding and show that CH_4 emissions may be reduced by 1% per kg of milk per year at the start, increasing to a 29% methane reduction in 2050. However, significant innovations are needed in four areas to make selective breeding as a mitigation strategy viable: i) extensive and automated registration of methane emissions per individual cow, ii) breeding value assessment models, iii) knowledge of the impact of selecting cows with lower emission levels (and other characteristics) and iv) implementation in practical and widely accepted tools with a potential to cut emissions. Re-Livestock project is developing a large database of 12,500 cattle with CH_4 phenotypes and 2,000 cattle with microbiome to re-define CH_4 trait, standardise across countries by combining genotypes (joint imputation of genotypes) and compare microbiome across countries to evaluate the predictive ability for CH_4 emissions.

Acknowledgments

Re-Livestock project (https://re-livestock.eu) is funded from the European Union’s Horizon Europe research and innovation programme under grant agreement N° 101059609

Why reducing methane still matters even under GWP*

DR TARO TAKAHASHI

AGRI-FOOD AND BIOSCIENCES INSTITUTE, HILLSBOROUGH,

Take home message:

The increasingly common belief across the ruminant industry that methane does not contribute to climate change due to its short life span is misguided. Efforts to reduce methane emissions are more important than ever and, without successful mitigation, the sector is unlikely to achieve net-zero.

Overview of the presentation

Amongst the three greenhouse gases that are pertinent to agricultural systems, methane remains in the atmosphere for a considerably shorter period of time post-emission than carbon dioxide and nitrous oxide. The 100-year time horizon global warming potentials impact assessment method (GWP100), the most frequently used mid-point proxy for climate change impact of anthropogenic activities, fails capture this difference sufficiently, with a tendency to overstate the effect of constant methane emissions on global surface temperature while understating the effect of additional methane emissions from new sources (IPCC, 2021).

As an alternative approach to address this issue, the GWP* method (Allen et al., 2018) is equipped with a capability to distinguish the approximated temperature effect of methane between short-term (< 20 years) and long-term (> 20 years). With the premise of GWP* more widely recognised, there is now a common belief across the ruminant industry that 'methane emissions do not matter' in the context of climate change. This thinking, however, is misguided for a number of interrelated reasons as outlined below:

1. The temperature effect of methane estimated under GWP* comprises two components, known as the rate term and the stock term (Cain et al., 2019). The former represents the short-term climate response to a change in radiative forcing and equates to zero at a constant emission rate. The latter represents the long-term equilibration to a change in radiative forcing,
2. a phenomenon attributable to increases in methane emissions in the recent past, and is positive even at a constant emission rate. Thus, the warming effect from methane is not completely limited to a short timeframe.
3. It is nevertheless true that, under GWP*, the methane gas newly introduced to the atmosphere does not cause a further increase in temperature as long as the volume emitted is sufficiently smaller than the 'old' volume it replaces (typically approximated by the volume emitted 20 years ago). Yet, an important consideration here is that this statement holds true solely because of the industry's own past emissions. As such, it remains debatable whether the ruminant industry can claim the "ownership" of, rather than the responsibility for, the old gas in the atmosphere.
4. Ruminant agriculture that induces methane emissions from enteric fermentation and manure management is always accompanied by nitrous oxide emissions elsewhere within the production system. As nitrous oxide does not break down (within a timeframe relevant to most climate change policy), the temperature trend over a very long term (> 100 years) is likely to be driven more by the effectiveness of nitrous oxide mitigation rather than methane mitigation (McAuliffe et al., 2023). More immediately, however, methane mitigation is likely to be a stronger determinant of the temperature trend due to its greater potency-corrected share in the overall greenhouse gas inventory associated with ruminant agriculture.
5. Methane is the only gas of which reduction in the atmosphere results in a temperature decrease. As such, if a ruminant farm is to achieve short-term (i.e. non-equilibrium) net-zero on carbon-saturated grassland without resorting to alternative land use to facilitate carbon sequestration, mitigating methane to offset the temperature effect of nitrous oxide

and carbon dioxide is theoretically the only feasible pathway. By definition, long-term (at-equilibrium) net-zero cannot be achieved without additional carbon sequestration.

This presentation discusses each of these points in greater detail and concludes with research priorities that need to be addressed.

Acknowledgements

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Genetic selection opportunities to reduce methane emissions from cattle and sheep.

MIKE COFFEY [1], ROSS EVANS [2]

SCOTLAND'S RURAL COLLEGE (SRUC) [1] ; IRISH CATTLE BREEDING FEDERATION (ICBF) [2]

Take home messages.

Genetic improvement across a wide range of traits has already led to substantial reductions in greenhouse gas (GHG) emissions intensity from dairy cattle. The same opportunities exist for beef cattle and to a lesser extent in sheep. However, with some structural changes and central investment in phenotyping important traits such as feed intake, large improvements could be made in dairy and beef cattle and sheep in the short term while new and effective methods of recording methane emissions are developed. Direct selection for reduced GHG emissions, while possible, has significant cost challenges and will be on top of direct selection for all other traits that affect GHG emissions.

