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Preface

Greenhouse gases in animal agriculture—Finding a balance between food production and emissions

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ABSTRACT

This preface summarizes papers published in the special issue which were previously presented at the Greenhouse Gases (GHG) in Animal Agriculture Conference in Banff (Alberta, Canada) in October of 2010. The conference had over 400 delegates from 36 countries, an attendance which attests to the global research effort ongoing in this area. The meeting addressed microbial aspects of ruminal CH_4 production, and methods to measure GHG from livestock and manure. Strategies to mitigate enteric CH_4 emissions from ruminants, as well as CH_4 and N_2O emissions from manure, were a key focus of the conference. Other papers outlined how modelling can be used to estimate GHG emissions at the animal, farm, regional and global scale. The key importance of modelling GHG from an agricultural systems perspective was apparent, both in a policy making and regulatory perspective, although its predictive accuracy is difficult to assess and lower than desirable, much lower in some cases. It is clear that mitigation strategies which reduce GHG emissions, while improving the efficiency and economic viability of livestock production, are the most likely to be adopted in practice. Such strategies will be required to ensure that animal agriculture will be able to satisfy the growing global demand for food with a minimal impact on the environment.

This article is part of the special issue entitled: Greenhouse Gases in Animal Agriculture – Finding a Balance between Food and Emissions, Guest Edited by T.A. McAllister, Section Guest Editors: K.A. Beauchemin, X. Hao, S.M. McGinn and Editor for Animal Feed Science and Technology, P.H. Robinson.

1. Introduction

A global increase in the incidence of extreme weather events has led to a growing awareness of the potential contribution of anthropomorphic sources of greenhouse gases (GHG), including agriculture, to climate change. Within the agricultural sector, livestock has been particularly scrutinized by regulators and environmental advocacy groups, in particular, as N_2O (298×) from manure and CH_4 (25×) from manure and enteric fermentation have global warming potentials considerably higher than CO_2 (1×). With the human population predicted to reach 9 billion by 2050, demand for livestock products is predicted to double, an event which will lead to increased GHG emissions from livestock. Furthermore, expansion in livestock populations is predicted to occur primarily in the developing world, where adaptation to climate change may be more difficult and opportunities to mitigate emissions limited. Given the choice between food shortages or reduced GHG emissions, it is certain that more food will be chosen and the implications of this choice for climate change are uncertain. Meat production is most efficient if livestock are fed high nutritional quality diets containing feeds such as cereal grains, and many livestock species have been specifically selected, and improved by genetic selection, for their ability to efficiently

Abbreviations: DGGE, denaturing gradient gel electrophoresis; GGAA, greenhouse gases in animal agriculture; GHG, greenhouse gases; PCR, polymerase chain reaction; RFLP, restriction fragment length polymorphism; SF_6, sulfur hexafluoride; SI, special issue; VFA, volatile fatty acids.

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covert these feed sources to products. This presents the dilemma of livestock utilizing feed sources which are suitable for direct consumption by people.

History suggests that people make choices to improve their quality of life. As living standards continue to improve in many regions of the world, it seems unlikely that there will be a mass shift in the human population from an omnivorous to a vegetarian diet. Indeed, past trends suggest the exact opposite. Therefore, if the premise that people will continue to eat meats is accepted, and that increased emissions of GHG are not desirable, it seems that GHG emissions from livestock must be assessed in terms of intensity (*i.e.*, kg of GHG/unit product). However, this concept is not without its challenges as there are a myriad of life cycle approaches to estimating GHG emissions from livestock production systems, and no clear consensus as to what constitutes the 'correct' approach. Even if international consensus on a life cycle assessment is achieved, such an approach could be politically unpopular as it could mean expansion of livestock production in efficient countries (*i.e.*, low GHG/unit product) and contraction in inefficient countries (*i.e.*, high GHG/unit product). Developed countries tend to be the most efficient, but livestock populations in many of these areas are decreasing.

