BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Reducing greenhouse gas emissions from livestock production

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Introduction

Recent IPCC reports have highlighted the environmental impact of livestock production as a major source of non-CO_2 emissions: methane (CH_4), nitrous oxide (N_2O) and ammonia (NH_3). The livestock sector must react to these reports and develop or implement methods that can reduce greenhouse (GHG) emissions from livestock production.

Part 1 of this volume focuses on the analysis of greenhouse gas emissions from livestock, specifically drawing attention to the range of methods that can be used to reduce these emissions. Chapters in Part 2 discuss breeding, animal husbandry and animal management and how improving these elements can help to reduce the environmental impact of livestock production. Part 3 concentrates on nutritional approaches such as improving feed efficiency, forage quality and using plant bioactive compounds to reduce GHG emissions. Chapters also review the use of feed supplements and how modifying the rumen environment can also help to reduce GHG emissions.

Part 1 Analysis

Chapter 1 looks at the key techniques used for measurement of CH_4 and other gas emissions from livestock production, ranging from individual animal measurements to herd scale measurements for grazing animals and whole farm emissions such as feedlots. Individual animal measurement techniques discussed include whole-animal respiration chambers and head capture measurement. Herd scale measurements include micrometeorological methods and the eddy covariance technique.

Expanding on topics previously covered in Chapter 1, Chapter 2 discusses greenhouse gas emissions in livestock production, focusing specifically on modelling methods, methane emission factors and mitigation strategies. The chapter begins by reviewing systems analysis and how it can be used to quantify GHG emissions from livestock. It then looks at the various stages of life cycle assessment and how it can be used to analysis the environmental effects of livestock production. Modelling applications and the importance national greenhouse gas inventory submissions are also considered in the chapter.

Part 2 Breeding, animal husbandry and manure management

The first chapter of Part 2 analyses the contribution of animal breeding to reducing the environmental impact of livestock production. Chapter 3 begins by addressing the impact of livestock production on the environment. It then goes on to discuss the environmental impact of broilers, layer hens, pigs and dairy cattle and how improving breeding techniques for all of these species can help to reduce the emissions they produce. The chapter also highlights future research directions and provides resources for further information on the subject.

Chapter 4 focuses on the environmental impact consequences of endemic livestock health challenges that lead to deterioration in animal health, and on the potential impacts arising from their mitigations. The first part of the chapter concentrates on the potential of animal health to affect the environmental impact of livestock systems. It also reviews the literature to date which has quantified the impact of health challenges for the environmental impacts of livestock systems. The potential of successful health interventions to mitigate negative environmental impacts represents a point of synergy between concerns around environmental sustainability and animal welfare, both of which represent 'hot topics' in the discourse surrounding the livestock industry and its sustainability. The chapter concludes by highlighting the challenges associated with modelling health interventions and their potential to mitigate environmental impacts.

The subject of Chapter 5 is sustainable nitrogen management for housed livestock, manure storage and manure processing. The chapter begins by discussing the various forms nitrogen can take, focusing specifically on ammonia, nitrous oxide and di-nitrogen. It then goes on to review livestock feeding and housing for dairy and beef cattle, pigs and poultry. The chapter also examines manure storage, treatment and processing by discussing the principles of emissions produced from these processes as well as mitigation measures that can be used. It also addresses the best practices and priority measures for livestock feeding, housing and manure storage, treatment and processing.

Chapter 6 discusses developments in anaerobic digestion (AD) to optimize use of livestock manure, particularly the use of livestock manure in the production of biogas. The chapter begins by reviewing the quantities and risks of livestock manure, which is then followed by a discussion of the biogas potential of livestock manure. The chapter also examines mono- and co-digestion and the various factors that can affect the efficiency of anaerobic digestion. It also discusses the use of biogas slurry and residues. The chapter shows how AD can play an important role in promoting circular agriculture. A case study on the use of AD in practice in Henan Province in China is also included.

Part 3 Nutrition

Part 3 opens with a chapter that examines the impact of improving feed efficiency on the environmental impact of livestock production. Chapter 7 starts by discussing the relation between greenhouse gases and dairy production, highlighting how important it is to the dairy sector to find ways of decreasing greenhouse gas output. The chapter then moves on to discuss the origins of methane and reactive nitrogen excretions in ruminants. A section on improving feed conversion efficiency is also included, which is then followed by a review of the nutritional practices that can be used to enhance feed conversion efficiency and decrease methane excretion. The chapter also examines the nutritional practices that can be used to increase milk protein efficiency and nitrous oxide excretion as well. Discussions on genetics and feed conversion efficiency and postabsorptive metabolism and feed conversion efficiency are also provided.