Overview of the presentation

In recent years in many developed dairying nations, genomic selection has been widely applied in dairy populations. This has led to improvements across a wide variety of traits that affect profitability, increasingly through selection for traits that cost money rather than those that generate income. Modern cows produce more, live longer, have less involuntary culling, have better health, better fertility, reduced disease incidence and are overall more efficient. Without knowingly selecting for efficiency, dairy farmers have successfully been doing so. The question is can we accelerate that and how would we adapt from dairy to beef and sheep.

Recent global events leading to large and rapid increases in energy costs and extreme weather events have drawn the whole issue of resource use efficiency into sharp focus. This focus is across the whole of agriculture but is specific to ruminants because of their production of methane as a by-product of the digestion of grass and forages that humans cannot digest. Indeed, significant governmental pressure has already been applied to reduce GHG at country and at EU level.

In the case of Ireland there is a legally binding necessity to reduce GHG emissions from agricultural practices by 25% by 2030 and net zero by 2030.

Dairy cattle.

The use of artificial insemination is approaching 95% in dairy cattle and recently those inseminations have been increasingly using sexed semen. The UK has the highest adoption of sexed semen worldwide with > 75% of inseminations, followed by the US at ~50%, Australia at ~40% and other countries below 20% but trending upwards (Newton, 2023). The update of dairy sexed semen in Ireland (~10%) has been slower due in part to the seasonal calving pattern in Ireland and the perceived reduced fertilization ability with sexed semen. Sexed semen has allowed a reduction in the proportion of cows used to breed replacements essentially doubling the selection intensity in cows. This has had an interesting co-benefit in that a greater proportion of beef now comes from the dairy herd and is mostly bred through AI using superior sires.

A growing list of national dairy evaluation centers are now also evaluating and in some cases including indicators of enteric methane and other GHG emissions in their selection indexes. These includes the UK (Envirocow), Ireland (Carbon Index), Australia (Sustainability Index) and Canada (stand-alone RBVs for Methane Efficiency). To date, all of these indicators are based on either the modelled relationship between traits already in the breeding goal with GHG emissions or in the case of Canada the trait is a proxy for methane derived from MIR spectral data. Validation of these indicators in all cases would have been done using numerically small numbers of cows directly measured for methane, reflecting the cost and difficulty with collecting direct methane measures on dairy cows.

Beef.

The use of AI in beef is much less than in dairy (28% in animal with recorded sires in Ireland). In both the UK and Ireland much of the industry revolves around the sale of live pedigree bulls for natural service in range type systems or as sweeper bulls in dairy herds. This has resulted in a lower rate of gain than that possible. The recent use of carcass traits data from abattoirs now means genetic indices are informed by a much larger data set that is closely aligned to the final product value. In the UK, the availability of BCMS and abattoir data combined has enabled the production of age at slaughter breeding values which have drawn attention to the large opportunity that exists in beef to reduce GHG emissions. Similarly in Ireland an age at finish trait will be included in the Beef indexes for the first time in November 2023 with both an economic value and a carbon value. The current average AAS in the UK is around 28 months. Reducing that to 16 months could halve the emissions from the national beef herd. Again, the question becomes how can we do that?

The inclusion of carbon indicators in beef breeding indexes to date has lagged behind their dairy counterparts. However, ICBF included a carbon component in the DBI (index for using beef sires on dairy cows) in late 2022 and will also include carbon in the suckler beef indexes in 2023. A large component of the knowledge gap in beef is the systems modelling to assess the impact of existing index traits on carbon output, however significant Teagasc research has resulted in the publication of the Marginal Abatement Cost Curve (MACC) which has reduced the knowledge gap in the Irish beef herd.

Sheep.

AI is very seldom used in sheep due to its cost and invasive nature. As such, alternative models of spreading and implementing genetic improvement must be adopted. Currently around 140,000 rams are traded in the UK. If a (distributed) nucleus flock were available that measured all the relevant traits such as feed intake, lamb survival, fecundity, growth rates, mature ewe weight, carcass characteristics then these 140,000 rams could all be genotyped and have genomic predictions for all the traits from the nucleus thereby creating a trade in rams with genomic predictions for all traits of economic significance.

Direct Selection for Methane.

Current technology available for recording of methane is either expensive to procure and maintain or difficult to record in commercial farm settings. ICBF have costed methane phenotyping using Greenfeeds at €400 per animal in an indoor finishing setting. Hence, similar to feed intake phenotyping, the recording of methane will likely be limited to progeny test facilities, research herds or demonstration farms until cheaper alternatives are developed. Potentially the biggest challenge in this area will be the collation of the data already being measured. Data is being gathered in different research institutes to fulfill different goals such as assessing diets, feed additives, effects of lactation, sex and for the purposes of deciphering genetic merit. In many cases the data is unavailable to share due to IP related reasons. If those challenges can be overcome, there exists an opportunity to collate all this data for the dual benefit of non-genetic and genetic research. This includes collaborating to ensure that the animals selected for these trials are genotyped and, if possible, balanced for genetic merit across experimental units to avoid any genetic merit bias, a win-win situation for geneticists and nutritionists alike.

