Greenhouse gas emissions in livestock production systems

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Abstract

Agriculture is responsible for a significant proportion of total anthropogenic greenhouse gas emissions (perhaps 18% globally), and therefore has the potential to contribute to efforts to reduce emissions as a means of minimising the risk of dangerous climate change. The largest contributions to emissions are attributed to ruminant methane production and nitrous oxide from animal waste and fertilised soils. Further, livestock, including ruminants, are an important component of global and Australian food production and there is a growing demand for animal protein sources. At the same time as governments and the community strengthen objectives to reduce greenhouse gas emissions, there are growing concerns about global food security. This paper provides an overview of a number of options for reducing methane and nitrous oxide emissions from ruminant production systems in Australia, while maintaining productivity to contribute to both objectives. Options include strategies for feed modification, animal breeding and herd management, rumen manipulation and animal waste and fertiliser management. Using currently available strategies, some reductions in emissions can be achieved, but practical commercially available techniques for significant reductions in methane emissions, particularly from extensive livestock production systems, will require greater time and resource investment. Decreases in the levels of emissions from these ruminant systems (*i.e.*, the amount of emissions per unit of product such as meat) have already been achieved. However, the technology has not yet been developed for eliminating production of methane from the rumen of cattle and sheep digesting the cellulose and lignin-rich grasses that make up a large part of the diet of animals grazing natural pastures, particularly in arid and semi-arid grazing lands. Nevertheless, the abatement that can be achieved will contribute significantly towards reaching greenhouse gas emissions reduction targets and research will achieve further advances.

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Introduction

Australian livestock industries play a vital role in Australia's culture and economy. The gross value of livestock production in 2008 was AUD 19.7 billion, with about AUD 14 billion as export earnings (ABARE 2008). Australia is the world's largest exporter of wool and second largest exporter of red meat. Livestock production systems in Australia are highly varied, but an economically and culturally important component is the extensive grazing systems of northern Australia dominated by tropical grasses and woodlands. These systems that support approximately 16 M beef cattle are complemented by an expanding feedlot industry.

Globally, the livestock sector is growing faster than any other agricultural sector. Global production of meat and dairy commodities is expected to more than double by 2050, owing largely to increasing consumption in developing countries, with recent reports proposing that an increase of 80% by 2030 may actually be needed to meet demand. The Australian livestock industries have the opportunity to capitalise on this increase in demand and contribute to addressing issues of global food security. Efficient and sustainable production can also contribute to global environmental goals, including reduced emissions of greenhouse gases.

Greenhouse gas emissions from ruminant production systems

Australia's greenhouse gas accounts show that methane from livestock is almost equivalent to the greenhouse gas emissions from the entire transport sector in Australia (Department of Climate Change 2008). About 50% of Australia's total methane emissions are derived from the livestock industries, and this represents about 10% of the total national greenhouse gas emissions. More than half of the methane emissions from livestock in Australia are attributed to beef cattle (Table 1). In addition, management of manure accounts for additional emissions equivalent to almost 1% of total national greenhouse gases, as nitrous oxide and methane.

While Australian livestock make only a small contribution to the total of approximately 80 M t of methane emitted globally from domestic and wild ruminants, successful development in Australia of abatement strategies with international potential could make a significant contribution to global mitigation efforts. Such strategies would also provide a competitive advantage for this country, because there is currently a lack of practical and cost-effective mitigation options. Importantly, as well as being a strong greenhouse gas, methane from digestion represents a loss of energy and therefore a 'loss' from production of food and fibre commodities. Similarly, nitrous oxide release represents inefficiency in nitrogen capture for plant growth.

The high variability in livestock production systems in Australia, ranging from cattle on savannah woodlands in northern Australia, through sheep and cattle on arid and semi-arid rangelands, to intensive dairy and beef cattle production on improved pastures in higher rainfall regions of southern Australia, means that there is also a wide range of impacts on carbon and nitrogen cycles in productive landscapes. The range of these impacts is exacerbated by the fact that the production systems are managed against a background of one of the most variable climates in the world.

Table 1. Methane emissions from rumen digestion of livestock in Australia in 2006 (Department of Climate Change 2008).

