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Invited paper:

Reducing the environmental impact of animal production

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Abstract. Global food demand will increase in the next 30 years to meet the needs of the increasing population. Demand for animal products (meat, milk and eggs) is likely to increase at a faster rate than demand for cereals. There is pressure to reduce environmental impacts of livestock systems, particularly greenhouse gas emissions (GHG) and excretion of nitrogen and phosphorus. The main driver of environmental impact in animal systems is production efficiency, i.e. output of milk, meat, eggs or pollutants per unit of input. Production efficiency is related to performance per animal, reproductive rate and replacement rate. Higher production efficiency means that fewer animals are needed per unit of product, so that 'unproductive' emissions and excretions associated with maintenance and the rearing phase are spread over more units of product. Nutrition can reduce emissions and excretions per animal. Methane emissions by ruminants are related to the quantity of forage digested, so increasing dietary proportions of concentrates, and increasing starch or fat content at the expense of fibre, will reduce methane per unit of product. Genetic selection for low methane emissions should only be considered alongside feed efficiency. Nitrogen and phosphorus excretions are related to dietary nitrogen and phosphorus contents, particularly with excess supplies. Precise diet formulation, using rumen degradable and undegradable protein requirements in ruminants, and digestible amino acid requirements in non-ruminants, can reduce nitrogen excretion. Reducing phosphorus content of diets, and phytase enzymes in non-ruminant diets, can reduce phosphorus excretion. In conclusion, the main strategy for reducing the environmental footprint of livestock systems must be to reduce wastage of breeding animals through premature culling for fertility and diseases. This will also improve profitability. Therefore, a whole-system approach is needed which considers environmental cost of diet formulation as well as economic cost.

Key words: Environmental impact, Livestock systems, Methane, Nitrogen excretion, Non-ruminants, Nutrition, Phosphorus excretion, Ruminants

Reducir el impacto ambiental de la producción animal

Resumen. La demanda mundial de alimentos aumentará en los próximos 30 años para satisfacer las necesidades de la creciente población. Es probable que la demanda de productos de origen animal (carne, leche y huevos) aumente a un ritmo más rápido que la demanda de cereales. Hay presión para reducir los impactos ambientales de los sistemas pecuarios, en particular las emisiones de gases de efecto invernadero (GEI) y la excreción de nitrógeno y fósforo. El principal impulsor del impacto ambiental en los sistemas animales es la eficiencia de la producción, es decir, la producción de leche, carne, huevos o contaminantes por unidad de insumo. La eficiencia de producción está relacionada con el rendimiento por animal, la tasa de reproducción y la tasa de reemplazo. Una mayor eficiencia de producción significa que se necesitan

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menos animales por unidad de producto, de modo que las emisiones y excreciones "improductivas" asociadas con el mantenimiento y la fase de crianza se distribuyen en más unidades de producto. La nutrición puede reducir las emisiones y las excreciones por animal. Las emisiones de metano de los rumiantes están relacionadas con la cantidad de forraje digerido, por lo que aumentar las proporciones de la dieta de los concentrados y aumentar el contenido de almidón o grasa a expensas de la fibra, reducirá el metano por unidad de producto. La selección genética para bajas emisiones de metano solo debe considerarse junto con la eficiencia de la alimentación. Las excreciones de nitrógeno y fósforo están relacionadas con el contenido de nitrógeno y fósforo en la dieta, particularmente con exceso de suministros. La formulación precisa de la dieta, el uso de requisitos proteicos degradables e indestructibles del rumen en los rumiantes y los requisitos de aminoácidos digestibles en los no rumiantes, puede reducir la excreción de nitrógeno. La reducción del contenido de fósforo en las dietas y las enzimas fitasas en las dietas no rumiantes pueden reducir la excreción de fósforo. En conclusión, la principal estrategia para reducir la huella ambiental de los sistemas pecuarios debe ser reducir el desperdicio de animales reproductores mediante el sacrificio prematuro de fertilidad y enfermedades. Esto también mejorará la rentabilidad. Por lo tanto, se necesita un enfoque de todo el sistema que considere el costo ambiental de la formulación de la dieta, así como el costo económico.

Palabras clave: Excreción de fósforo, Excreción de nitrógeno, Impacto medioambiental, No rumiantes, metano, Nutrición, Rumiantes, Sistemas de ganado

Introduction

World human population is predicted to increase to over nine billion by 2050, with most population growth occurring in developing countries. Consequently, Global food demand in the next 30 years is projected to increase by over 60% compared to 2006 (FAO). As developing countries achieve higher incomes, demand for animal products is expected to increase at a faster rate than demand for cereals. With policy drives to reduce environmental impacts of livestock systems, increasing attention is being paid to greenhouse gas emissions (GHG) and excretion of nitrogen (N) and phosphorus (P).

