Reducing animal greenhouse gas emissions

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Global demand for food is expected to increase by 70% by 2050 (FAO, 2009) as a result of population growth. To meet this demand, the worldwide production of meat and milk is projected to have to more than double. This strong growth in meat production will be driven not only by increasing population numbers but also by a rising demand for animal produce as more sectors of the population become increasingly affluent.

Unfortunately, animal production and, in particular, ruminant production, carries with it a significant environmental cost - both at the local level and globally. While local environmental impact is mainly associated with intensive operations that contaminate the air, land or water with nitrogenous and phosphorus compounds, the global effect is predominantly due to the contribution of both intensive and extensive systems to the emissions of greenhouse gases (GHG).

The role of livestock systems in sustainable agriculture

Livestock sustain the livelihoods of millions of people across the world, both in developing and developed economies. Globally, livestock production typically represents around 40% of the global income (GDP) earned by agriculture, and employs around 1.3 billion people in a variety of directly and indirectly related jobs (Steinfeld et al., 2006). Up to 12% of the world's population is highly dependent on domestic animals for its sustenance; in particular the rural poor for whom livestock are a multifunctional asset central to their livelihoods, not only for food but sometimes also for warmth and social status (Randolph et al., 2007; Thornton et al., 2007; FAO, 2009). An anticipated rise in world population of 30% and the subsequent increased demand for food (FAO, 2009) brings with it challenges in terms of global resource usage and food security (World Bank, 2008). Clearly, there is a need to develop sustainable systems that maximise human-edible food production.

Livestock production has rapidly responded to the growing demand, which particularly in developing countries is at least in part driven by economic growth and higher incomes. Global consumption of meat is expected to triple from 133 million tonnes (mt) per annum in 1980 to 452 mt in 2050. For milk, consumption is expected to more than double from 342 mt in 1980 to 880 mt per year by 2050 (Figure 1). Over the last 20 years, production increases have been largely achieved through increased livestock numbers rather than enhanced output per animal (yield). While major advances in productivity have occurred in some pig, poultry and dairy cattle systems, increased yields from beef and sheep have been far less frequent.

Grazing systems account for 26% of the Earth's ice-free land mass and typically use land that is unsuitable for cropping. Importantly, such areas include land cleared from rainforests, contributing to soil erosion and further deforestation. Industrial (intensive) systems account for approximately 75%, 40% and 65% of poultry meat, pig meat and egg production, respectively. Domesticated livestock convert forages, arable crops and associated by-products into desirable human foods of high nutritional value (especially in relation to high quality protein and micronutrients) and play a key role in food security. However many livestock diets include ingredients such as cereal grains which could be eaten directly by man. This has opened up a debate on the competition between livestock and humans for land, food and other resources. Globally livestock use some 33% of cereals produced. Although monogastric livestock are more efficient in terms of total food resource use than ruminants, when diets are based on forages and crop by-products, then ruminant systems can be net contributors to human-edible food. Gill et al. (2010) estimated that only between 6% and 26% of dietary energy was recovered in ruminant products. However, when calculated as human-edible efficiency (human-edible energy contained in the product divided by