Chapter 8 reviews grazing management strategies that can contribute to reducing livestock greenhouse gas emissions. Strategies discussed include grazing season length and timing as well as sward structure and quality, including dry matter and clover content. The chapter also discusses the use of condensed tannin legumes such as chicory and plantain, as well as measurement issues including life cycle assessment.

Chapter 9 focuses on the opportunity to use plant bioactive compounds in ruminant diets for their potential to mitigate greenhouse gas emissions, particularly enteric methane. Nitrous oxide emissions related to urinary nitrogen waste are addressed when information is available. The main families considered are plant lipids and plant secondary compounds (tannins, saponins, halogenated compounds and essential oils). The effects of these compounds in vivo, their mechanisms of action, and their potential adoption on farms are discussed, and future trends in this research area are highlighted.

The next chapter looks at the use of feed supplements to reduce livestock greenhouse gas emissions, specifically focusing on direct-fed microbials. Chapter 10 outlines the strategy of using feed supplements for the reduction of greenhouse gas emissions in ruminants, including methane (CH_4), carbon dioxide and nitrous oxide, given that feed intake is an important variable in predicting these emissions. The chapter focuses on direct-fed microbials, a term reserved for live microbes which can be supplemented to feed to elicit a beneficial response. The viability of such methods is also analysed for their use in large scale on-farm operations.

Chapter 11 focuses on modifying the rumen environment to reduce greenhouse gas emissions. Ruminants were among the first domesticated animals and have been providing food, leather, wool, draft and by-products to humanity for at least 10 000 years. However, rumen methanogens reduce CO_2 to CH_4 in association with other rumen microbes that generate substrates for methanogenesis. Consequently, other rumen microbiota can directly and indirectly impact the abundance and activity of methanogens. Enteric methanogenesis from ruminants accounts for approximately 6% of total anthropogenic greenhouse gases emissions and can represent from 2% to 12% of the host's gross energy intake. A myriad of strategies to mitigate CH_4

emissions have been investigated, but few have been adopted by industry. This chapter reviews rumen- and feed-associated factors affecting CH_4 production and outlines the challenges associated with achieving a reduction in enteric CH_4 emissions. The pros and cons of these strategies are discussed in an attempt to define the best approaches to mitigate CH_4 emissions from ruminant production systems.

Chapter 1

Measuring methane emissions from livestock

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1 Introduction

Methane (CH_4) gas was first isolated by the Italian physicist Alessandro Volta in 1776 and described as the 'inflammable air native of marshes'. Although recognized as a local gas associated with decaying biological matter, CH_4 was thought to be a relatively static and minor component of the atmosphere. It would be another 200 years before advances in gas chromatography (GC) allowed Rasmussen and Khalil (1981) to show that CH_4 concentration in the atmosphere was not static but was increasing by an estimated 2% per year. With continued atmospheric monitoring and a lengthening historic record derived from ice-core data, the nature of rising CH_4 concentration and its relevance to global warming became increasingly apparent.

The establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and a growing awareness of the need to curb emissions sparked a flurry of research related to cattle CH_4 emissions beginning in the 1990s. Mitigation of enteric CH_4 emissions and the development of measurement techniques to validate the effectiveness of mitigation practices continue to be ongoing areas of research. Strategies that alter the rumen environment and the digestion process (Hristov et al., 2013) through the use of feed additives

http://dx.doi.org/10.19103/AS.2020.0077.03
Published by Burleigh Dodds Science Publishing Limited, 2021.

(Grainger et al., 2008) can improve feed efficiency and decrease enteric CH_4 emissions per kg of meat produced. Farm management and grazing strategies can also influence CH_4 emissions and the genetic selection of more efficient cattle (kg CH_4 per kg live weight) is also an ongoing promising area of research (Basarab et al., 2013).

Mitigation of CH_4 emissions requires emission measurements that are sensitive enough to measure the difference between standard practices and proposed mitigation strategies. Emission measurement methods also need to be operational at a range of spatial scales from the individual animal to *in situ* measurements under typical animal management conditions. This chapter reports on key techniques used for measuring CH_4 emission in agriculture at a variety of spatial scales. Advances in these techniques and promising new approaches to measure CH_4 emissions are also discussed.