Although there is no easy solution to meeting the growing demand for food while decreasing GHG emissions, science has a role in quantifying, characterizing and suggesting mitigations of GHG emissions from livestock production systems. To meet this need, research on GHG emissions from animal agriculture is expanding globally and this special issue (SI) summarizes state-of-the-art research in the area. The 4th International Conference on Greenhouse Gases and Animal Agriculture Conference (GGAA), held in the Canadian Rocky Mountains, was an opportunity for researchers from all over the world to present the latest scientific advances in the area of GHG research in animal agriculture. The attendees witnessed climate change, as the meeting included a trip to the Athabasca glacier, which has lost half of its volume and receded 1.5 km in the last 125 years. The conference contributed critical information to industry and government on approaches to characterize emissions and achieve cost effective GHG mitigations within livestock production systems.

Of the 152 papers presented at the Banff conference, 81 survived critical review and are in this Special Issue. The Special Issue describes the microbial processes involved in GHG emissions, methods used to measure GHG emissions from livestock and manure, approaches to mitigating enteric emissions, ways to mitigate GHG emissions from manure, including through production of biogas. A number of approaches are presented to modelling GHG emissions at the enteric, farm and country level, which provides insight into possible impacts of climate change on future GHG emissions from animal agriculture. The Special Issue concludes with an emphasis on the need to develop a global consensus on procedures to estimate GHG emissions from animal agriculture. The concluding manuscript by Janzen is a marvellous look at the place of livestock on a re-greening earth and maintenance of the mutually beneficial 'ancient contract' between humans and livestock that has developed over the last 10,000 years.

2. Comments on the sections

2.1. Microbial ecology of methanogenesis

Given the emphasis on attributing CH_4 emissions to cattle, sheep and goats; that the microbial population within the digestive tract (as opposed to the ruminant host) is responsible for enteric CH_4 emissions is often overlooked by persons unfamiliar with the area. Perhaps the avoidance of this connection is deliberate, as the complexity of the microbial populations within the rumen has often led to it being referred to as a 'black box', even by experts in the area. However, advances in the field of molecular biology are enlightening this 'black box' with Atwood et al.'s exploration of methanogen genomes being an example. Sequencing of methanogen genomes has provided functional insight into approaches to manipulate rumen methanogens through development of specific enzyme inhibitors and vaccines targeted at cell surface proteins. This functional approach to GHG emissions mitigation is certain to prove more efficacious than past approaches which involve use of potential CH_4 inhibitors with little to no functional certainty. Zhou et al. describes how fingerprinting techniques, such as denaturing gradient gel electrophoresis (DGGE) and restriction fragment length polymorphism (RFLP) along with high-throughput metagenomic and metatranscriptomic sequencing, are providing insights into relationships between methanogens and other members of the microbial community. Several papers in the SI used DGGE to demonstrate that changes in diet composition can alter the species composition of the methanogen population without influencing overall CH_4 emissions. Conversely, real time quantitative polymerase chain reaction (PCR) procedures suggest that the number of methanogens in the rumen may remain relatively constant, even if changes in CH_4 emissions occur. This research suggests that molecular approaches to measure methanogenic activity, as opposed to population density or diversity, are more likely to provide insight into viable CH_4 mitigations.

Knight et al. used chloroform to lower CH_4 emissions more than 90% by specific inhibition of methanogens, which led to a decline in the methanogen population. Interestingly, this response did not alter rumen function raising the possibility that the accumulated reducing equivalents were respired as hydrogen gas or utilized by other members of the microbial community. Paul et al. describe novel sulfate-reducing bacteria in the rumen, a population which may also use excess reducing equivalents formed when methanogenesis is inhibited, thereby raising the possibility that, if methanogen specific inhibitors were developed, other electron-consuming rumen microbial populations may proliferate to utilize excess reducing equivalents and avoid detrimental impacts on fermentation. Verification of such an approach must include experiments to ensure that mitigations persist over the long term, and with no adverse affect on host productivity.