Livestock production is estimated to contribute 14.5% of human-induced GHG emissions, with beef cattle contributing 41%, dairy cattle 20%, pigs 9%, poultry 8% and small ruminants 7% of GHG emissions from livestock (Gerber *et al.,* 2013). Global excretion of N is estimated to be approximately 140 Mt/yr, with cattle contributing 69%, small ruminants 14%, poultry 9%, and pigs 8% of N excretion by livestock (Table 1). Global excretion of P is estimated to be approximately 66 Mt/yr, with cattle contributing 48%, small ruminants 17%, pigs 18%, and poultry 17% of P excretion by livestock (Table 1).

Livestock consume approximately 6 billion tonnes of feed dry matter annually, including one third of global cereal production. The majority (86%) of livestock feed, however, comprises materials that are currently not eaten by humans. Ruminant diets contain more than 57% grass and

Table 1. Global livestock numbers and estimated excretions of nitrogen and phosphate[1]

	Billion head 2017	Nitrogen kg/head/yr	MT/yr	Total %	Phosphorus kg/head/yr	MT/yr	Total %
Cattle and buffaloes	1.67	58.0	96.9	68.6	19.0	31.7	48.3
Sheep and goats	2.18	9.2	20.1	14.2	5.0	10.9	16.6
Pigs	0.98	12.0	11.8	8.4	12.0	11.8	17.9
Poultry	24.80	0.5	12.4	8.8	0.5	11.3	17.2
Global Excretion			141.1			65.7	

[1]Data sources: FAOSTAT; IPCC; Barnett (1994); Author's own estimates.

forages, whereas non-ruminants (pigs and poultry) consume 72% of the grain fed to livestock (FAO GLEAM). Thus, although ruminant livestock have a greater environmental impact than non-ruminants, they have greater potential to utilise land that cannot grow crops for direct human consumption. In terms of human-edible feed conversion efficiency (heFCE), beef and lamb (21-43% heFCE) are comparable with pigs and poultry (26-43% heFCE), although milk production (237% heFCE) is by far the most efficient animal production system (Wilkinson, 2011).

Production Efficiency – Dairy

Whether the environmental impact of animal systems is calculated as total impact or impact per unit of product, the main driver of impact is production efficiency. Production efficiency is the opposite of impact efficiency, and is the overall output of milk, meat, eggs or pollutants per unit of input. Efficiency in both cases is directly related to animal numbers (including producing, breeding and replacement animals), which are in turn related to performance per animal, reproductive rate and replacement rate. Figure 1 shows the relationships between milk yield, cow numbers and efficiency in dairy systems.

Higher-yielding cows produce more milk per lactation and fertile cows survive for a greater number of lactations. This means that "unproductive" emissions and excretions associated with maintenance and the rearing phase are spread over more units of milk across the lifetime (Table 2).

There has been a trend in most countries of the world over the past 30 years for increased milk yield per cow. Approximately 50% of this is due to genetics and 50% to improved feeding and management (Pryce *et al.,* 2004). As milk yield per cow increases, number of cows required for a defined level of output decreases, so methane emissions decrease because there are fewer methane emissions associated with maintenance. The expected reduction in methane emissions is actually greater when adjusted for diet because high yielding cows are usually fed on diets with lower proportions of forage (Figure 2; Garnsworthy, 2004a).

There is a challenge to reduction in emissions by increasing milk yield. As genetic merit for milk yield increases, there is usually an accompanying decline in fertility (Royal *et al.,* 2000). The result is that replacement rate may increase, so there are increased numbers of non-productive youngstock and each cow has a lower lifetime performance. Consequently, methane emissions will decline to a lesser extent unless fertility is addressed. Garnsworthy (2004a) modelled the effect of fertility at current levels of fertility, replacement heifers on methane and ammonia emissions by dairy herds;

