The Environmental Impact of Fertility in Dairy Cows

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Take Home Messages

- The main driver for environmental impact of dairy cows is lifetime production efficiency, which is milk output per unit of feed input.
- Each cow has 'unproductive' impacts associated with its rearing and maintenance, so higher-yielding cows have lower impact per litre of milk because fewer cows are required.
- Poor fertility reduces both annual and lifetime milk yield per cow, and also increases the number of replacements needed, thus increasing impact.
- Strategies to improve fertility include maintaining body condition score between 2.5 and 3.0 to minimize negative energy balance; increasing dietary starch in early lactation to stimulate insulin and ovulation; and increasing dietary fat around mating to improve conception rate. These strategies are commensurate with lower methane emissions per cow.

Environmental Impact of Dairying

There can be no doubt that dairy systems have a significant impact on the environment. With policy drives to reduce impacts, increasing attention is being paid to greenhouse gas emissions and excretion of nitrogen and phosphorus. Estimates vary, but most authorities agree that dairy systems contribute between 20 and 30% of emissions and excretions in the UK and worldwide.

The cow is extremely efficient at converting food which is unsuitable for human consumption (principally grass and other forages) into a high quality food product (milk). Wilkinson (2010) estimated that human-edible feed conversion is approximately 200% for dairying. In terms of nutrient efficiency, the cow is not so efficient – only 20 to 30% of nutrients consumed are converted into product; the remaining 70 to 80% are released to the environment.

Whether the impact of dairy systems is calculated as total impact or impact per litre of milk produced, the main driver of impact is production efficiency. Production efficiency is analogous to impact efficiency and is the output of milk or pollutants per unit of input. Efficiency in both cases is directly related to animal numbers (both lactating cows and replacement heifers), which are in turn related to milk yield per cow and replacement rate, i.e. lifetime output per cow. Higher-yielding cows produce more milk per lactation. This means that 'unproductive' emissions and excretions associated with maintenance requirements and the rearing phase are spread over more units of milk (Figure 1).

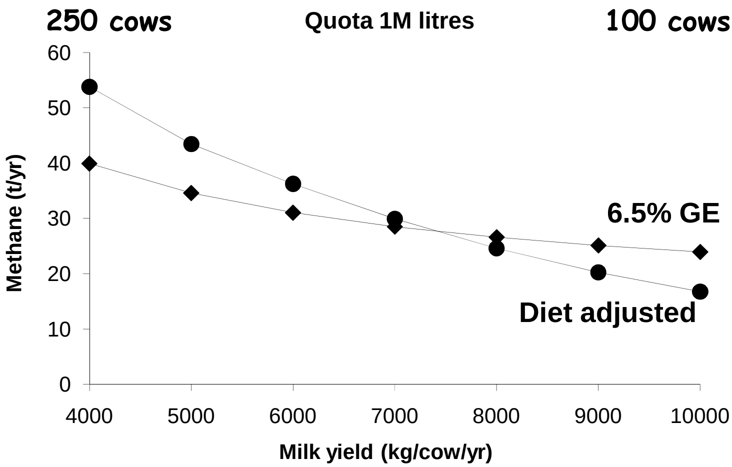

Figure 1. Effect of milk yield per cow on methane per million tonnes of milk.

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). Since the introduction of milk quotas in 1984, cow numbers in the UK, as in most countries of Europe, have decreased while total milk supply has remained relatively constant. Projecting the rate of change in cow numbers to 2050 suggests that methane emissions from UK dairying will reduce by 31% of 1990 values (Garnsworthy, 2004a).

The dairy sector in Canada has reduced its GHG emissions by 1% per year since 1990 through a reduction in number of cows whilst maintaining total milk output, thus improving production efficiency (www.dairyfarmers.ca).

Historical Changes in Fertility

There is a major obstacle to achievement of continued reduction in emissions. As milk yield has increased over the past 30 years, there has been an accompanying decline in fertility (Royal, 2000). As discussed at this conference last year (LeBlanc, 2010), however, this negative association does not prove cause and effect. There are many high-yielding herds with good fertility and many low-yielding herds with poor fertility. Furthermore, changes in cow management, herd size, housing, labour, oestrous detection and feeding systems can account for some of the decline in reproductive efficiency. Nevertheless, in the UK replacement rate increased from 25% to 33% over the past 20 years and national statistics suggest that replacement rate also increased in Canada between 1990 and the present day (Fig 2).