Heritability is a key metric for a trait to be a candidate for genetic selection. Literature estimates of heritability for dairy cattle for enteric CH_4 range from 0.11 ± 0.02 (Netherlands; van Engelen et al., 2018) to 0.45 ± 0.11 (United Kingdom; Breider et al., 2019). Published heritability estimates for enteric CH_4 from beef populations are much fewer to date and have been derived from expensive respiration chamber measurements on Angus cattle (0.27) (Donoghue et al., 2016; Hayes et al., 2016). Data collected at the ICBF Tully research station on 1,200 AI bred finishing animals indicates a workable heritability estimate varying from 9 to 20% depending on trait definition Ryan et al., WCGALP 2023) and substantial genetic variation both within and across breeds. The next phase of this work will focus on the relationship between methane output from indoor TMR type diets in finishing animals and methane output in growing animals and mature cows on grass-based diets. In sheep, New Zealand have been the pioneers regarding methane. Hickey et al, 2022 reported a heritability of 26% for enteric methane on a dataset of over 9,000 observations on 2,200 sheep. Sheep Ireland and Teagasc are also investing heavily in methane phenotyping using portable chambers with initial results also indicating heritability estimates in the same range as the NZ study.

Opportunities for methane selection exist to be exploited such as genomic prediction (all species), proxy phenotypes from MIR (dairy) and utilization of genetic correlation in genetic evaluations to extrapolate genetic merit to non-phenotyped animals (all species). The evolution of genomics has in some traits reduced the need for widespread industry coverage of large volumes of phenotypes. In the case of methane, more targeted phenotyping for genomic reference training and then large-scale genotyping to extrapolate to the rest of the population via SNP keys will make more sense. Numerous research papers have shown a strong relationship between feed intake and methane across species. In some cases (Langhill for dairy cows, Tully for beef cattle), feed intake recording has been carried out for 30+ years. These datasets can potentially now be leveraged as correlated predictor traits for methane.

Conclusion.

Dairy, beef and sheep producers are already selecting for efficiency in varying degrees. All sectors have opportunities to increase but each are limited by history, social pressures, industry accepted practices and lack of drive. It is easy to imagine government financial support instruments applied to existing technologies to accelerate reductions in GHG emissions while technologies to record methane are further developed to a state to be widely and cheaply used. Genetic selection has been proven in tandem with better management practices across all the farmed species to deliver more profitable animals through permanent and cumulative genetic progress. There is no reason why the new challenge of improved sustainability and reduction in GHG cannot be realized with the same synergy.

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Evaluation and development of feed additives to reduce methane emissions in Irish beef production systems

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Take home messages.

- Methane, a potent agricultural GHG generated during enteric fermentation of feed in ruminants, needs to be reduced significantly in order to meet national and international targets on agricultural GHG emissions.
- Promising anti-methanogenic feed additives have been evaluated through the 'Meth-Abate' project with Bovaer and RumenGlas showing reductions of approximately 30% in confined systems.
- Current research is focusing on developing slow release formats and bolus technology with anti-methanogenic actives incorporated, for pasture based production systems.

Summary

In Ireland, national greenhouse gas (GHG) emissions amounted to 60.76 MT CO2 equivalents in 2021, 38.4% of which originating from the agricultural sector (EPA, 2023) rendering it the single largest contributor to GHG emissions in Ireland. Methane (CH_4) generated during enteric fermentation accounts for 62.6% of Irish agricultural emissions. This substantial GHG contribution is threatening the production potential of the agri-sector, as the European Union and the National Government have signed legally binding agreements to reduce agricultural emissions by 25% by 2030 (DECC, 2021), which could ultimately result in a reduction of the national herd if alternative GHG mitigation measures are not developed and adopted. In light of this, research into the mitigation of enteric CH_4 has proliferated. Strategies such as breeding lower methane emitting animals (Smith et al., 2021), improving digestibility of feed and altering the forage:concentrate ratio of diets (Shibata and Terada, 2010), assessing diverse pastures (Jonker et al., 2019) and forage types (Meo-Filho et al., 2023) and a particular emphasis on rumen manipulation through the supplementation of dietary feed additives (Beauchemin et al., 2022) are being explored.

The primary aim of the METH-ABATE project is to develop a ready to use, commercially available dietary feed additive. A range of anti-methanogenic compounds were initially screened *in vitro* using the rumen simulation technique. The most promising were refined and optimized and subsequently brought forward to *in vivo* studies; sheep, followed by indoor beef studies, and subsequently moving on to pasture based beef and dairy studies.

Developing a feed additive that can be delivered in a simplistic mechanism (i.e. once a day supplementation, slow release bolus), has no food safety or residue implications and no negative effects on performance characteristics as well as having a consistent CH_4 reduction potential allowing it be counted in the national inventories are all essential attributes to its successful adoption. Additionally, a feed additive that is low cost, of natural origin and results in enhanced animal performance would be desirable attributes of a feed additive.

The addition of oils high in polyunsaturated fatty acids to ruminant diets have the ability to reduce CH_4 production via the alteration of rumen volatile fatty acid profiles, promoting propionate production, inhibiting protozoal activity, and to a lesser extent, sequestering of hydrogen via ruminal biohydrogenation of the fatty acids (Toprak, 2015). Including soya oil at 4% of DMI reduced CH_4 g/d in mature ewes by 9% (Roskam et al., 2023c). Supplementing beef cattle with rapeseed and linseed oil at 2.5 and 4% inclusion of dry matter intake reduced CH_4 g/d by 8% (Folliard et al., 2023, unpublished) and 18% (Roskam et al., 2023b) respectively. However, supplementing ruminant diets with oil at levels >5% can lead to a reduction in diet digestibility and hence animal productivity. While oils can be costly to add to the diet however, they increase the energy value of the feed significantly.