Livestock category	Rumen methane (Mt CO_2-e)
Beef cattle	36.6
Feedlot cattle	2.1
Dairy cattle	6.8
Sheep	13.6
Other	0.24

Rumen methane

The rumen allows animals, predominantly sheep and cattle in Australia, to break down cellulose in grasses and other forages to obtain energy and nutrients for growth. Methane is a by-product of this anaerobic digestive process (enteric fermentation). In this first stage of digestion, the forage is acted on by the varied population of microorganisms, including bacteria, fungi and protozoa, in the fore-stomach. This process releases hydrogen, while producing volatile fatty acids and microbial cells containing energy and essential proteins to be made available for the growth of the animal. In ruminants, the hydrogen is removed through the action of a group of microbes called methanogenic archaea (methanogens) that gain their energy through combining carbon dioxide with hydrogen to form methane. Hence, methane emissions provide a mechanism for preventing hydrogen from building up in the rumen with resultant adverse effects on animal productivity, and therefore strategies to reduce methane emissions must also provide for an alternative pathway to remove hydrogen.

Most of the methane that accumulates in the rumen is expelled via the mouth through belching and breathing. Microorganisms that grow and reproduce in the fermentation processes in the rumen can pass into the later stages of digestion in the ruminant providing protein and additional energy for growth. However, methane does represent a loss of energy from the animal production system with 6–12% of gross energy intake lost as methane. This can exceed the gross energy intake directed to liveweight gain or wool production by as much as 3–4 times (Kurihara *et al*. 1999). Table 2 (Eckard *et al*. 2009) demonstrates the potential productivity gain from reducing methane emissions and it has been this objective of increasing efficiency of feed intake that has

Table 2. Typical ranges in methane emissions from 3 classes of ruminants, energy lost as CH_4, with an estimate of effective annual grazing days lost (Eckard *et al.* 2009).

Animal Class	Av. Liveweight (kg)	CH_4 (kg/hd/year)	MJ CH_4 lost / hd/day	Av Daily Energy requirement (MJ/ hd/day)	Effective annual grazing days lost
Mature ewe	48	10 to 13	1.5 to 2.0	13	43 to 55
Beef steer	470	50 to 90	7.6 to 13.6	83	33 to 60
Lactating dairy cow	550	91 to 146	13.6 to 22.1	203	25 to 40

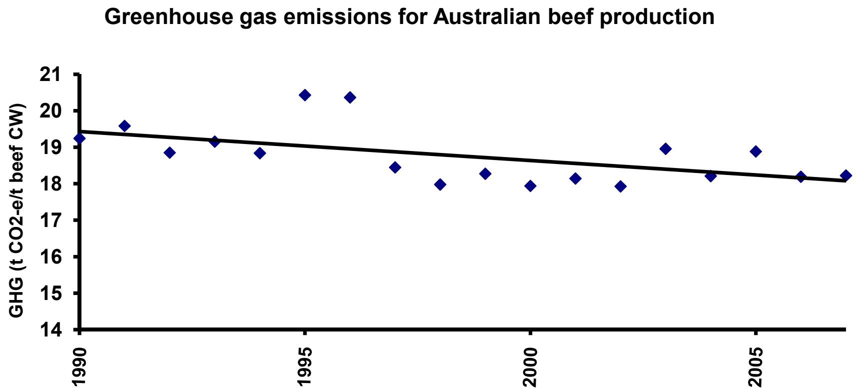

Figure 1. Improvement in the greenhouse efficiency of livestock industries using the example of beef production in Australia based on beef cattle emissions data since 1990 (tonnes CO_2-e) from the Department of Climate Change and beef production data from Meat & Livestock Australia.

historically driven research into methane abatement from livestock.

As a result of improvements in animal breeding, diet and management, methane emitted per unit of production has trended downwards over the past couple of decades (Figure 1). Introduction of policies to reduce greenhouse gas emissions from human activities, based on government and community concern about the threat of dangerous climate change, is now increasing investment in rumen methane research nationally and internationally. Strategies and current research directions for reducing rumen methane emissions are discussed below, and some suggestions are provided for currently available practical options for managing the intensity of emissions in livestock production systems in Australia.

