Livestock Science 130 (2010) 47–56

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Options for the abatement of methane and nitrous oxide from ruminant production: A review ☆

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ARTICLE INFO

Keywords:
Enteric
Nitrogen
Dung
Urine
Greenhouse gas
Mitigation

ABSTRACT

Agriculture produces ~10%–12% of total global anthropogenic greenhouse gas emissions, contributing ~50% and ~60% of all anthropogenic methane (CH_4) and nitrous oxide (N_2O), respectively. Apart from their significant contribution to anthropogenic greenhouse gas emissions, the energy lost as CH_4 and total N losses are two of the most significant inefficiencies remaining in ruminant production systems. A number of options are reviewed to reduce production of enteric CH_4 and N_2O from ruminant production systems, mainly focusing on breeding, feeding, animal management, soil and fertilizer management, and rumen manipulation. To fully assess the net abatement potential, each strategy must be subjected to whole-farm systems modelling and a full life-cycle assessment, to ensure that a reduction in emissions at one point does not stimulate higher emissions elsewhere in the production system. Most of the options reviewed require many years of research before practical strategies and commercially viable products are available for use on farms. This paper reviews the options available for livestock production to reduce CH_4 and N_2O emissions while improving production, and highlights research issues and the need for a systems approach to the evaluation of the relative merits of abatement options.

1. Introduction

Agriculture produces ~10%–12% of total global anthropogenic greenhouse gas emissions, contributing ~50% and ~60% of all anthropogenic methane (CH_4) and nitrous oxide (N_2O), respectively (Smith et al., 2007). Both CH_4 and N_2O are powerful greenhouse gasses, with global warming potentials of 25 (CH_4) and 298 (N_2O). These conversion factors are currently used to report emissions under the Kyoto Protocol, although there is debate over the specific global warming potentials that should be used (Forster et al., 2007).

Apart from their contribution to anthropogenic greenhouse gas emissions, energy and N losses are two of the most significant inefficiencies in ruminant production systems. Therefore, the challenge for research is to develop technologies and strategies to improve the efficiency of the energy and N cycles in ruminant production, leading to more efficient and sustainable production systems in the future.

Several reviews of enteric CH_4 and N_2O production and mitigation have recently been published (Dalal et al., 2003; Beauchemin et al., 2008; de Klein and Eckard, 2008; McAllister and Newbold, 2008). Therefore, this paper only summarizes the current state of knowledge relevant to ruminant production systems, highlighting future research needs and directions.

2. Enteric methane

Globally, ruminant livestock produce ~80 million tonnes of CH_4 annually, accounting for ~33% of anthropogenic emissions of CH_4 (Beauchemin et al., 2008). Enteric CH_4 is produced under anaerobic conditions in the rumen by methanogenic Archaea,

☆ This article is part of the special issue entitled “10th World Conference on Animal Production (WCAP)” guest edited by Norman Casey.

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doi:10.1016/j.livsci.2010.02.010

using CO_2 and H_2 to form CH_4, and thus reducing the metabolic H_2 produced during microbial metabolism (McAllister and Newbold, 2008). If H_2 accumulates, the re-oxidation of NADH is inhibited, inhibiting microbial growth, forage digestion, and the associated production of acetate, propionate, and butyrate (Joblin, 1999). Therefore, any mitigation strategy that reduces methanogen populations must also include an alternative pathway for H_2 removal from the rumen.

With an energy content of 55.22 MJ/kg (Brouwer, 1965), CH_4 represents a significant loss of dietary energy from the production system (Table 1). Typically, about 6%–10% of the total gross energy consumed by the dairy cow is converted to CH_4 and released via the breath. Therefore, reducing enteric CH_4 production may also lead to production benefits. Fig. 1 presents a summary of the main options for reducing enteric CH_4 production, which are reviewed below.