Oils have proven to reduce CH_4 production (Jordan et al., 2006; Mao et al., 2010; Boland et al., 2020) in cattle, however this strategy is more suited to indoor finishing systems with incorporation of the oil in the concentrates. Oil supplementation would not be suitable in an outdoor feeding scenario due to the high levels of oil required in the diet.

Seaweed has been in the public eye with regards to its CH_4 mitigation potential for many years (Abbott et al., 2020). As part of METH-ABATE a range of brown, green and red seaweeds were assessed in vitro, with *Asparagopsis taxiformis* being the only seaweed to have a CH_4 mitigating effect when included at 1% of dry matter (Roskam et al., 2022). Supplementation of the red seaweed, *A. taxiformis,* has been widely researched and has resulted in CH_4 reductions of 80% in beef steers (Roque et al., 2021). However *A. taxiformis* is a tropical seaweed which is not readily available in Europe. There are also concerns regarding the volatilisation of the anti-methanogenic compound, bromoform, which can affect the CH_4 mitigating consistency of the seaweed (Glasson et al., 2022). Subsequently, further *in vitro* studies were conducted assessing brown and green seaweeds at a higher inclusion rate (4% of dry matter), resulting in 36% reduction in CH_4 mmol/d with the supplementation of brown seaweed, *Ascophyllum nodosum*, additionally, a condensed version of *A. nodosum* (seaweed extract) resulted in a 15% reduction in CH_4 mmol/d. *A. nodosum* had no CH_4 mitigating effect in sheep or beef cattle, whilst the *A. nodosum* extract reduced CH_4 g/d by 9 and 7% in sheep and beef cattle, respectively (Roskam et al., 2023c; Roskam et al., 2023b).

The feed additive Bovaer (3-nitrooxypropanol; 3-NOP) has been extensively researched, concluding that it has a CH_4 mitigating potential of 30% in dairy cows if it is ingested throughout the day (Kebreab et al., 2023). In Ireland, Bovaer was assessed through a total mixed ration, resulting in CH_4 reductions of 30% in beef cattle (Kirwan et al., in press) and 26% in dairy cattle (Costigan et al., unpublished). However this delivery mechanism is unsuitable to the Irish pastoral production system during the grazing season. Therefore, Costigan et al. (2023, unpublished) assessed Bovaer in a twice daily supplementation regimen at pasture, which demonstrated a transient effect, resulting in a ~6% reduction in CH_4. Further research is required to refine 3-NOP, in order for it to be applicable in grazing systems, either in a format with a slower rate of metabolism or in a slow-release bolus form.

Finally, the novel peroxide based product, 'RumenGlas' is a novel, untapped dietary material which has anti-methanogenic potential *in vitro* (Graham et al., 2023). A pilot scale study was completed using fistulated steers prior to beginning large scale bovine studies, in order to refine the peroxide based feed additive and select the most appropriate dosage rate with regards to palatability, nutrient digestion and CH_4 abatement. Dietary supplementation in beef cattle with calcium peroxide (CaO_2) has yielded a reduction of 28% with no effects on feed intake or animal productivity when fed in a twice daily regimen, through concentrate feed, in a pelleted format (resistant to pressure and temperature) (Roskam et al., 2023a). This is the most effective anti-methanogenic compound in a periodic feeding strategy in bovines reported to-date. This compound was developed and optimised *in vitro* (O'Donnell et al., 2023; Graham et al., 2023), followed by further optimisation with regards to palatability, nutrient digestion and predicted CH_4 production *in vivo* in fistulated steers (Graham et al., 2022). Inclusion of CaO_2 in the diet breaks down to calcium, oxygen and water in the rumen, elevating the oxidative reduction potential of the rumen (Figure 1), hence making an unfavourable environment for anaerobic microorganisms such as methanogens. However further work is required to optimise CaO_2 to enable a slower release of oxygen, as there are concerns regarding its effects on digestibility in high forage diets. The study from Roskam et al. (2023a) concludes that CaO_2 can be successfully managed indoors in a twice daily feeding regimen with a 28% reduction in CH_4, however further research is required assessing the effects of CaO_2 on the rumen microbiome, on differing diet types, stages of production and its potential as an early life supplement.

Conclusion

The development of long lasting and sustainable feed additives for beef and dairy grazing systems is vital to reach the GHG targets set for the Irish agricultural industry. The aforementioned anti-methanogenic compounds have varying degrees of readiness and practicality, however there is a major focus on the re-formulation of promising feed additives into slow release formats that can be incorporated into once a day concentrate supplement or a rumen bolus for long lasting mitigation effects during grazing. Currently, encapsulated CaO_2 is being developed, targeting a once a day regimen at pasture in a small amount of concentrate feed. This will be the first suitable anti-methanogenic feed supplement that can be administered to pasture based animals (Figure 2). Following on from this, research will focus on developing a slow release bolus with the anti-methanogenic active incorporated, negating the necessity for concentrate supplementation.