Strategies for managing emissions from livestock

Herd management

Methane emissions from a farm depend on the number of animals and the emissions per head. Management efficiencies such as reducing the number of unproductive animals and increasing reproductive efficiency to enable fewer breeders to provide the same number of offspring per year will reduce methane emissions as well as increasing profitability. Good feed quality and maintaining animal health will improve the fertility of the herd and increase weaning rate with flow-on effects to lower total methane emissions from the herd. Further, minimising disease and environmental stress through an effective disease-management plan will improve productivity of the herd and result in a reduction in methane emissions per unit of product.

Through earlier finishing of beef cattle in feedlots, slaughter weights are achieved at younger ages, with reduced lifetime emissions per animal, and thus proportionately fewer animals producing methane. Strategies such as extended lactation in dairy cows, where cows calve every 18 months rather than annually, reduce herd energy demand and replacement rates and therefore potentially reduce on-farm methane emissions by a similar amount (Smith *et al*. 2007).

Animal breeding

Selection for genetic lines of sheep and cattle that have lower methane emissions (both in absolute terms and as a function of productivity) has the potential to be an effective long-term and economically sound approach to reducing methane emissions from livestock. Genetic approaches are suited to extensive grazing systems, where management and husbandry interventions will continue to be impractical, at least in the near future. In more intensive livestock systems, genetic improvements can be combined with management approaches.

The extent of the genetic improvement that is possible depends on the amount of variation exhibited between animals and the proportion of this variation that is heritable. Measurements suggest that animal breeding could achieve a reduction of 10–20% in methane production from dry matter during digestion (Waghorn *et al*. 2006). Since methane production occurs through the activity of the methanogens in the rumen, selection would likely be through interaction between the host and microbial ecology in the rumen, or through the animal's digestive physiology. However, some results indicate that differences in methane emissions between individual animals reflect an interaction between genotype and nutrition. For example, Hegarty *et al*. (2007) found that the relationship between methane production and residual feed intake in Angus cattle explained only a small proportion of the variation in methane emissions.

Diet and nutrition management

The digestibility and quality of feed are major determinants of energy available for animal growth and, therefore, of the performance of ruminants and of methane production. The efficiency of nutrient utilisation by microbial organisms in the rumen controls the fermentation process, which in turn affects the activity of methanogens relative to other microbial species.

Forage quality can be improved through feeding forages with lower fibre and higher soluble carbohydrates, changing from C4 tropical grasses to (mostly temperate) C3 species, or grazing less mature pastures. These options can also reduce methane production (Beauchemin *et al*. 2008). Methane production per unit of cellulose digested has been shown to be 3 times that of hemicellulose, while cellulose and hemicellulose ferment at a slower rate than non-structural carbohydrate, thus yielding more methane per unit of substrate digested (Eckard *et al*. 2009). Adding grain to a forage diet increases starch and reduces fibre intake, reducing rumen pH and promoting the production of propionate in the rumen (McAllister and Newbold 2008). Propionate production tends to reduce methanogenesis in the rumen. Methane emissions are also commonly lower with higher proportions of forage legumes in the diet, partly due to lower fibre content, faster rate of passage and, in some cases, the presence of condensed tannins (Beauchemin *et al*. 2008). Plant breeding therefore offers some potential to improve the efficiency of digestion, while reducing methane production.

Improving forage quality tends to increase the amount of feed consumed, increasing energy available for animal growth and production. Therefore, improving diet quality can result in better animal performance as well as reducing methane production, as measured by a reduction in methane emissions per unit of animal product. However, overall farm-level methane emissions may remain the same or increase if stocking rate is increased to take advantage of the improved forage availability. Adding more grain to the diet can also result in an increase in nitrous oxide emissions through fertiliser applications for grain production. Further research and modelling will provide a better understanding of the overall relationships between improving diet quality and feed intake, stocking rate and net greenhouse gas production. These relationships will vary with different production systems.

In intensive livestock production systems, dietary supplements have the potential to profitably reduce methane emissions, with many strategies already available for implementation on-farm, *e.g.* dietary oils (Eckard *et al*. 2009). Reductions of 10–25% may be achievable through the addition of dietary oils to the diets of ruminants (Beauchemin *et al*. 2008). Possible mechanisms by which added lipid can reduce methane production include: (a) by reducing fibre digestion (mainly in long-chain fatty acids); (b) by lowering dry matter intake (if total dietary fat exceeds 6–7%); (c) through suppression of methanogens (mainly in medium-chain fatty acids); (d) through suppression of rumen protozoa; and (e) to a limited extent through biohydrogenation (Beauchemin *et al*. 2008; Eckard *et al*. 2009). These authors reviewed 17 studies with beef, sheep and dairy cattle and concluded that for every 1% increase in fat, methane, estimated on a dry matter intake basis, was reduced by 5.6%. Plant breeding may in future offer opportunities to increase oil levels in selected forages and therefore increase oil intake directly as animals graze.