2 Individual animal measurement techniques: whole-animal respiration chambers and head capture measurement

2.1 Whole-animal respiration chambers

The first estimates of CH_4 emissions from ruminants came from chamber studies, long before CH_4 had ever been measured in the atmosphere. The animal nutrition laboratory of the Pennsylvania State College constructed a respiration calorimeter in 1902 as a key component to better understanding animal physiology and ruminant nutrition (Armsby and Fries, 1903). Animal CH_4 production was recognized as a loss in feed energy and the Armsby respiration chamber, as it came to be known, was instrumental in generating feed ration and nutrition guidelines for America's expanding cattle industry. Measurement of CH_4 emissions was accomplished by routing a known volume of chamber air to a combustion furnace (Fries, 1910) and recording the change in combustion end products. After many years of experiments, Bratzler and Forbes (1940) developed a simple model relating animal CH_4 production with carbohydrate intake.

Modern chambers are more sophisticated, offering fine control of temperature, humidity and airflow, and advances in sensor technology have allowed for analysis of more components. Construction of chambers represents a considerable expense, but the importance of CH_4 as a source of agricultural greenhouse gas (GHG) emission has hastened their development. Whole-animal respiration chambers are now found at animal research facilities throughout the world. Chamber results have contributed to the current understanding of animal energetics and are considered a 'gold standard' measurement technique. Chambers offer a direct measure of emissions with few assumptions and a methodology that can be easily validated through gas release and recovery tests (McLean and Tobin, 1988). While whole-animal respiration chambers have been extremely valuable for mitigation work and quantifying treatment effects, the chamber represents a constrained environment, and it is less certain to what extent results can be extrapolated to actual cattle production systems (Johnson et al., 1994).

2.2 Head capture measurement

Measurement techniques capable of operating within real agricultural production environments are necessary for validating methane mitigation measures under typical animal management conditions. As an alternative to large animal chambers, a variety of systems have been designed to measure emissions, principally through focused airflow and concentration measurements of the area around the animal's head. These methods include:

- sniffer methods, where a sampling unit is incorporated into feed troughs;
- ventilated hood or headbox systems, which provide a more controlled environment but allow the animal access to food and water; and
- mask systems, which are fitted to the animal's nose and mouth.

The latter two techniques are also known as flux methods since they involve greater control of the airflow to capture emitted gases and measure CH_4 fluxes. A different approach is the use of handheld laser methane detectors (LMD) which are pointed by an operator at an animal's nostrils to measure methane column density along the length of the laser beam.

These techniques can be used within existing barn facilities and, depending upon the design, can be used to measure emissions continuously over a 24-h period or through spot measurements over the course of the day (Hammond et al., 2016a; Kebreab, 2015). Similar to respiration chamber measurement, these techniques can be affected by decreased feed intake, and intensive training is required for animals to become familiar with the hood apparatus, making it impractical to measure large numbers of animals (NASEM, 2018).

Sniffer methods are based on continuous breath analysis of exhaled air from animals using feed troughs in environments such as automated milking systems. A sampling unit is placed in the feed trough, and the air around the animal's muzzle is continuously monitored during feeding. Sensor systems detect the animal and activate breath analyzers located in the troughs, including Fourier transform infrared (FTIR) and non-dispersive infrared (NDIR) techniques. Measurements can then be used to develop an index of CH_4 emissions during milking as a product of peak frequency and mean peak area of CH_4 concentration (Garnswothy et al., 2012), or using the ratio of CO_2 to CH_4 (Lassen et al., 2012; Lassen and Løvendahl, 2016; Bell et al., 2014). Sniffer methods may be more affected by variable air-mixing conditions due to factors such as the geometry of the feed trough, muzzle position and movement, suggesting that flux techniques are more reliable (Huhtanen et al., 2015). However, recent research suggests that results from sniffer and flux methods are both comparable with each other and with respiration chambers, suggesting a growing degree of accuracy (Sorg et al., 2018; Difford et al., 2018).