Figures:

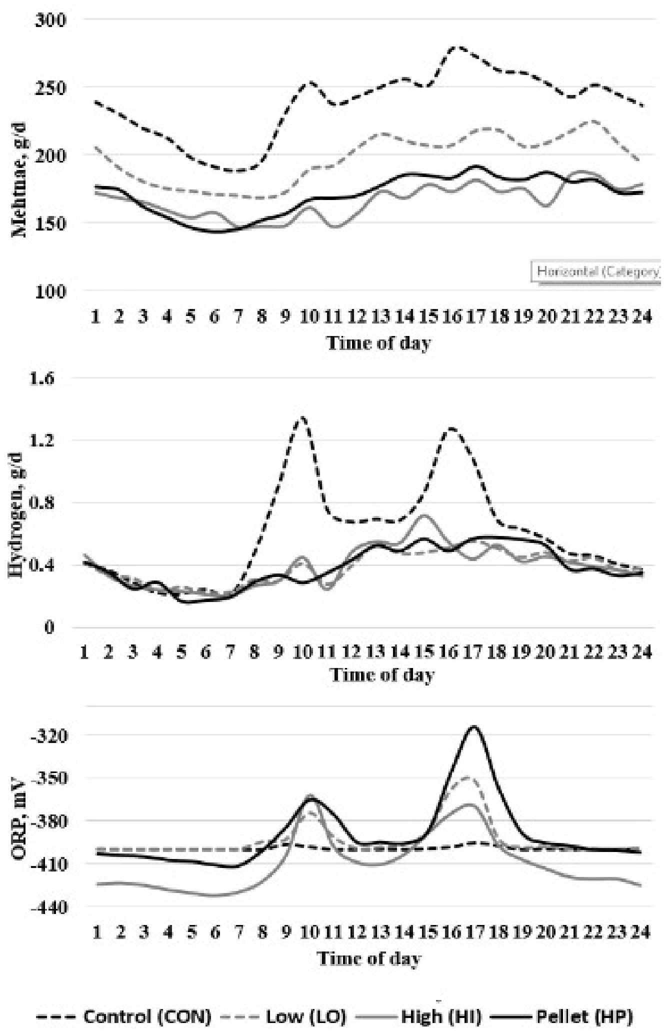

FIGURE 1. ASSESSING **CaO_2** IN A TWICE DAILY FEEDING REGIMEN (0800 H, 1500 H) IN BEEF CATTLE. DIURNAL PATTERN OF DAILY CH_4 (G/D), H2 (G/D) AND ORP (MV). SOURCED FROM ROSKAM ET AL. (2023A).

FIGURE 2. CHAROLAIS STEER UTILISING GREENFEED DURING EXPERIMENT ASSESSING THE EFFECTS OF FEED ADDITIVES AT PASTURE AT TEAGASC GRANGE.

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Approvals process for feed additives intended to reduce greenhouse gas emissions from ruminants

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Take home messages

1. Products intended to reduce enteric methane production would mostly be expected to be regulated as zootechnical feed additives, favourably affecting the environmental consequences of animal production.
2. The regulatory framework is currently based on retained European regulations, and the application and assessment processes are informed by the European Food Safety Authority (EFSA) guidance documents, as interpreted by Food Standards Agency (FSA) of the UK.
3. Currently there are no differences between GB and EU requirements, but the processes used by EFSA and FSA for risk assessment and risk management differ.
4. Risk assessment is separated from the risk management process – the risk assessment is undertaken by FSA Risk Assessment Team, with the Advisory Committee on Animal Feedingstuffs providing science advice.
5. The risk assessment for a feed additive intended to reduce methane production from enteric fermentation would be required to demonstrate compliance in all of the requirements for any feed additive: identity (including manufacture and purity), safety (including to animals, the consumer, users of the product, environment), and efficacy (product must be effective).
6. The endpoint requirements for demonstration of efficacy (i.e., reduction of methane) have not been tightly defined, but all applications must document the relevant performance effects of the product (for example, growth rates and milk production).
7. Although there is a class of Urgent Authorisation, this applies only in special cases in which urgent authorisation is essential for the protection of animal welfare. It seems unlikely that it would be applied to methane-reducing feed additives.
8. FSA and ACAF are working hard to streamline the process, but it is slow, and non-compliance with the guidance documents often results in substantial delays.

Regulatory basis for authorisation of feed additives

The umbrella regulation for feed additives in GB is *Retained EU REGULATION (EC) No 1831/2003 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 September 2003 on additives for use in animal nutrition.* This sets out the legal framework, and the details are provided by *Retained EU REGULATION (EC) No 429/2008 of 25 April 2008 on detailed rules for the implementation of Regulation (EC) No 1831/2003 of the European Parliament and of the Council as regards the preparation and the presentation of applications and the assessment and the authorisation of feed additives.* To interpret these documents and translate them into risk-assessable applications for authorisation, the European Food Safety Authority (EFSA) Panel on Additives and Products or Substances used in Animal Feed (FEEDAP) has produced guidance documents for each of the components of the authorisation process. These documents specify the evidence that must be provided in support of an application. The process of risk assessment is carried out by Food Standards Agency (FSA) staff, advised by the Advisory Committee for Animal Feedingstuffs (ACAF). Additional regulations that are relevant to the authorisation process include the *Retained REGULATION (EU) No 68/2013 of 16 January 2013 on the Catalogue of feed materials* *and the DIRECTIVE (EC) 96/25/EC of 29 April 1996 on the circulation of feed materials.*