Some secondary plant compounds, such as tannins, have been shown to reduce methane production by 13–16% (Eckard *et al*. 2009). These compounds may act through a direct toxicity effect on methanogens, but may reduce dry matter intake and protein digestibility. There is evidence that plant saponins may also reduce methane production, probably through their antiprotozoal properties (Beauchemin *et al*. 2008).

Future research might provide an indication of the likely success of additives in the diet that act by reducing the hydrogen available for methane production. Yeast cultures of *Saccharomyces cerevisiae* have the potential to reduce formation of methane through reduction in the amount of available hydrogen, because they stimulate acetogenic microbes in the rumen, consuming hydrogen to form acetate. However, results are inconsistent and further research is still required to screen a large number of yeast strains and also enzymes such as cellulases and hemicellulases to isolate those with both a production benefit and significant methane abatement potential. Chemicals such as fumerate and malate, that are precursors of propionate, also act by taking up hydrogen and decreasing the amount available for methane production. However, these chemicals tend to be very expensive and, to date, high levels of supplementation have been needed to achieve significant reductions in methane emissions.

Rumen manipulation

Manipulating microbial populations in the rumen, through chemical means, by introducing competitive or predatory microbes, or through vaccination approaches, can reduce methane production (Eckard *et al*. 2009). Many of these techniques are in the early stages of research in terms of a practical and cost-effective method of abatement, but some are outlined below as examples of potential future opportunities.

1. Vaccines that inhibit the activity of methanogens are an attractive possibility as a straightforward ‘solution’ for extensive production systems. However, to date, research has not indicated that a practical commercially viable vaccine will be developed in the near future.
2. Reductive acetogenesis may be an alternative to methanogenesis as a means of removing the hydrogen from fermentation processes, through formation of acetate. Acetate is a source of energy. While acetogens are present in the rumen, methanogens effectively outcompete them for hydrogen (McAllister and Newbold 2008). Acetogenic bacteria demonstrate higher population densities and an ability to be dominant under some conditions (*e.g.* in some macropods) (Ouwerkerk *et al*. 2005).
3. Some chemicals such as bromochloromethane and chloroform are potent inhibitors of methane formation in ruminants, because they mimic methane in structure, with bromochloromethane reducing methane emissions on a dry matter intake basis by up to 91% in feedlot steers using high doses (Tomkins *et al*. 2009). However, chemical inhibitors require further testing and development to overcome potential problems including host toxicity, adaptation by rumen microbial populations and suppression of digestion.
4. Protozoa in the rumen provide a habitat for methanogens and supply them with a source of hydrogen, thus increasing their numbers. Reducing numbers of protozoa has been shown to reduce methane by up to 26% (McAllister and Newbold 2008). However, the

effectiveness of chemicals, such as detergents which remove protozoa, does not persist even though increases in productivity may continue. Further, addition of synthetic chemicals to animal diets would have to be acceptable to consumers.

5. Antibiotics (ionophores), such as monensin, act by attaching to the cell membrane of ruminal bacteria and protozoa, resulting in a decrease in the proportion of acetate relative to propionate in the rumen. This effectively decreases methane production but the inhibitory effect on methane production appears to be dose-dependent, with higher doses needed but reducing methane production by 0–10%. As noted for chemical additives, there are questions around the persistence of methane suppression and acceptability of antibiotics in food production systems (Eckard *et al*. 2000).

Nitrous oxide

Nitrous oxide emissions account for about 10% of global greenhouse gas emissions with about 90% derived from agricultural practices (Eckard *et al*. 2009). About 60% of Australia's nitrous oxide emissions come from agricultural soils, with nitrous oxide produced predominantly by the microbial process of denitrification with some produced also through nitrification. Soil nitrate levels and soil aeration are key factors affecting nitrous oxide emissions from grazing systems (Eckard *et al*. 2003) and hence strategies for improving the efficiency of nitrogen cycling in animal production systems, and improving soil aeration, should also lead to lower nitrous oxide emissions (Eckard *et al*. 2009). De Klein and Eckard (2008) and Eckard *et al.* (2009) described the main options for reducing nitrous oxide production and only a brief summary is included here.