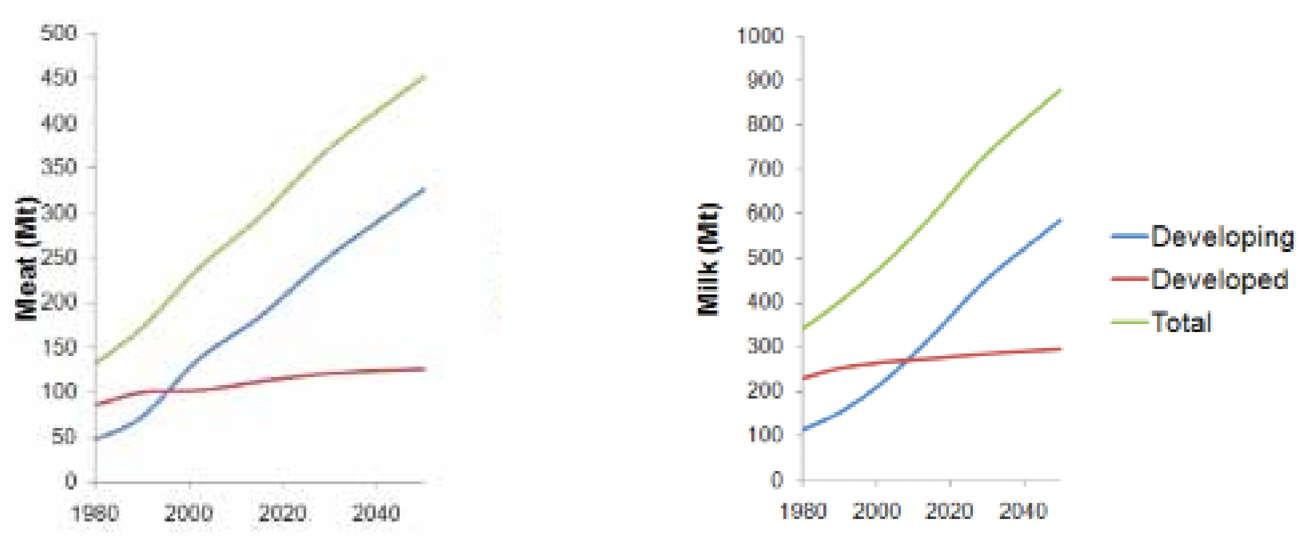

Figure 1. *Past and projected trends in consumption of meat and milk in developing and developed countries. Data for 1980-2015 from Steinfeld et al. (2006) and for 2030-2050 from FAO (2009).*

human-edible inputs), these values increased to between 65% and 374% recovery, dependent on the production system, and reflect the ability of ruminants to exploit fibrous feedstuffs not readily utilised by monogastrics, including man (Table 1). Gill et al. (2010) therefore conclude that, when used to transform fibrous feedstuffs produced on land not suitable for primary cropping or by-products of the food industry, ruminants can certainly be net contributors to the global supply of human-edible food.

Table 1. *Comparative efficiencies of different livestock production systems in the USA (adapted from Gill et al., 2010).*

	Energy Total efficiency[1]	Human-edible efficiency[2]	Protein Total efficiency[1]	Human-edible efficiency[2]
Milk	0.25	1.07	0.21	2.08
Beef	0.07	0.65	0.08	1.19
Pigs	0.21	0.3	0.19	0.29
Poultry meat	0.19	0.28	0.31	0.62

[1] Total efficiency calculated as outputs of human-edible energy and protein divided by total energy and protein inputs

[2] Human-edible efficiency calculated as outputs of human-edible energy and protein divided by human-edible inputs.

The livestock industry and climate change

It has been estimated that global anthropogenic greenhouse gas (GHG) emissions from the livestock sector approximate to between 4.1 and 7.1 billion tonnes of CO_2 equivalents per year, equating to 15-24% of total global anthropogenic GHG emissions (Steinfeld et al., 2006). The term 'CO_2 equivalent' represents the total impact of a particular GHG in the atmosphere on heat retention, and the Global Warming Potential (GWP) for a particular GHG is the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO_2. While the GWP of CO_2 is 1, the GWP for methane (CH_4) and nitrous oxide (N_2O) are x 23 and x 296 the GWP of CO_2 when expressed over a 100 year time frame (IPCC, 2001). With livestock estimated to produce 9, 35-40 and 65% of the total anthropogenic emissions of CO_2, CH_4 and N_2O respectively, effects on global warming can clearly be significant. While some more recent studies have suggested that these estimates are conservative, others propose that these percentages are too high (Goodland and Ahang, 2009; Pitesky et al., 2009). Part of this variation is associated with disputed methods of calculation; more specifically in where to draw a boundary around what constitutes a legitimately direct livestock sector emission as opposed to an emission that may be only indirectly due to animals.

Most of the emissions of both CH_4 and N_2O from livestock systems arise on the farm - CH_4 primarily from rumen fermentation and N_2O mostly from animal manures. As an example, in a New Zealand export lamb system, it was calculated that while 80% of the GHG footprint arose on-farm, only 3% was from meat processing, 5% from transportation and 12% from consumers (Ledgard et al., 2010). The other major contributory factor to GHG production from livestock systems relates to land use changes. The relative balance of emissions from CH_4 and N_2O largely depends on the production system being studied. With ruminant systems, emissions are dominated by CH_4 from rumen fermentation, while with pigs, N_2O emissions from manures are the most significant. However, as ruminant systems become more intensive, the balance of environmental impact also shifts from methane towards N_2O.