Process of an application for authorisation

The application process is initiated by the submission of an application via the online portal. The dossier is submitted by the applicant through the online portal. There is currently no charge for the application and assessment process. The Regulated Products Approvals Team within FSA checks the application for errors, and the Feed Additives Policy Team checks for overall compliance. The ACAF Secretariat makes a completeness check, based on the requirements laid out in the EFSA scientific guidance and REUL 429/2008. At this point information may be requested from the applicant (request for information – RFI), including missing documents and sections, clarifications, out of date certification, and corrections. Most applications are subject to at least one RFI. Depending on the type of authorisation (whether it is a completely new feed additive, a renewal, re-authorisation, extension of use), and other factors including whether an opinion has already been published by EFSA, it will either be processed by FSA Risk Assessors, or passed to ACAF, which will give it detailed consideration. The ACAF will then likely request further information from the applicant, on receipt of which the application will be returned to ACAF, and an opinion will be drafted as a recommendation for consideration by the Risk Managers in FSA. The opinion is then published (usually in tranches) for public consultation, prior to ministerial approval and writing into law.

The criteria that must be satisfied

Applications for authorisation must address three main areas: 1) Identity, 2) Safety, and 3) Efficacy.

1. **Identity, characterisation and conditions of use of feed additives:**
   Applicants must provide evidence that the product is properly characterised, its composition quantified, impurities identified, homogeneity, dustiness, batch to batch variation, analytical methods defined, the manufacturing process described, with critical control points identified. The stability and shelf-life of the product must be tested and the conditions of use must be described – where the product is a chemical substance, safety data sheets must be presented, and in all cases, the labelling requirements set out.

2. **Safety:**
   There is a small group of novel additives for which safety can be presumed without provision of supporting studies, but the criteria are quite stringent and quite rarely met by new products. In other cases, evidence for safety must be provided for the target organism, for the consumer, for workers using the product, and for the environment.

   - **Safety for the target animal:** The requirements include 1) literature reviews, 2) toxicity data from repeated dose studies on laboratory animals that allow for the establishment of "no observed adverse effect levels" (NOAEL), 3) tolerance studies in target animals to establish short term toxicity and a margin of safety for the target species, 4) genotoxicity and reproductive studies.

   - **Safety for the consumer:** The requirements include 1) absorption, distribution, metabolism and excretion (ADME) data from laboratory animals, to identify the residues in edible tissues and products, and to establish the kinetics of these residues, 2) ADME in target species, 3) residue studies, 4) toxicological studies including genotoxicity, subchronic oral toxicity, chronic oral toxicity, reproduction and prenatal development toxicity, carcinogenicity, 5) assessment of consumer safety, including estimation of a safe dose, a highest safe intake (e.g., an acceptable daily intake – ADI), estimation of consumer exposure, 6) determination of a maximum residue limit (MRL).

   - **Safety for users and workers.** The requirements include a toxicological risk assessment addressing 1) effects on respiratory system, 2) effects on eyes and skin, 3) systemic toxicity, 4) exposure assessment, 5) proposed measures to control exposure.

   - **Safety for the environment**: The Guidance prescribes a stepwise approach in which all feed additives are subjected to a Phase I assessment to determine whether a significant environmental effect is likely and whether a Phase II assessment is required. There are a number of potential exemptions from the Phase II assessment including 1) additive is intended only for non-food producing animals, 2) the additive is a completely natural substance and would not alter the concentration of that substance in the environment from its natural level, 3) the additive is extensively metabolized in the target animal, 4) the additive is not a potential persistent, bioaccumulative and toxic (PBT) or a very persistent and very bioaccumulative (vPvB) substance, 5) the action of the additive doesn't give any reason for concern, 6) the predicted environmental concentration (PEC) is below a threshold level. The Phase II assessment is a much larger and more stringent assessment, and where it is provided, ACAF usually obtains assistance in its evaluation from specialists and/or other government agencies.

3. **Efficacy:**
   The evaluation of efficacy of a feed additive for which a methane reduction claim is made is probably the main area of discussion around the authorisation of such products. The Guidance documents are not highly specific in their statements on how efficacy of such products should be assessed, stating that "For additives which favourably affect the environment by direct or indirect means (e.g., reduction of nitrogen or phosphorus excretion, methane production or odour), efficacy for the target species can be demonstrated by short-term studies. These studies should take into consideration the possibility of an adaptive response to the additive." It is also stated under the heading of "Endpoints", that "Direct effects on the environment may include, for example, reduction on methane, ammonia, carbon dioxide emissions and reduction of odour or odorous compounds. Indirect effects on the environment may result from an increased nutrient utilisation and result in a reduced excretion of, e.g. nitrogen, phosphorus and sulphur, if appropriate dietary adjustments are made." In general, consistent with the approach to assessing efficacy in all cases, at least 3 studies with statistically significant results should be provided for each of the required classes of animals – calves, cattle for fattening, cows.

Other societal factors

There has been some discussion regarding whether broader societal considerations should be taken into consideration in assessment of risk – for example, where there might be some perceived public good arising from the authorisation of a product, which benefit might not be easy to quantify, or which might be so great as to offset some of the potential harms arising from a product. Such considerations would fall in the "risk management" aspect of the authorisation process, outside the control of ACAF.