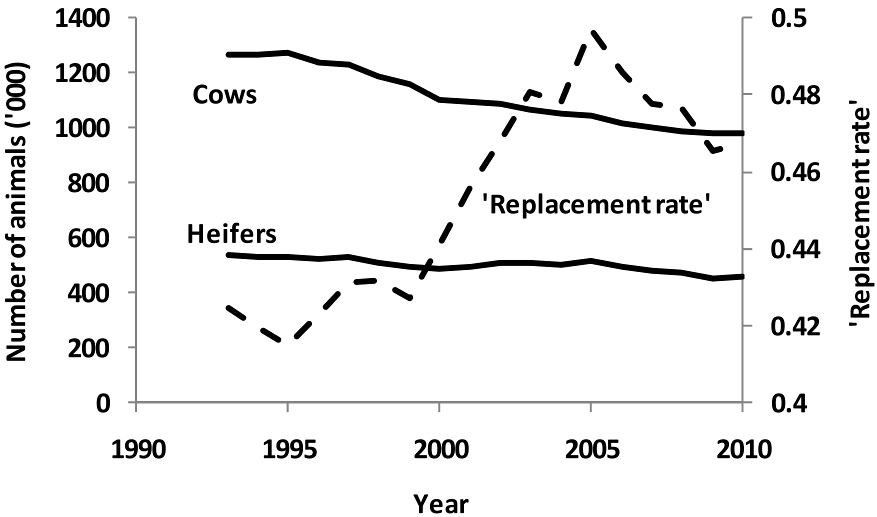

Figure 2. Changes in numbers of dairy cows and heifers, and apparent replacement rate, in Canada 1993-2010 (Source: Canadian Dairy Information Centre, www.dairyinfo.gc.ca)

Modelling Fertility and Methane Emissions

To quantify the impact of fertility on methane emissions, a model was developed to predict the effects of changes in fertility on herd structure, number of replacements, milk yield, nutrient requirements and methane emissions (Garnsworthy, 2004b). The model was then used to investigate the impact of changing fertility parameters on total methane emissions at the herd level.

Variable oestrous detection rates (OD), and conception rates (CR) to first and subsequent services were used to calculate the distribution of cows by stage of lactation within a herd. Cows were culled if they did not conceive after eight oestrous cycles. Herd structure was determined by assuming that the number of heifers entering the herd each year was equal to the total number of cows culled. For simplicity, it was assumed that cows calved all year round and that heifers entered the herd at two years of age. The effects of oestrous detection rate and conception rate on methane emissions were examined for herds with annual milk yields of either 6,000 l/cow (UK average) or 9,000 l/cow (UK high-yielding), with a milk quota of one million litres per annum.

As expected, the model predicted that fertility has a major effect on the number of heifer replacements required to maintain herd size, with replacement rates ranging from 17% to 45% for the fertility levels examined (Fig 3).

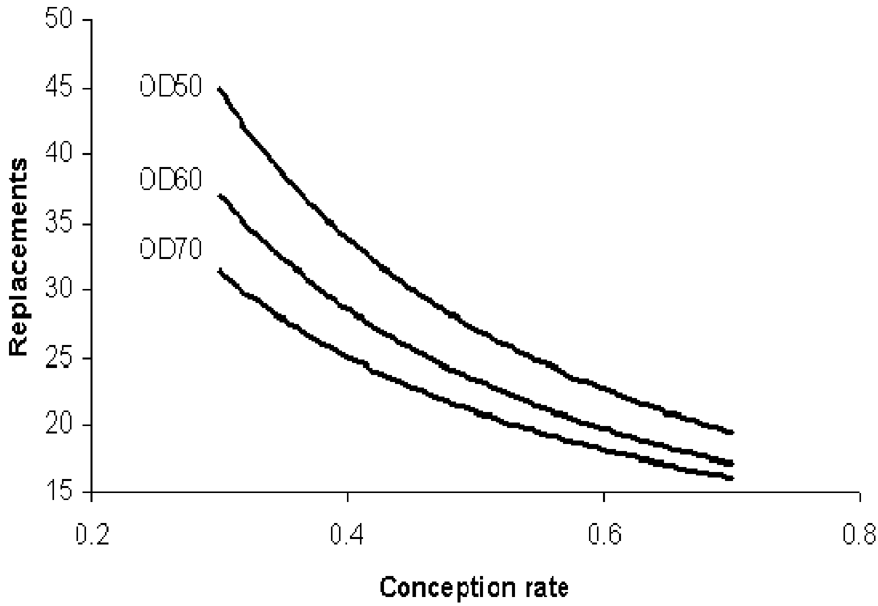

Figure 3. Number of replacements per 100 cows per annum in dairy herds with varying conception rate and oestrous detection (OD) rates of 50, 60 or 70%.