2.2. Approaches to measuring greenhouse gases from livestock

Research on measuring GHG emissions from animal agriculture has advanced on several fronts. Holistic studies are developing models to investigate systems with multiple interactions, and there continues to be advances in more accurate and precise measurements of GHG emissions to improve applications, such as national inventories and mitigations. Studies reported in the SI use numerous measurement techniques to provide emission estimates of enteric CH_4 from livestock, and CH_4 and N_2O from livestock manure. However, as aptly pointed out by Rochette for N_2O emissions, there is a need to standardize approaches to measure GHG emissions as differences among approaches and methods can exceed differences among mitigations.

There are two basic approaches to measuring enteric CH_4 production, being *in vitro* procedures to measure CH_4 emissions from a rumen microbial population in the laboratory and *in vivo* techniques to measure emissions from the whole animal or farm. *In vitro* measurements are best used to assist in screening of, for example, additives which may mitigate emissions where a positive response potentially identifies a useful treatment. Araujo et al. and Navarro-Villa et al. suggest modifications to this procedure in order to improve estimates of CH_4 production from feedstuffs during fermentation. However, responses measured using *in vitro* techniques may have limited value in reflecting responses from a whole animal or farm as they fail to consider impacts of animal physiology and management. Results from such *in vitro* experiments must be followed with *in vivo* studies to examine impacts at the whole animal scale.

Use of respiratory chambers is an *in vivo* technique where the whole animal response is gauged, but where the impact of management and the farm environment are lacking. Whole animal chambers have the advantage of enabling feed intake of the animal to be precisely measured and related to emissions. As a result, chambers are often considered to be the 'gold standard' for comparison among mitigation options, but there use is often limited because this level of confinement dramatically alters animal behaviour from that in a normal production environment. Goopy et al. describe portable static chambers to measure emissions over 1–2 h, at least partly *in situ*, a practice which may reduce the extent to which the chamber alters normal animal behaviour.

Less intrusive *in vivo* techniques exist, such as the sulfur hexafluoride (SF_6) tracer and micrometeorological techniques. However, as noted by Pinares-Patiño et al., emission estimates using the SF_6 technique are more variable than those from chambers and, as a result, more animals are required to detect differences in emissions among treatments. Lassey et al. and Swainson et al. outline some of the factors which may contribute to variability of the SF_6 technique. However, the SF_6 tracer technique has the advantage in that it is relatively inexpensive and can be used to measure emissions from grazing and confined ruminants. Consequently, the SF_6 technique is often the measurement method of choice for estimating emissions from ruminants in developing countries. However, sufficient animals are required to overcome impacts of among animal variability and more research is required to increase its accuracy and precision.

Micrometeorological techniques for measuring GHG emissions, as described by Harper et al., have the capacity to measure emissions from whole farms. Such an approach may be particularly desirable to estimate emissions for regional or national inventory purposes. Tomkins et al. reported comparable CH_4 emissions per kg of feed dry matter intake from cattle using micrometeorological and chamber techniques. However, the scale of micrometeorological techniques makes it difficult to use the technique to measure responses to mitigations.

It is evident that there is no one technique suitable for measuring livestock emissions under all applications. In choosing a method, it is necessary to weigh the sensitivity of the technique against research objectives. This requires insight into errors associated with the technique and a 'feeling' for the anticipated treatment differences among mitigations, and/or the level of desired accuracy of inventories. Unfortunately, in some cases, differences among measurement techniques exceed differences among treatments making it difficult to compare among studies which used different techniques, while making it difficult to use values created by different techniques in a quantitative sense.

