Feed Efficiency and Sustainability of the Cattle Industry[1]

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Introduction

Key Points

- Production and reproduction efficiencies are strongly related to environmental impacts of the dairy or beef cattle operation. Optimization of efficiencies is the most important tool in environmental impact mitigation.
- In US dairy herds, the current national average age at first calving is 25.2 months. Increasing first-lactation milk yield could improve milk's life-cycle production efficiency and decrease emissions.
- The productive life of dairy Holsteins in the United States born in 2000 decreased by 3.95 months compared with Holstein cows born in 1980. This negative trend needs to be halted to achieve environmental and economic gains.

Production efficiency in the dairy and beef industry can be defined as minimizing the amount of inputs (e.g., feed, fossil fuels) and undesirable outputs (e.g., ammonia, NH_3; greenhouse gases, **GHG**) to produce a given quantity of milk or meat. The present paper will focus on the dairy example. Production efficiency improvements can come from minimizing waste, maximizing a dairy cow's milk production, and maximizing the proportion of her life spent in peak milk production without sacrificing animal health and well-being. To a degree, when milk production per cow is improved, the life-cycle emissions of dairy production decrease per unit of milk (i.e., per kg of 3.5% fat-corrected milk (**FCM**); VandeHaar and St-Pierre; 2006). This is achieved through a dilution of maintenance costs per kilogram of FCM at the level of both the individual cow and the entire US dairy production system. Cows that produce more milk reduce the proportion of total consumed feedstuffs going toward maintenance energy costs (Moe and Tyrell, 1975; Bauman et al., 1985; VandeHaar, 1998). Secondly, more milk per cow can decrease the total lactating herd size needed to produce a given quantity of milk (Capper et al., 2008, 2009). Past improvements demonstrate the ability of production efficiency to decrease the environmental impact per unit of milk. Capper et al. (2009) found that historical advances in genetics, nutrition, and management of dairy farms allowed dairy production in 2007 to emit 43% of the CH_4 and 56% of the N_2O that were emitted in 1944 to produce one billion kilograms of milk. As the following sections

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demonstrate, more opportunities for improving a dairy's production efficiency exist that could lead to further reductions in emissions per kilogram of FCM.

Heifer Management

Replacement heifers are an important part of the life-cycle emissions of a kilogram of FCM. Before calving, heifers are consuming inputs and producing both GHG and air pollutants without contributing to the production of milk. In the milk-fed stage of a heifer's life, she can efficiently convert consumed energy and protein into lean body tissue without depending on emission-producing rumen microbes. Recent research has found that increasing and altering the nutrients supplied to milk-fed calves can improve growth rates and feed efficiency (Brown et al., 2005; Bascom et al., 2007; Hill et al., 2008). "Intensified" feeding programs for dairy heifers have been shown to lower age at first calving (Raeth-Knight et al. 2009), with no reduction (Van Amburgh et al., 1998) or even an improvement in first-lactation milk yield (Drackley et al., 2007). Both decreasing the current national average age at first calving of 25.2 months (USDA, 2007) and increasing first-lactation milk yield could improve milk's life-cycle production efficiency and decrease emissions per kilogram of FCM.

Colostrum administration is another aspect of heifer management that can affect GHG and air quality emissions per kilogram of FCM. Dairy calves depend on passive immunization from the absorption of antibodies in colostrum to provide adequate immunity during their early life stages (Robison et al., 1988). Failure of passive transfer of immunity leads to increased mortality and morbidity and decreased growth performance (Robison et al., 1988; Beam et al., 2009). Administering the proper quantity of high quality colostrum within the first few hours of life has been shown to improve long-term animal health and first-lactation performance (DeNise et al., 1989; Faber et al., 2005). Beam et al. (2009) estimated that failure of passive transfer occurs in 19.2% of US dairy heifer calves; therefore, decreasing this incidence could substantially decrease death and performance losses and lessen emissions per kilogram of FCM.