Considerations around efficacy for products that reduce methane emissions

There are some important considerations regarding efficacy that might be considered.

1. Adaptation is likely with the use of some products, and the alternative pathways promoted by them also result in some contribution to total GHG.
2. Benefits of the product only last while the product is being used.
3. Some products that reduce enteric methane production per unit of feed intake are likely to do so with no production benefit, or might reduce performance, potentially increasing the GHG emissions intensity.
4. In contrast to most other zootechnical feed additives, end users (farmers) very rarely have the technology to assess the efficacy of products on their own farms.
5. Given that most of these products have no significant performance- or efficiency-enhancing effects, the likely business model for manufacturers will be based on their use being prescribed by food retailers.

Taken together, it could be argued that although there is clear societal benefit from products that might reduce methane emissions, the evidence threshold for efficacy should be higher than for products for which the performance of animals can be tested more readily on-farm.

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Adoption by industry & the inventory – a Northern European perspective

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Take home messages

Adoption of methane mitigation feed additives by the dairy and beef industry and in national inventory models will be a major challenge due to difficulties in compiling reliable activity data, especially on farm level. Challenges are the potential interactions with farm management systems such as breed, production level, and diet composition and other methane mitigation strategies including new potent feed additives, even if these feed additives have different modes of action. In addition, for some methane mitigating additives, the active component may have minor, but unwanted, side effects related to production efficiency (feed intake, milk production), animal health and welfare, product quality, or human health, which may reduce the acceptance by stakeholders and thereby adoption by the industry.

Introduction

Despite significant research activity over the last 2 decades within enteric methane from ruminants, only a disappointingly low number of instruments to reduce their enteric methane are ready for implementation. A major barrier is of course the financial costs, but also the lack of approval and inclusion of such instruments in national accounting systems is a major barrier. This chicken-and-egg problem where, on one side, biotech companies have lacked business plans that could promote major investments in developing e.g. methane reducing feed additives, and on the other side, incentive programs have been on hold due to lack of instruments, has been a major set-back for obtaining significant reductions within all sectors, but perhaps mostly within the agricultural sector where GHG originates from biological processes.

Accounting on a global level

Assuming that feed efficiency and milk production is unchanged, adoption of a given methane mitigating feed additive will come with a cost, and the on-farm decision on which strategy to choose will always depend on economic cost of the strategy related to the reduction in CO_2-eq. This poses the first challenge: How to transform a biological reduction in methane production in the rumen of a cow into arbitrary CO_2 equivalents used in GHG accounting. At present a 100-year global warming potential (GWP) of 25-28 is used as default to transform CH4 into CO_2-eq, but this factor could just as well have been based on a 20-year (GWP = 80) or 500-year (GWP=6) perspective, making the cost-benefit analysis very different.

Accounting on a national level (Denmark)

In Denmark, a tax on CO_2-eq from agriculture is expected soon and stakeholders are also in the process of implementing internal incentive models on farm level. These initiatives already affect Danish livestock production and are expected to have a profound effect on future livestock production. This will facilitate and make the business case for use of potent methane mitigating feed additives obvious, but at present only Bovaer® from DSM and SilvAir from Cargill are expected to be listed soon as methane mitigating feed compounds for dairy cows with a proven reduction potential in Danish national inventory models and in farm accounting models. However, diet composition also has a significant influence on enteric methane emissions, but at present the mitigating effect of adding fat to the diet is expected to be the only major direct dietary change to be accounted for in the farm level GHG accounts besides changes in overall nutrient composition.

Side effects

Use of a given methane mitigating feed additive or dietary change may be associated with unwanted side effects. Examples of which are the use of the tropical red seaweed Asparagopsis and nitrate or very high levels of concentrate or fat in the diet. In Asparagopsis the active component is bromoform which might be transferred to products. Nitrate may affect the animal's oxygen transport and/or end up in products, which is a special challenge concerning infant milk powder products. From a nutrition perspective pronounced increases in concentrate level or fat supplementation to dairy cows are potent methane mitigating strategies, but also accompanied by increased risk of diseases related to rumen fermentation and nutrient metabolism and accompanying reductions in feed intake and milk production.

From a Northern European stakeholder perspective, such interventions may be perceived as unacceptable even though the increased level of the unwanted compounds when using potent feed additives are well below the recommended thresholds. On the contrary, it may be fully acceptable in other parts of the word if levels in products are below official recommendations. This poses a major problem if the economic value of a low carbon footprint becomes significant, since milk and beef are commodities that are traded on a global market and therefore a major setback for European producers' competitiveness on the global market may be envisioned if these mitigation strategies are not accepted globally.

Ethical considerations

Some additives might affect the behavior and/or welfare of the animals, as e.g., reduced feed intake has been found in some experiments using seaweed, Bovaer®, nitrate. If this is followed by an impact on welfare, would that then be acceptable, or can't we accept solutions reducing welfare? How to balance between reduced CO_2 footprint and animal welfare is a difficult question, and such ethical considerations must be addressed by the industry and by stakeholders setting the regulatory framework for adoption of such additives.