2.3. Finding approaches to mitigating CH_4 without compromising production

Of all of the areas of GHG research in animal agriculture, perhaps the most effort has been expended on identifying strategies to mitigate enteric CH_4 emissions from ruminants. Despite considerable effort, few viable enteric CH_4 mitigation options have been identified, an outcome which may reflect the complexity of the rumen ecosystem as outlined by Wright and Klieve. Most mitigations which have showed promise in reducing CH_4 production *in vitro* have failed to produce similar results *in vivo*. When *in vivo* reductions in CH_4 production have been observed, they have often been at the expense of a decrease in feed intake, digestibility and/or productivity. And, the rumen microbial population also has a tendency to adapt to feed based mitigations, causing emissions reductions to erode with time. Given the current lack of economic incentives for livestock farmers to reduce GHG emissions, any mitigation which lowers emissions at the expense of productivity is certain to be non-viable. However, even in incidences where emissions are lowered with increased production efficiency, the improvement in efficiency must offset the cost of the mitigation for adoption to occur in practice.

Moate et al., Avila et al. and Lee et al. all note that some by-products of ethanol and biodiesel production have the ability to reduce enteric emissions in ruminants. Use of these products as dietary feeds to lower enteric CH_4 emissions is particularly attractive as they often already fit into diet formulations. Many of these by-product feeds contain 8–12% residual fat and, as outlined by Grainger and Beauchemin, of all mitigation practices dietary fat addition results in the most consistent decrease in enteric CH_4 emissions. However, care must be taken to ensure that the level of fat in the diet does not depress digestibility or alter animal products in a negative manner, such as by depressing milk fat synthesis. While fats cannot easily be fed to grazing ruminants, they are relatively easily included in diets of confined ruminants. However, plant derived fats are often expensive, and compete directly with direct human consumption and production of biodiesel and, as a result, fat mediated reductions in enteric CH_4 emissions to improve production efficiency are frequently insufficient to offset the cost of their addition to the diet.

Lowering CH_4 emissions through genetic selection of ruminants for improved feed efficiency may be one means to overcome economic barriers to use of expensive dietary mitigations. Waghorn and Hegarty outline the latest efforts to lower CH_4 emissions through selection of ruminants for improved feed conversion efficiency. Only a few studies have directly measured CH_4 emissions from ruminants with divergent feed efficiencies but, as shown by Jones et al., individuals which are efficient on high nutritional quality diets may not be the same ones that are most efficient on low nutritional quality diets. The ability of genetic selection to reduce CH_4 production will depend on the heritability of efficiency and, given that CH_4 only arises from microbial sources, emissions are likely to be heavily influenced by the nature of the rumen microbial population. Regardless, selection for feed efficiency will likely need to be environment specific as individual animals adapted to one environment are unlikely to be as efficient in an environment to which they are not adapted.

Plant secondary compounds, including tannins and essential oils, have also been extensively examined for their ability to reduce enteric CH_4 emissions. If secondary compounds which reduce enteric emissions in forages can be identified, they may have the potential to mitigate CH_4 emissions in pastured ruminants. Although several essential oils have been shown to reduce CH_4 production *in vitro*, Benchaar and Greathead note that these responses often occur at concentrations which are unsuitably high for use *in vivo*. Williams et al. illustrate that impacts of condensed tannins on CH_4 production in continuous cultures depends on the source of condensed tannin, possibly reflecting differences in molecular formulae, and weight, as described by Huang et al. Condensed tannin containing forages have often failed to lower CH_4 emissions *in vivo* without adversely impacting animal production. Furthermore, the negative agronomic properties of condensed tannin containing forages often limit their use in grazing systems.

Research is required to characterize how changes in forage composition influence ruminant CH_4 emissions. Sun et al. measured similar levels of CH_4 production per kg feed dry matter intake in sheep consuming chicory or perennial ryegrass, despite the chemical composition of the forages differing substantially. Factors such as concentration of plant secondary compounds, starch to fibre ratio and degree of lignification of plant cell walls may all influence enteric CH_4 emissions from forages. Clearly, plant concentrations of these compounds are not constant throughout the growing season, making it probable that stage of maturity has an important impact on their impacts on enteric CH_4 emissions.