Replacement rate and milk yield influence total methane emissions by herds (Figure 4). The proportion of total methane emissions that is produced by replacements can be reduced from 30% at poor fertility levels (OD 50%: CR 30%) to 10% under ideal conditions (OD 70%: CR 60%).

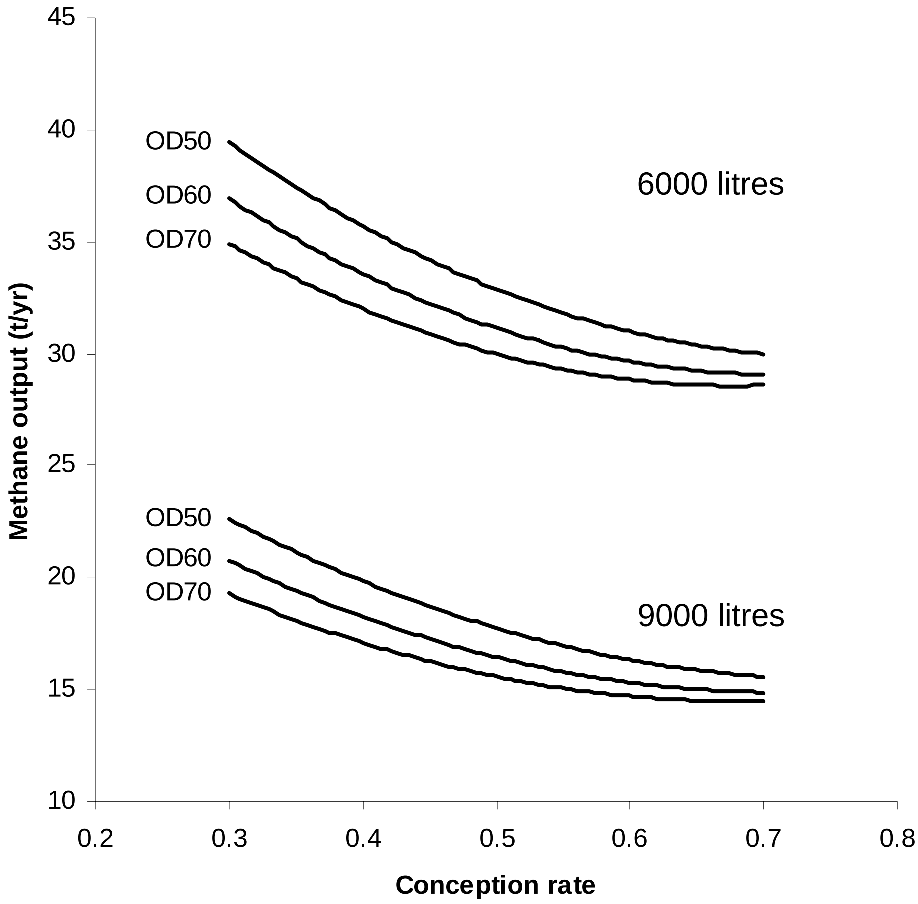

Figure 4. Annual methane output in dairy herds with varying conception rate and oestrous detection (OD) rates of 50, 60 or 70%, with a milk quota of 1 million litres/annum and average annual milk yield of 6000 or 9000 litres/cow.

At current fertility levels (OD 50%: CR 38 %, Royal et al., 2000), total herd emissions were 37 t methane/yr for a herd yielding 6000 litres and 19 t methane/yr for a herd yielding 9000 litres. Methane emissions could be reduced by 10% if fertility is restored to 1995 levels (OD 55%: CR 47%, Kossaibati and Esslemont, 1995) and by 24% if fertility is improved to ideal levels (OD 70%: CR 60%).

Lower emissions from the herd yielding 9000 litres result from a combination of fewer cows to meet quota and lower forage to concentrate ratio in the diet. Within yield levels, improvements in fertility will increase average milk yield per annum due to a reduced tail to the lactation curve and a shorter dry period

(Esslemont and Peeler, 1993), so the proportion of milk produced in early lactation increases. During late lactation and the dry period, cows are fed on diets containing relatively high proportions of forage. Therefore, improved fertility decreases the proportion of forage in the total annual diet, which will reduce methane emissions.

▪ Fertility and Lifetime Performance

Approximately 50% of cows culled in the UK are perfectly healthy, they just fail to get pregnant and start another lactation. On average cows survive for three lactations (33% replacement rate), compared with four lactations (25% replacement rate) 30 years ago. Given a calf sex ratio of 50:50, and losses during heifer rearing and breeding, a dairy cow will only just replace herself in three lactations. At the current rate of decline in fertility, Maas et al. (2009) estimated that the UK dairy herd would be unsustainable due to a shortage of heifer replacements within 10 years.