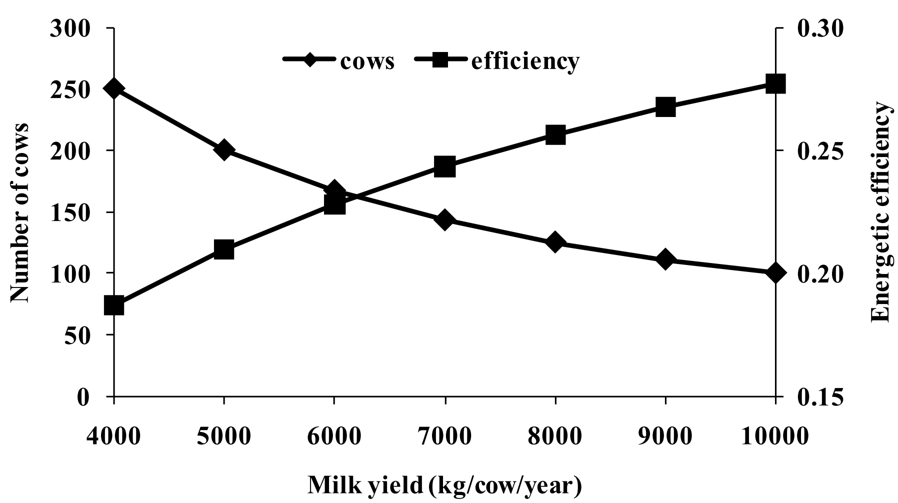

Figure 1. Influence of annual milk yield per cow on number of cows required to produce one million litres of milk and overall energetic efficiency (Net energy output over gross energy intake)

Table 2. Lifetime milk yield, methane emissions and nitrogen excretion of cows surviving for three or four lactations[1]

	Lactations		
	3	4	3 vs 4
Milk yield (t)	22.7	28.9	+27%
Methane (GJ)	39.1	44.2	+13%
Methane (MJ/L)	1.72	1.53	-13%
Nitrogen (kg)	341	435	+28%
Nitrogen (kg/L)	15.02	15.05	+0.2%

[1]Data for 'average' UK cows from Garnsworthy (2004a)

contributed 27 % of methane emissions and 15 % of nitrogen emissions in a high-yielding herd, but these could be reduced to 15 % and 8 % if fertility was restored to ideal levels.

Production Efficiency – Pigs and Poultry

Production efficiency also influences environmental impact of intensive meat and egg production systems. This is illustrated for breeding and growing pigs in Figure 3. Growth rate or egg yield, feed efficiency, mortality and reproductive performance all influence overall product output per unit input and per unit of emissions. In egg production, for example, average yield is predicted to reach 360 eggs/bird per year before 2030, which will reduce nitrogen excretion by 24% compared with current production levels (Garnsworthy, 2004b). Growth rate of pigs is predicted to be 28% faster in 2050, which will reduce the number of days to slaughter by 22% and will reduce overall nitrogen excretion by 14% (Garnsworthy, 2004b). Optimising amino acid balance for growing pigs, particularly with the inclusion of synthetic amino acids, can reduce nitrogen excretion by up to 40% (Verstegen and Tamminga, 2002). As in the dairy herd, replacement rate in the pig breeding herd has been increasing due to reproductive failure, particularly of animals in parities 1 and 2 (Hughes

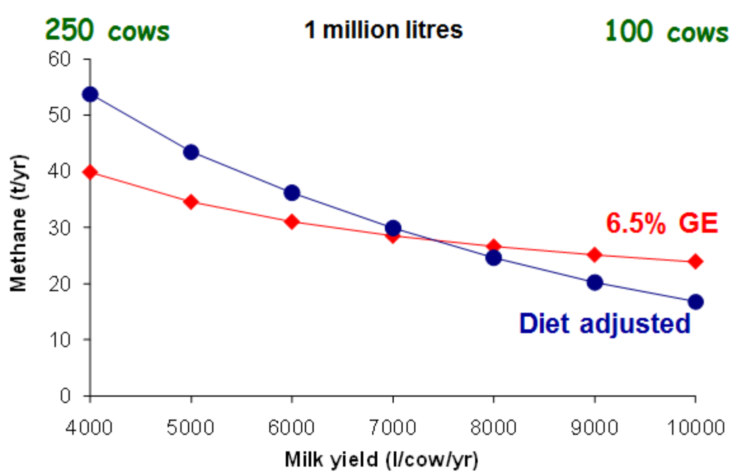

Figure 2. Influence of annual milk yield per cow on number of cows required to produce one million litres of milk and methane emissions calculated using a fixed factor or adjusted for diet composition (Garnsworthy, 2004a)