The GreenFeed system (GF) (C-Lock Inc, Rapid City SD, USA) incorporates elements of the ventilated hood chamber into an automated feeder that dispenses a programmed amount of pelletized feed as bait to encourage visits to the GF. The GF is a robust system and can be incorporated into the production environment with one GF unit capable of measuring many animals consecutively. A proximity sensor in the head chamber identifies the visiting animal through its ear tag and initiates a gas sampling routine during which bait pellets are dispensed to keep the animals head in the feeder for 3–7 min during which time an emission rate is calculated. The procedure for deriving emission rates is reported by McGinn et al. (2021).

The GF unit can be programmed to limit the number of permitted visits per day but this measurement method is dependent on the animal's desire for the bait in the feeder, and the actual number of visits each animal makes per day will vary as will the number of animals that visit the device. For this reason, measurements are typically accumulated over several weeks to establish a daily emissions pattern for each animal that regularly uses the GF (Hammond et al., 2016b; Hristov et al., 2015; Huhtanen et al., 2019). When using spot measurements to determine daily emissions, care must be taken to prevent sampling bias by ensuring sampling times are appropriate for the daily feeding cycle of the animals using the device (Hammond et al., 2016a). As with ventilated hood chambers and head masks, the GF system is unable to capture the small emission eructed through the rectum, which has been reported to be between 4% and 8% of the total emission from cattle nose, mouth and rectum (Grainger et al., 2007b; McGinn et al., 2006a; Ulyatt et al., 1999). Muñoz et al. (2012) assumed 3% ± 1.5% emission was from the rectum.

3 Individual animal measurement techniques: tracer techniques

Tracer techniques rely on the co-location of a tracer gas source (with a known release rate) and the source to be measured, based on the assumption that both gases will be transported in the atmosphere in the same manner. Concentration measurements of the tracer gas and the source gas are made at some distance downwind. The ratio of gas concentrations is used with the known release rate of the tracer to determine the emission rate. Tracer techniques offer the advantage of a strictly ratiometric measure independent of meteorological conditions.

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3.1 Sulfur hexafluoride tracer technique

The sulfur hexafluoride (SF_6) tracer technique (Johnson et al., 1994) was developed to overcome the limitations of chamber measurements, providing individual animal emission estimates without constraints on the animal's typical behavior in the production environment. The technique requires placing a small permeation tube in the animal's rumen which emits SF_6 at a pre-calibrated rate. This tracer gas is expelled through eructation along with the CH_4 produced in the rumen, while a collection device attached to the animal slowly draws air, usually for 24 h, from the nose and mouth region through an intake affixed to a halter. This technique provided the first measurements of animal emissions from grazing systems (Lassey et al., 1997; McCaughey et al., 1997). It also provided a means to monitor the dynamics of pasture conditions by conducting short measurement programs over a year (Pavao-Zuckerman et al., 1999; Ulyatt et al., 2002).

The technique gained in popularity as many agricultural research facilities already had the capacity for gas chromatographic analysis of the air samples collected with the SF_6 technique. With a modest outlay to construct the sampling apparatus and prepare the permeation tubes, a technique was now available to obtain measurements of animal CH_4 emissions from their typical production environment. With an increasing number of users, the technique was improved through a better understanding of animal emission variability compared with chamber measurements (Grainger et al., 2007a), the release characteristics of the permeation tubes with time (Lassey et al., 2001), the effect of permeation rate on emissions estimates (Vlaming et al., 2007), the effect of background measurements (Williams et al., 2011) and the importance of the sample collection rate (Deighton et al., 2014).

The SF_6 tracer technique has proven valuable for mitigation work and is well suited to measurements on small groups of animals, particularly within dairy systems where animals are accustomed to daily handling and sampler changes can be coordinated with daily milking. Implementation in grazing systems is more problematic as cattle require extensive training to become accustomed to handling and the fitting of yokes (DeRamus et al., 2003). The technique is also limited by higher between-cow variability in measurement accuracy (Pinares-Patiño et al., 2011). In addition to the permeation tube approach, SF_6 has also been used as a tracer gas to estimate CH_4 emissions from whole farms by releasing gas along barn vents and pen railings (McGinn et al., 2006b) and collecting downwind air samples for GC analysis of SF_6 and CH_4.

3.2 Other tracer techniques: nitrous oxide-tracer Fourier transform infrared spectroscopy

Tracer studies have also been carried out using open-path FTIR and nitrous oxide (N_2O) as tracer gas (Griffith et al., 2008). The open-path FTIR has proven

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