Lifetime milk and methane outputs for cows with average or good fertility are compared in Table 1. Although milk yield per lactation is lower for cows with a CI of 365 days, milk yield per year is greater. Lifetime milk yield and methane emissions are greater for cows surviving for four lactations, but methane per litre of milk produced is considerably lower.

Table 1. Lifetime milk and methane outputs from cows with good fertility (calving interval (CI) 365 days for 4 lactations) or average fertility (CI 415 days for 3 lactations)

			Parity				
		heifer	1	2	3	4	Sum
365 d CI	Milk (l)	0	6060	7163	7845	7845	28913
305 DIM	CH_4 (MJ)	9837	8811	8920	8986	7639	44192
	MJ/l		1.45	1.25	1.15	0.97	
	MJ/l life		3.08	2.08	1.75	1.53	
415 d CI	Milk (l)	0	6533	7717	8487		22737
345 DIM	CH_4 (MJ)	9837	10105	10223	8951		39116
	MJ/l		1.55	1.32	1.05		
	MJ/l life		3.05	2.12	1.72		

How To Improve Fertility

Having identified the fertility issue in the late 1990s, we embarked on a five-year program to study nutritional effects on fertility in dairy cows. The main priorities identified are to minimize negative energy balance in early lactation and to maintain adequate plasma insulin concentrations at strategic phases of the reproductive cycle. The main driver of negative energy balance is body condition score (BCS) at calving because cows calving above BCS 3.0 will have reduced appetite and mobilize in excess of 1 BCS unit, with detrimental effects on fertility (Garnsworthy, 2006). Our early work demonstrated that diet-induced increases in postpartum insulin status could increase the proportion of cows ovulating during the first 50 days of lactation (Gong et al., 2002). Subsequent studies, however, showed that high insulin can have detrimental effects on oocyte quality, which would decrease pregnancy rate. In a concept experiment, we fed cows on an insulin-stimulating diet (high starch, low fat) immediately postpartum and then changed to an insulin-reducing diet (high fat, low starch) after cows started to cycle. Compared with continuous feeding of either diet or the reverse strategy (low – high insulin), there was a significant improvement in the proportion of cows pregnant at 120 days of lactation from 27% to 60% (Garnsworthy et al., 2009). Further work is needed to confirm this finding and translate it into commercial recommendations, but recent support has come from a New Zealand grazing study (Burke et al., 2010).

Reducing Methane Emissions Per Cow

In addition to reducing the number of animals used to meet milk supply requirements, there are some opportunities to reduce emissions and excretions per cow. Methane is produced by bacteria-like archaea during rumen fermentation of cellulose. This 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 by 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. Fortunately, our nutritional strategies to improve fertility involve raising dietary starch and fat concentrations, so there is no conflict with methane mitigation at the cow level.

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. The rumen microbial ecosystem is extremely adaptable and short-term perturbations are overcome within a few days or weeks. Often methane inhibitors have detrimental effects on overall microbial efficiency.

The major strategy remains, therefore, to increase production efficiency and reduce reliance on grass and grass silage. Possible strategies for the future include genetic selection for feed efficiency (measured as residual feed intake) and genetic selection for individual methane production. We have recently conducted a study that shows variation among cows in the frequency of eructation and concentration of methane in breath, even in cows fed on the same diet and producing the same quantity of milk.

▪ Nitrogen Excretion

Nitrogen excretion per unit of milk production can also be reduced by increasing production efficiency through better fertility. Excretion per cow 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 feces. 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 minimize excretion of the volatile (urine) form and to reduce losses during housing and spreading of manure.

▪ Conclusions

The main effect of fertility on environmental impact of dairy systems is through the number of replacements required. Changes in calving interval, average annual milk yield and diet composition have additional effects. Improved fertility is not only financially beneficial to dairy farmers, but also has benefits for the environment. Modest improvements in fertility could reduce emissions from dairy herds by 10%. Potential reductions in emissions are as high as 25%.

In conclusion, the main strategy for reducing the environmental impact of dairy systems must be to reduce wastage of cows through premature culling for fertility and diseases. Coupled with this is increased production efficiency through use of cows with higher genetic merit for milk yield. Both of these approaches lead to less reliance on grass as a major feed source, so they should have concomitant reductions in methane emissions. Greater use of cereal-based concentrates could, however, 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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