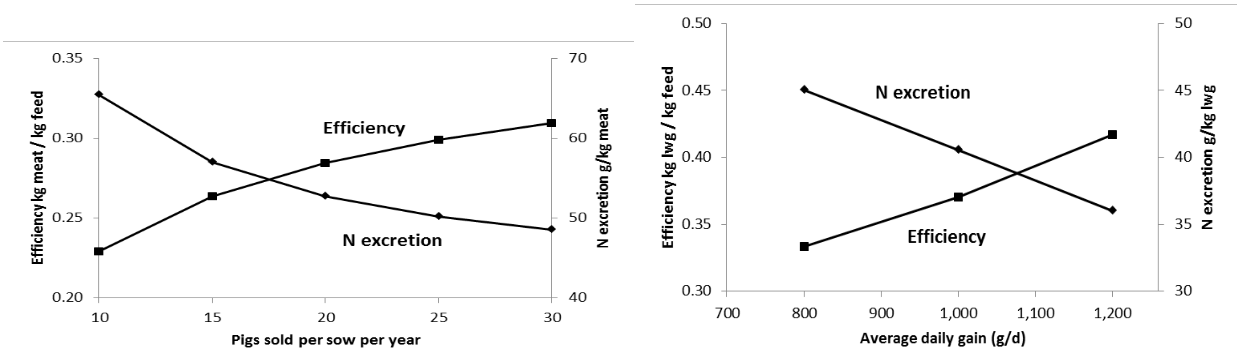

Figure 3. Influence of output in breeding pigs (top) and growth rate in fattening pigs (botom) on production efficiency and nitrogen excretion

and Varley, 2003). The annual replacement rate in the UK pig herd increased from 36% in 1980 to 43% in 2003, requiring an increase of 17% in the number of gilts reared per year, which is equivalent to an extra 360 tonnes of nitrogen excreted per year.

Nutritional Mitigation

In addition to reducing the number of animals used to meet milk or meat supply requirements by ruminants, there are opportunities to reduce methane emissions and nitrogen excretions per animal. Methane is produced by archaea during rumen fermentation of carbohydrates, particularly cellulose. Methane production is an essential metabolic function to maintain rumen pH and fermentation of forages. However, there is scope for altering fermentation by changing the proportion of concentrates in the diet and increasing dietary starch or fat content at the expense of fibre content. The net effect is a reduction in rumen hydrogen production and, therefore, reduced conversion to methane. Researchers have been striving since the 1960s to find a reliable methane inhibitor. With the possible exception of ionophores, which are banned in Europe, promising results *in vitro* have not been translated into practical mitigation strategies (Beauchemin *et al.,* 2008). The rumen microbial ecosystem is extremely adaptable and short-term perturbations are overcome within a few days or weeks. Often effective methane inhibitors have detrimental effects on overall microbial efficiency and forage digestibility. The major strategy remains, therefore, to increase production efficiency and to reduce reliance on grass and forages. Possible strategies for the future include genetic selection for feed efficiency and genetic selection for individual methane production. Even cows fed on the same diet and producing the same quantity of milk show considerable variation in methane emissions. It is important, however, to link selection for low methane emissions with selection for feed efficiency. Otherwise, the low emitters selected will be the ones that do not digest forage efficiently.

Nitrogen excretion per unit product can also be reduced by increasing production efficiency. Excretion per animal is directly related to dietary nitrogen content and excess nitrogen is increasingly excreted in urine, which has greater pollution potential than organic nitrogen found in faeces. The scope for reducing nitrogen content of diets, without compromising milk production, is greater in higher-yielding cows. Even so, the most efficient cows still excrete approximately 70% of nitrogen consumed. The major challenge is to minimise excretion of the volatile (urine) form and to reduce losses during housing and spreading of manure.

Ruminants can survive on very low phosphorus diets because of an extremely efficient recycling system via the saliva (Ferris, 2010). Rumen microbes can utilise organic phosphorus found in plant cells walls, as well as inorganic phosphorus provide via mineral supplements. Excess phosphorus is excreted in faeces, with little being excreted in urine. Nutritionists are reluctant to reduce dietary phosphorus content because of perceived implications for health and production. However, after production efficiency, this would be the best strategy for reducing phosphorus pollution by ruminants. Non-ruminants lack the phytase enzyme required to release phosphorus from phytic acid bound in plant cell walls. An effective strategy for reducing phosphorus excretion by non-ruminants is to add phytase to diets so that organic phosphorus becomes available to the animal and total dietary phosphorus content can be reduced.

Conclusions

In conclusion, the main strategy for reducing the environmental footprint of livestock systems must be to reduce wastage of breeding animals through premature culling for fertility and diseases. Coupled with this is increased production efficiency through use of animals with higher genetic merit for milk yield, growth rate or egg production. Both of these approaches will reduce the proportions of energy and protein used for 'unproductive' functions, such as maintenance and rearing, and should also improve profitability. Care must be taken to avoid increased use of cereal-based concentrates, however, which compete as human food and lead to greater emissions of nitrous oxide. In fact, every mitigation strategy involves a trade-off of some sort. Therefore, a whole-system approach is needed which considers the environmental cost of diet formulation as well as the economic cost.

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