Direct comparison of emissions from different livestock systems is difficult due to the wide variety of production systems used. However, Williams et al. (2006) estimated the GHG emissions (in terms of CO_2 equivalents) of food products to the farm gate based on typical UK production systems (Figure 2). Clearly, higher emissions are associated with meat from ruminant livestock (cattle and sheep) as opposed to monogastrics (pigs and poultry) which do not emit large quantities of methane. Strikingly, however, milk from the dairy sector compares favourably with pig and poultry meat in terms of CO_2 equivalents. It would seem evident, therefore, that if the ruminant livestock sector is to continue to flourish and grow, new technologies must be developed and implemented that allow it do so while simultaneously decreasing emissions.

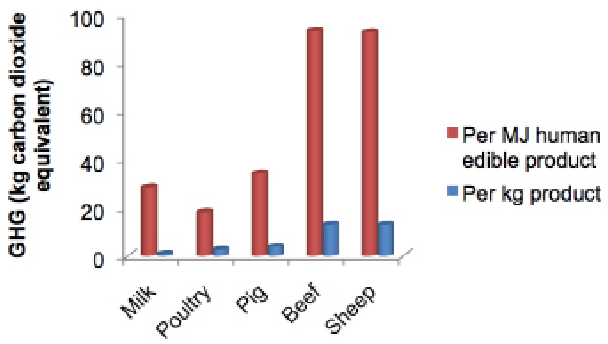

Figure 2. *Greenhouse gas (GHG) emissions per unit of livestock product (kg) or per MJ of human-edible products (adapted from Williams et al., 2006).*

Mitigation of greenhouse gas emissions

Three main approaches to mitigating GHG emissions from ruminant animal production can be envisaged:

i) Improvements in efficiency through application of best practise in 'on-farm' management, the application of animal genetics and improved feed quality.
ii) Biotechnological solutions based on the introduction of new or modified microorganisms to the animal, immunological and hormonal control of gut function, or the use of GM crops and/or animals.
iii) Dietary change including novel forages and dietary additives that manipulate rumen function.

Approaches i) and ii) are outside the scope of this article. Improvements in efficiency through application of best practice represent on-farm approaches that will be driven by improved advice to farmers. Such approaches have been reviewed by Gill et al. (2010) amongst others (Figure 3) and are being driven forward within IBERS through the creation of the Canolfan Hinsawdd Cymru (Wales Climate Centre), a joint initiative with Bangor University to help Welsh farmers adapt to and mitigate the effects of climate change (www.climate-wales.org.uk). Approaches associated with option ii) are likely to be applicable only over an extended timescale. In this paper, therefore, we will focus on dietary changes, including the introduction of both novel forages and dietary additives, each of which represents a significant opportunity for the ruminant livestock industry to decrease its level of emissions.

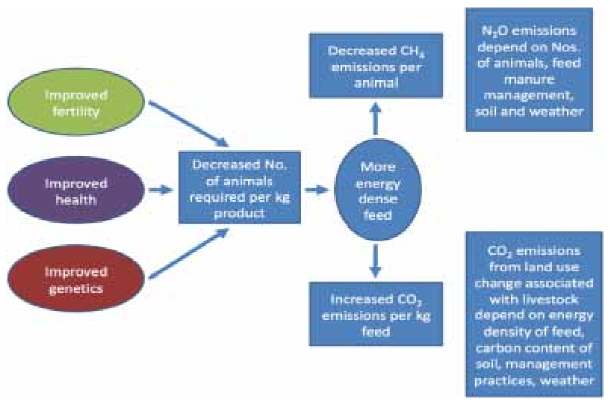

Figure 3. *Avenues to improve productivity and reduce GHG emissions from livestock (adapted from Gill et al., 2010).*

Improved feed formulation

Methane production in the rumen is driven by the content of the food supply (substrate). Fermentations with higher propionate concentrations in the rumen have been widely associated with lower levels of final methane emissions (Moss, 1993). A variety of nutritional management strategies to bring about such reductions in enteric methane (CH_4) production have been suggested. Approaches based on increasing the level of grain in the diet and/ or the inclusion of lipids have been the most promising in terms of reducing emissions per unit of intake (Beauchemin et al., 2008). However, such approaches may raise emissions elsewhere in the supply chain and are not compatible with all production systems. Improved pasture management and, in particular, replacing grass silage with maize silage and introducing certain legumes, holds some promise for CH_4 mitigation and its use continues to be investigated (Bannink et al., 2010).