2.1. Animal manipulation

A number of experiments have reported variations between animals in CH_4 emission per unit of feed intake. In a trial involving 302 grazing dairy cows, mean CH_4 emissions of 19.3 ± 2.9 g/kg dry matter intake (DMI) were reported (Clark et al., 2005), the 15% variance suggesting heritable differences in methanogenesis. Similar responses have been reported in sheep on an unlimited pasture diet (Pinares-Patiño et al., 2003). However, although Hegarty et al. (2007) also reported a significant ($P = 0.01$) positive relationship between CH_4 production and net feed intake (NFI) in Angus steers (slope of 13.38), this explained only a small proportion of the observed variation in CH_4, perhaps indicating a genotype × nutrition interaction. These data suggest that animal breeding could achieve a 10%–20% reduction in CH_4 losses from dry matter (DM) during digestion (Waghorn et al., 2006). However, breeding for reduced methanogenesis is unlikely to be compatible with other competing breeding objectives. In contrast, breeding for improved feed conversion efficiency (lower NFI) should be compatible with existing breeding objectives and is likely to reduce both CH_4 and the ratio of CH_4 per unit product.

Reducing the number of unproductive animals on a farm can potentially both improve profitability and reduce CH_4. Strategies such as extended lactation in dairying, where cows calve every 18 months rather than annually, reduce herd energy demand by 10.4% (Trapnell and Malcolm, 2006) and thus potentially reduce on-farm CH_4 emissions by a similar amount (Smith et al., 2007). With earlier finishing of beef cattle in feed lots, slaughter weights are reached at a younger age, with reduced lifetime emissions per animal and thus proportionately fewer animals producing CH_4 (Smith et al., 2007).

Therefore, a number of options exist, such as breeding ruminants with lower CH_4 production, minimizing unproductive animal numbers on farms, and changing to novel production systems, all of which can potentially both reduce total CH_4 emissions and improve on-farm profitability.

2.2. Dietary manipulation

2.2.1. Forage quality

Improving forage quality, either through feeding forage with lower fibre and higher soluble carbohydrates, changing from C4 to C3 grasses, or even grazing on less-mature pastures, can reduce CH_4 production (Ulyatt et al., 2002; Beauchemin et al., 2008). Methane production per unit cellulose digested has been shown to be three times that of hemicellulose (Moe and Tyrrell, 1979), while cellulose and hemicellulose ferment at slower rates than do non-structural carbohydrates, thus yielding more CH_4 per unit substrate digested (McAllister et al., 1996). Consequently, the addition of grain to forage diet increases starch and reduces fibre intake, reducing the rumen pH and favouring the production of propionate rather than acetate in the rumen (McAllister and Newbold, 2008). Improving forage quality also tends to increase the voluntary intake and reduces the retention time in the rumen, promoting energetically more efficient post-ruminal digestion and reducing the proportion of dietary energy converted to CH_4 (Blaxter and Clapperton, 1965). Methane emissions are also commonly lower with higher proportions of forage legumes in the diet, partly because of the lower fibre content, the faster rate of passage, and in some cases, the presence of condensed tannins (CTs) (Beauchemin et al., 2008).

Improving diet quality can both improve animal performance and reduce CH_4 production, but it can also improve efficiency by reducing CH_4 emissions per unit of animal product. Therefore, plant breeding can potentially improve digestibility as well as reduce CH_4. However, many of these strategies can also lead to increased DM intake per animal, and may also provide the farmer with an opportunity to increase the stocking rate, resulting in either no net change or even a net increase in CH_4 production. Similarly, the addition of more grain to the diet will incur additional N_2O and transport emissions during the grain production processes. Therefore, further research and modelling is required to understand the likely relationships between improvements in diet quality and voluntary intake, stocking rates, and net CH_4 production for a range of production systems.

Table 1
Typical ranges of CH_4 emissions from three classes of ruminant, energy lost as CH_4, with an estimate of effective annual grazing days lost.

Animal Class	Average live weight (kg)	CH_4 (kg/hd/year) [a]	MJ CH_4 lost /hd/day [b]	Average daily energy requirement (MJ/hd/day) [c]	Effective annual grazing days lost [d]
Mature ewe	48	10–13	1.5–2.0	13	43–55
Beef steer	470	50–90	7.6–13.6	83	33–60
Dairy cow [e]	550	91–146	13.6–22.1	203	25–40

[a] Data drawn from studies reviewed here.
[b] Assuming an energy density of 55.22 MJ/kg CH_4 (Brouwer, 1965).
[c] (Standing Committee on Agriculture, 1990).
[d] Effective annual grazing days lost = ([c]daily requirement/[b]energy lost) × 365.25.
[e] In lactation.