2.4. Deriving value from manure through reduced greenhouse gas emissions

With intensification of livestock production, manure has been increasingly viewed as a waste product in need of disposal as opposed to a source of fertilizer for integrated cropping and livestock production systems. This mindset arises mainly from the concentration of nutrients within the vicinity of livestock operations and the investment needed to transport nutrients to regions of deficiency. Integration of biogas production with livestock operations, as outlined by Massé et al., may enable farmers to derive additional value from manure and reduce off-site nutrient transportation costs. However, the capital investment for biogas facilities are often prohibitive, a situation which, as noted by Baylis and Paulson, may change if carbon offset programs are established. Co-digestion of municipal food wastes with livestock manure may also help amortize initial capital investments. However, without development of regulatory policies and incentives to encourage off grid power generation, which are currently lacking in many countries, widespread implementation of anaerobic digestion is likely to be very limited.

VanderZaag et al. and Chadwick et al. offer excellent reviews of a number of manure management practices which can be used to reduce N_2O emissions from stored and land applied manure. Dietary manipulation, manure treatment, application rate and time, and method of incorporation all influence N_2O emissions from land applied manure. Nitrification inhibitors, such as dicyandiamide described by Klein et al., show promise in reducing N_2O emissions from urine patches (*i.e.*, locations on a pasture where an animal has urinated) in New Zealand. Dinuiccio et al. describe how mechanical separation of liquid and solids can alter GHG and ammonia emissions from manure, while Hao et al. used condensed tannins to alter ammonia emissions by partitioning N from urine to feces in cattle.

However, GHG emissions from manure tend to be spatially and temporally variable, even in storage systems such as those described by Todd et al. and Vanderzaag et al. Quantifying indirect emissions of N_2O continues to be a major challenge and environmental factors such as soil moisture, pH and temperature all influence N_2O and CH_4 emissions. Manure emissions must be assessed from a holistic perspective as emission reductions at one stage of the manure management cycle can lead to higher emissions at another stage.

2.5. Role of modelling in finding the balance between GHG emissions and food production

Modelling of GHG emissions from animal agriculture occurs at a number of levels ranging from quantifying hydrogen flow through volatile fatty acid (VFA) stoichiometry at the individual animal level, to estimating GHG emissions at a farm, country, region or global scale. As with all models, GHG emission models for animal agriculture are only as accurate and precise as the information from which they are derived. In many instances, uncertainties associated with measurement of GHG (*e.g.*, indirect emissions of N_2O) are large and so models often extrapolate far beyond the resolution of their GHG measurement. Although models provide insight into research direction and may identify emission 'hot-spots' within animal production systems, those who use model outputs should always have an appreciation of the often substantive assumptions at the foundation of the model.

Development of indirect methods to estimate CH_4 production in ruminants, such as on the basis of milk fatty acid profiles, as described by Dijkstra et al. and Montoya et al., have obvious appeal. However, Alemu et al. illustrate that there are serious limitations in the ability of stoichiometric models to predict ruminal VFA production solely from estimates of ruminal VFA concentration. Clearly, there remain large gaps in our knowledge of the stoichiometry of hydrogen flow in the rumen.

Models have obvious utility in estimating GHG emissions at the regional and country scale (Bannink et al., Aljaloud et al., Merino et al., Browne et al., Beukes et al.). Assessing mitigations from a systems perspective can identify those steps in the production cycle which are responsible for the highest GHG emissions. Such an approach can also be used to ensure that mitigation of emissions at one point in the production cycle does not lead to increased emissions at another. For example, although the fat in corn distillers' grains may reduce enteric CH_4 emissions, the higher excretion of N as a result of inclusion of this feedstuff in the diet could increase manure N_2O emissions thereby off-setting a reduction in CH_4 emissions. Finally, Beauchemin et al. show that the vast majority of GHG emissions from the North American beef production cycle occur in the cow-calf sector, questioning the extensive effort which has gone into mitigating CH_4 emissions from feedlot cattle.