In relation to N_2O emissions, avoiding excess nitrogen (N) in the diet, correctly balancing protein with energy requirements, and/or making dietary N more available for digestion, allows the concentration of N in the diet to be reduced without adversely affecting animal performance. By reducing the amount of N excreted, either directly to grazed fields or via manure application, these methods can minimise additions to the pools of N already existing in the soil that are the sources of emissions (Niderkorn and Baumont, 2009).

Chemical additives

A wide range of chemicals has been used to decrease methane production in the rumen: classically chloroform can abolish rumen methane production for a short period until the rumen adapts to its presence (McAllister and Newbold, 2008). Halogenated analogues of methane are also potent inhibitors of CH_4 formation in ruminants, although methanogen species differ in their sensitivity to these analogues (Ungerfeld et al., 2004). Bromoethanesulfonic acid (BES) is particularly effective (Dong et al.,1999), with research showing that methane emissions can be reduced from 3.9% to 0.6% of gross energy intake in feedlot steers (Tomkins & Hunter, 2003). The ionophoric antibiotic monensin has also been shown to cause small decreases in methane emissions (Odongo et al., 2007), presumably by shifting the overall pattern of ruminal fermentation since the compound alone is not toxic to rumen methanogens (Russell and Strobel, 1989). However, these effects appear to be somewhat transient and disappear after a few weeks of treatment (Guan et al., 2006). Ionophores also improve N metabolism in the rumen by reducing the degradation of protein and inhibiting the breakdown of amino acids (Russell et al., 1988).

At this point, it seems unlikely that halogenated analogues will gain widespread acceptance as a mitigation strategy because of regulatory restrictions and a movement away from using chemically-synthesised additives in livestock diets. Similarly, antibiotics such as monensin are currently not allowed in animal feeds within the EU and, as noted, may have somewhat variable effects.

Probiotics and live micro-organisms

By comparison, yeast cultures based on *Saccharomyces cerevisiae* are widely used in ruminant diets. The feeding of such probiotic products is widely associated with increases in livestock production, enhanced ruminal capture of ammonia into microbial protein, improving dietary N usage and reducing emissions (Chaucheyras-Durand et al., 2008). The use of yeast and other live microorganisms to specifically decrease methane emissions has been suggested (Newbold and Rode, 2006); however, to date, the overall effects appear to be rather small and inconsistent (Beauchemin et al., 2008). More experimental approaches based on the addition of acetogens (Lopez et al., 1996), methane-oxidising organisms (Valdés et al., 1996), bacteriocins and bacteriophages (McAllister and Newbold, 2008) have been postulated but, while potentially promising, are some years away from commercial exploitation.

Plant extracts

We have recently reviewed the use of plant extracts to manipulate rumen fermentation both in terms of decreasing CH_4 emissions and improving the efficiency of N utilisation (Hart et al., 2008). Over the last 6 years, research has been published on the effects of more than 25 different plant extracts on *in vitro* rumen microbial fermentation and methane production (Cardozo et al., 2004, 2005; Busquet et al., 2005a, 2006). Bodas et al. (2008) screened 450 plant extracts for their ability to inhibit methane production in *in vitro* incubations of rumen fluid and found that 35 plants extracts decreased methane production by more than 15% *vs* those with corresponding control cultures and that, with six of these plant additives, the depression in methane production was more than 25%, with no adverse effects on digestion or fermentation.

Amongst the various plant extracts that have been investigated for their effect on methane production in the rumen, experience with garlic-based compounds perhaps helps to illustrate both the state of the art and the current constraints that require further research input. Garlic oil is a mix of a large number of different molecules that are found in the plant or occur as the result of changes during oil extraction and processing. Although garlic oil is known for a wide variety of therapeutic properties (antiparasitic, insecticidal, anticancer, antioxidant, inumunodomulatory, anti-inflammatory, hypoglycaemic), and its antimicrobial activity against a wide spectrum of gram-positive and gram-negative bacteria is often seen as its most prominent activity and has been thoroughly studied (Reuter et al., 1996), its potential effect on modifying rumen microbial fermentation has not been researched until recently. *In vitro* rumen fluid fermentation trials by Busquet et al. (2005b, 2006) showed that garlic oil altered rumen fermentation and decreased methane production. We have shown that a commercially available aqueous allicin extract from garlic had no effect on general rumen fermentation but caused a 94% decrease in methane production, and that this was accompanied by a reduction in the number of methane producing Archaea in the rumen assessed by qPCR (Figure 4).