Additivity

Accounting systems are always faced by the discrepancy between setting up a simple system and setting up a fair system that takes farm differences into account. Potential lack of additivity is the major challenge for including multiple methane mitigation strategies in national and farm accounting models. A recent study from Aarhus University showed that when dietary supplementation of fat, nitrate and Bovaer® were combined, the observed reductions in methane production, yield and intensity were lower than what could be expected based on the individual responses to the treatments, despite different modes of actions relating to methane mitigation. This makes it very difficult to model the expected response to combinations of methane mitigation strategies under practical conditions, especially in the future where a long list of feed additives (hopefully) will be available.

Documentation

On a national level, reliable activity data on purchased amounts of a given additive can be used to estimate the number of cows fed the additive in question.

On farm level, the documentation of the actual use of a given feed additive is more difficult. Documentation of actual inclusion in the diet will, however, be helped by demands for the additive to be included either in the purchased concentrate mix or in purchased mineral mix and not purchased in its pure form. In Denmark, most cows are fed TMR diets and grazing is not common among conventional farmer and this, together with the tradition for high level of registration on Danish farms, makes documentation of actual dosage doable in contradiction to more extensive pasture-based systems, and in systems with separate feeding of concentrate.

If the price of the product is very high, this may result in fraud, such as providing documentation in the form of feeding plans that are not in accordance with what is actually fed. One way forward could be that the price of a mineral mix or a concentrate is lower if an additive is included, meaning that the marginal cost is covered by premiums from stakeholders.

In this way, there would not be an incentive to present biased feed plans differing from actual plans used during control, and at present it is expected that a significant cost of the use of e.g., Bovaer® will be covered by premiums from the Danish government.

The level of on farm control by public and industry stakeholders in a Danish setting can go from documentation of purchase of the given additive combined with feed plans, to actual analyses of the diet for content of the active component. The latter will be extremely resource demanding, and therefore not applicable in a practical setting. It would be essential to monitor how methane emission from the animal/herd has been reduced or if the use of proxies for reduction in methane are present in milk. When additives reduce methane significantly, it is also followed by a change in rumen fermentation, and therefore a potential for proxies in milk. A dream solution would be that proxies were detectable by MIR (Mid Infrared Reflection), as dairies already MIR-scan milk to monitor composition for payment reasons. Another future solution would be to monitor the methane emission on an animal/herd level. On animal level, sniffer systems measuring methane and CO_2 in breath and using the ratio to quantify the methane emission might be an economically reachable solution, but more economically sound solutions might be measures on herd level, although it would be challenging in modern very open barns.

Standardization of effects

Differences in stipulated efficacy of a methane mitigating feed additive between different accounting systems within country, and in inventory models and stakeholder incentive programs between countries, may give rise to significant critique. If a given additive has a methane mitigation potential of 25 % in the national inventory model and 35 % in the incentive model of an industrial stakeholder, one stakeholder may face allegations from other stakeholders for greenwashing. Furthermore, the national inventory model may at the same time face allegations for underestimating the effectiveness, which may have pronounced effects for the industry and for the individual farmer. Differences in efficacy between countries may also pose problems if they cannot be documented due to obvious differences in production systems. This is especially the case for companies like Arla, located in different countries. A common European inventory system model for efficacy of new methane mitigation feed additives will therefore be a huge step forward and be beneficial for all stakeholders and for moving towards a dairy industry with a lower climate impact.

Conclusion

Compiling reliable activity data, especially on farm level is difficult and quantification of actual on farm effects poses a challenge due to interactions. Methane mitigating additives may have unwanted side-effects which may reduce acceptance by stakeholders.

Reducing agricultural greenhouse gases – a New Zealand perspective

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Take home messages:

- Reductions in agricultural emissions will be critical for meeting New Zealand's climate change targets.
- Limited options exist to reduce emissions from pasture-based livestock farming systems, although promising new approaches are emerging.
- New Zealand is investing heavily into agricultural mitigation research and is planning to introduce a farm-based pricing policy in 2025.
- More consideration of barriers to uptake needed for realistic assessments of mitigation potential and to achieve mitigation in practice.

Overview of the presentation

Domestically, New Zealand has committed to reaching net zero emissions of long-lived greenhouse gases by 2050 and reducing biogenic methane emissions between 24-47% by 2050. Its international commitment is to reduce carbon dioxide equivalent emissions by 50 per cent below 2005 levels by 2030. Agriculture contributes significantly to the New Zealand economy, culture, and physical landscape. However, agriculture also produces almost half of its carbon dioxide equivalent greenhouse gas emissions (49% in 2021) and 90% of its methane emissions. Reductions in New Zealand's agricultural emissions will be critical for meeting domestic and international reduction targets. To accelerate mitigation efforts New Zealand is investing heavily into agricultural mitigation research and is planning to introduce a farm-based pricing policy in 2025.

Currently, limited options exist to reduce emissions from pasture-based livestock farming systems, although promising new approaches are emerging. Reducing emissions from New Zealand agriculture will be challenging but are necessary if New Zealand wants to maintain its reputation as one of the world's most efficient and environmentally friendly producers of high-quality food.

Acknowledgments

The New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) is a core component of the New Zealand Government's approach to understanding, managing, and reducing greenhouse gases in agriculture.

The goal of the NZAGRC is to discover, develop, and make available to New Zealand farmers and growers, products, tools, and knowledge that enable the practical and cost-effective reduction of agricultural greenhouse gas emissions.

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