The foundation of most farm and regional GHG models arises from approaches developed by the Intergovernmental Panel on Climate Change for estimating country specific GHG inventories. Livestock census data is critical to these estimates and, in many areas of the world, it is difficult to obtain accurate regional estimates of livestock populations. Alterations in population estimates and, as outlined by Herrero et al., how GHG are attributed to livestock production can result in very large differences in estimated contributions of livestock to anthropogenic GHG emissions. This leaves both policy makers and the general public wondering which numbers to believe. Standardization of modelling approaches is imperative to establishing a clear message to policy makers and the public, and consistent expression of agriculture emissions on an intensity basis (*i.e.*, emissions/kg product) is a critical step in this direction. Unfortunately, even if livestock populations remain static, Eckard and Cullen show that regional emissions are likely to increase as climate change impacts intensity and rate of GHG emissions from livestock production systems.

3. Final comments

The International Commission on Stratigraphy has been tasked with determining if there is sufficient evidence to establish a new geological epoch known as the Anthropocene or 'Age of Man'. The last epoch, known as the Holocene, began at the end of the last ice age nearly 11,500 years ago. It has been estimated that the human biomass is 100× larger than that of any other large animal species which has ever occupied Earth. This speaks to the enormity of the impact which humans have had on the Earth and its environment. Although ∼38% of the planet's ice-free land is dedicated to food production, agriculture accounts for only 10–12% of global anthropogenic GHG emissions, and the majority of these emissions arise from short term cycling of CO_2 from the atmosphere to plants, to livestock and back to the atmosphere. This contrasts to combustion of fossil fuels, which releases CO_2 from long term carbon stores which have developed over millions of years. Herrero et al. discuss how including expired CO_2 as a GHG, as well as exaggerated contributions from livestock related land use change and the global warming potential of CH_4, results in livestock producing almost 50% of anthropogenic GHG emissions. Such exaggerated estimates detract from the root cause of climate change, which is the burning of fossil fuels.

A complicating factor is that, in many countries, livestock are not used simply as food, but also for cultural purposes, as draft power and for financial security. Thus considering livestock as solely a source of food in efforts to plan the nature of future animal population systems is a grave error. Despite this reality, animal agriculture has an obligation to reduce GHG emissions and to improve efficiency of food production if, for no other reason, than to meet the growing food needs of the human population. Research to characterize the mechanisms and develop strategies to mitigate GHG emissions in animal agriculture is poised for global expansion through organizations such as the recently established Global Research Alliance on Agricultural Greenhouse Gases. Research solutions must considered from a global perspective with applicability to both developed and developing nations.

Past research suggests that mitigations are likely to result in only modest reductions in GHG emissions from livestock production systems per unit product produced. The largest increases in livestock system production efficiency are likely to arise from increased animal productivity and dilution of maintenance nutrient needs. Unfortunately, current research priorities seldom target increasing animal productivity. There is also considerable room to improve the efficiency of food utilization since, as outlined in a February 26 (2011) special report in 'The Economist', 30–50% of food which is produced spoils before it can be consumed. There is little evidence that application of multiple mitigations will consistently result in additive reduction in GHG emissions. Furthermore, reductions of emissions at one point in the livestock production cycle often lead to increased emissions at other points. Ultimately, anthropogenic GHG emissions are unavoidable and humanity may be faced with the decision as to what extent it wishes to reduce emissions by limiting human activity in the energy, transportation, industrial or agricultural sectors. If humanity hopes to feed the 9 billion people projected to occupy Earth in 2050, limiting agricultural production is not a viable option. Ultimately, the dilemma becomes whether food production can be increased to meet the needs of humanity before it is limited by climate change. People who are fed, educated and content have fewer children and a natural decline in the human population, with a much reduced reliance on fossil fuels, may be the best strategy to reducing GHG emissions and their contribution to climate change. However continued research into approaches to improve animal production efficiency, and reduce GHG from animal agriculture have merit, and will be highlighted at the 2013 GGAA meeting in Dublin, Ireland.

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