Nitrous oxide is produced from nitrogen fertilisers, urine deposited by livestock on soils and from manure and effluent during storage and treatment. Of the dietary nitrogen consumed by ruminants, less than 30% is utilised for production, with more than 60% being lost from the grazing system. The effective nitrogen application rate within a urine patch from a dairy cow is commonly between 800 and 1300 kg/ha N. Since these deposition rates of N are much greater than soil-plant systems can efficiently utilise, strategies for improving the efficiency of nitrogen cycling effectively also reduce nitrous oxide emissions. If animal urine in grazing systems was spread more evenly across the paddock, the effective nitrogen requirement of the system would be greatly reduced, but any attempts to achieve this objective are hampered by the lack of an effective means of achieving more even spread.

Genetic management or breeding of animals may enable selection of animals with higher ruminal nitrogen conversion efficiency, animals that urinate more frequently or animals that walk while urinating, all of which would achieve lower nitrogen concentrations or greater spread of urine. Ruminants on lush spring pasture commonly provide a scenario of higher ruminal ammonia concentrations being excreted in the urine as urea. In general, ensuring the energy requirements of the animals are supplied through more digestible feed provided at levels sufficient for optimal performance, without nutrients in excess of requirements, will assist in managing nitrous oxide emissions.

Adding supplements such as tannins may also increase the efficiency of protein digestion with less nitrogen in urine and dung. Adding salt increases water intake in ruminants, both reducing urinary nitrogen concentration and inducing more frequent urination events, thus spreading urine more evenly across grazed pasture. The most common method of managing livestock waste is to apply it to soils, and the rate, timing and placement of effluent affect nitrous oxide emissions, as well as enhancing soil nutrient levels and consequently benefits for pasture growth.

Cattle manure contains in the order of 16–24 kg N per tonne. Nitrogen in waste can occur as organic nitrogen, ammonium and nitrate with a range of transformations possible after application to land. Manure is most effectively applied to pastures or crops based on assessment of plant nutrient needs and land condition, *e.g*. stage in a crop cycle or pasture cover and soil moisture content. Moisture and aeration in manure stockpiles should also be managed to maximise aerobic decomposition to minimise methane production as well as ammonia volatilisation, as the deposition of this ammonia will result in some secondary nitrous oxide being emitted.

Nitrification inhibitors are chemicals that inhibit the oxidation of ammonium to nitrate in soils and, thereby, reduce nitrous oxide emissions from urine (or from ammonia-based fertilisers). Nitrification inhibitor-coated fertilisers are known to be effective in reducing nitrification and reducing nitrous oxide emissions and, when applied as a spray, can also be effective in reducing nitrous oxide emissions from animal urine by 61–91%. However, nitrification inhibitors are less effective at high temperatures and may only be suited to temperate pastures or during the winter period in warmer latitudes. They are currently the only documented technology available for reducing the loss of nitrogen from soils, and while their use has not been cost-effective to date, they offer the potential to significantly contribute to future abatement requirements.

Conclusion

There are a number of strategies available at present that provide opportunities to reduce greenhouse gas emissions from livestock production systems, while maintaining (and potentially increasing) productivity. The degree of abatement achievable is mostly not large (<20%) and, while able to make a significant contribution, is unlikely to deliver the level of reduction desirable to mitigate the threat of dangerous climate change. Significant levels of abatement will require additional innovation from intensive research and development over several years and this will be achieved only with dedicated resources. The challenge is particularly difficult for extensive production systems, where few options currently exist for practical intervention. In more intensive ruminant production systems, strategies such as feeding supplements and using nitrification inhibitors can be developed for widespread application, subject to cost.

Acknowledgement

This paper is not an original analysis but represents a summary of recent reviews and research papers by Australian and international experts including, but not restricted to, those papers referenced. It is intended to provide an introduction to the status of current scientific thinking on greenhouse gas emissions from livestock production systems, and interested readers are strongly encouraged to seek further information from experts in ruminant physiology and livestock management.

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