However, with many additives, the anti-methanogenic activity is short-term as the rumen adapts to overcome the new chemical introduced (McAllister and Newbold, 2008). The same is true for some plant extracts, where effects on fermentation seem to disappear when tested for longer periods of time (Cardozo et al., 2004; Molero et al., 2004; Castillejos et al., 2007). The long-term effect of products based on garlic is not yet known, although relatively short-term animal trials (5-6 weeks) have recorded consistent decreases in methane emissions over this period, and an increase in ruminal propionate, suggesting that the rumen can adapt to find an alternative hydrogen sink. Nevertheless, the lack of long-term trials is a major deficiency in the literature concerning the use of plant extracts to decrease methane emissions. Similarly, reports of taint in the milk of animals eating wild garlic and onions exist from the 1930s (Babcock, 1938). Whilst it is possible that commercial extracts produced from garlic may not taint milk and meat, the possibility of taint is a very real concern and, unless tested and addressed, will remain a likely barrier to the uptake of any technology based on compounds isolated from garlic or other plant extracts.

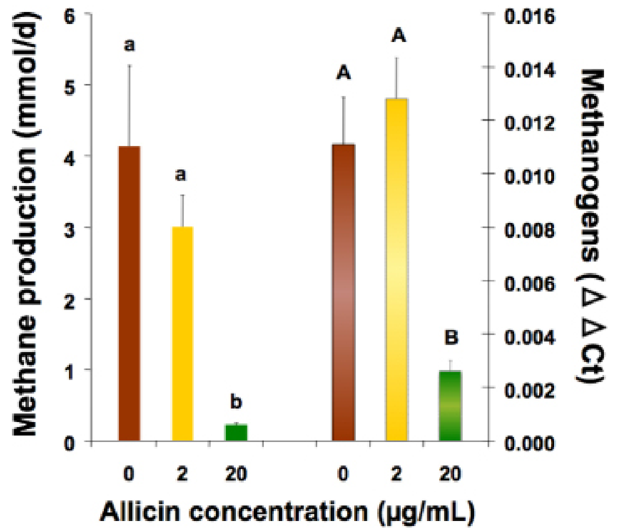

Figure 4. *The effect of Allicin on methane production and methanogen numbers in the rumen simulating fermentor Rusitec (adapted from Hart et al., 2008). a,b or A,B: Means differ at P < 0.05.*

Novel forages and feeds

It is possible that, rather than using plant extracts as direct additives, a longer-term solution might be to ensure that the relevant bio-active compounds are expressed in the animal's normal diet - grass. Whilst such approaches are perhaps unlikely to be available in the short-term, significant progress has been made in the development of perennial ryegrasses with increased water-soluble carbohydrate (WSC) content. Feeding such forages significantly increases the capture of N into microbial protein in the rumen (Moorby et al., 2006) and, as such, might be expected to decrease nitric oxide emissions from the animal's excreta. There is also evidence that using clovers and grasses with high WSC in animal diets can directly reduce methane emissions (Lovett et al, 2004), with recent unpublished observations from our own group suggesting that this might be due to enhanced capture of metabolic hydrogen into microbial protein, thus diverting substrate away from the methanogenic Archaea in the rumen. Experiments are ongoing to investigate the effect of novel forages on emissions over the whole grazing season (**Figure 5**).

Figure 5. *Measuring GHG emissions from sheep grazing different pastures using polytunnels.*

Conclusion

It has been suggested that ruminant livestock production and consumption make a large contribution to the greenhouse gas (GHG) emissions which can be attributable to food production. Given the association between GHG and climate change, this is clearly of great concern to the livestock industry worldwide. However, ruminant livestock also play an important role in global food security as they can convert the ligno-cellulosic and non-protein nitrogen compounds, found widely in plants but indigestible to all monogastric animals including man, into high value proteins for human consumption. Future ruminant production systems will need to capitalise on this important benefit. It is therefore proposed that ruminant agriculture has a key role to play in maintaining and enhancing provision of quality proteins and essential micronutrients in man's diet - provided that the challenge of reducing GHG emissions, and methane in particular, can be successfully addressed.

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