Herd Health

Herd-health challenges affect per-unit of-milk emissions by increasing mortality and losses of saleable milk and decreasing reproductive performance and milk production efficiency. Herd health is influenced by many factors, including management, nutrition, the environment, and social stressors. Over the past 25 yr, the dairy industry has steadily shifted its structure toward fewer farms with larger herds and fewer workers per cow. In 2008, 3,350 US dairy farms with 500 or more cows (approximately 5% of total dairy operations) produced 58.5% of the nation's milk with 54.9% of the nation's dairy cows (NASS, 2009). Along with the industry's consolidation, milk production per cow has doubled over the past 25 yr, although it appears that disease incidence has remained stable (LeBlanc et al., 2006). However, the productive life of Holsteins in the United States born in 2000 decreased by 3.95 months compared with Holstein cows born in 1980 (Dechow and Goodling, 2008). Thus, opportunities exist for the dairy industry to advance production efficiency by improving herd health to simultaneously enhance milk production, reproductive performance, and cow longevity. When dairy cattle transition from a pregnant, non-lactating state to a lactating state, they face a tremendous change in their metabolic requirements (e.g., Ca requirements are estimated to increase 4-fold on the day of parturition; Overton and Waldron, 2004). Consequently, most health concerns arise during the transition period. Approximately 75% of disease occurs within the first month after calving (LeBlanc et al., 2006), and a study of Pennsylvania dairy herds found that 26.2% of dairy culls occur from 21 d before to 60 d after calving (Dechow and Goodling, 2008). Recent research has linked disease incidence and excessive negative energy balances during the transition period with significant decreases in milk yield and reproductive success during the subsequent lactation (Drackley, 1999). Further research into the biology and management of transition cows and the extension of this critical knowledge to commercial herds can enhance the life-cycle efficiency of the US dairy production system. Environmental or social stressors can decrease the production efficiency of the cow and subsequently increase the emissions of each kilogram of milk that she produces. Heat stress has been estimated to cost the dairy industry nearly $1 billion per year in decreased milk production, reproductive performance, and increased death losses (St-Pierre et al., 2003). With regard to social stress, grouping animals according to size and age and minimizing overcrowding can improve DMI, consequentially improving milk production (Grant and Albright, 2001). Improving cow cooling during hot summer months and grouping animals to minimize behavioral stress has been the focus of research to improve farm profitability, but these improvements have the potential to decrease emissions per kilogram of FCM as well.

Mastitis is a herd-health challenge that can affect emissions per kilogram of FCM by decreasing milk production performance and increasing losses of saleable milk. Hospido and Sonesson (2005) analyzed the environmental impact of mastitis using a Life Cycle Analysis (**LCA**) of dairy herds in Galicia, Spain. The authors found that decreasing the clinical mastitis rate from 25 to 18% and the subclinical mastitis rate from 33 to 15% reduced the Global Warming Potential (**GWP**) of a unit of milk by 2.5% (Hospido and Sonesson, 2005) because of increased input-use efficiency, decreased losses of milk production, and a decreased amount of waste milk.

Lameness is a critical herd-health concern that seems to have worsened over the past 25 yr (LeBlanc et al., 2006). Lameness or injury is responsible for approximately 20% of mortalities and 16% of selective culls in mature US dairy cows (USDA, 2007). In addition to decreased survivability, lameness causes decreased milk production (Warnick et al., 2001) and poorer reproductive performance in affected cows (Garbarino et al., 2004). Improved facilities, management, nutrition, and genetics all have the potential to decrease the incidence of lameness (Baird et al., 2009) and decrease emissions per kilogram of FCM.

Nutrition and Feed Production

The nutrition of dairy cattle greatly determines the emissions produced directly by the ruminant animal and its waste. Diet composition can alter rumen fermentation to reduce the amount of CH_4 produced (Ellis et al., 2008) and, as previously discussed, the NH_3 emissions produced from the manure (James et al., 1999; VandeHaar and St-Pierre, 2006). The substrates used by methanogens are byproducts of structural carbohydrate fermentation; thus, high concentrate diets containing more nonstructural carbohydrates can lead to decreased CH_4 emissions (Lana et al., 1998; Ellis et al., 2008). However, diets very high in concentrate (such as those fed to the majority of US beef feedlot cattle) can decrease rumen pH and lead to rumen acidosis (Owens et al., 1998). Furthermore, very high-concentrate diets diminish the principal environmental benefit of dairy cows: their ability to convert cellulose, indigestible to humans and the Earth's most abundant organic molecule, into high-quality proteins for human consumption (Oltjen and Beckett, 1996). Therefore, the CH_4 produced by dairy cattle cannot simply be seen as a gross energy loss and GHG source but is a necessary consequence of transforming inedible fibrous forages and byproducts (e.g., almond hulls, citrus pulp, distillers grains) into food and fiber products fit for human use. Nonetheless, substantial reductions in CH_4 emissions can be achieved without feeding high levels of concentrates by altering the previously mentioned nutritional factors: microbial-altering feed additives, dietary lipids, and forage processing and quality (Johnson and Johnson, 1995). Feed additives, such as the ionophore monensin, can change microbial processes in the rumen to potentially improve feed efficiency and reduce CH_4 emissions (Tedeschi et al., 2003). However, research with monensin has shown conflicting results (Guan et al., 2006; Odongo et al., 2007; Hamilton et al, 2009; Hook et al., 2009), which suggests a need for more in-depth research on its effect on rumen microbial populations and the metabolism of dairy cows. Alternatives to ionophores such as probiotics (e.g., yeast), essential oils, and biologically active plant compounds (e.g., condensed tannins) have shown promise for CH_4 reductions; however, most research to date has been conducted in vitro and more in vivo studies are needed to evaluate the effect of these alternatives on CH_4 and their commercial viability (Calsamiglia et al., 2007; Beauchemin et al., 2009b). Dietary lipids, specifically unsaturated fatty acids, have the potential to act as an alternate H sink in the rumen, thereby reducing the H available to methanogens and the CH_4 produced (Ellis et al., 2008). Additionally, CH_4 reductions from feeding dietary lipids can be attributed to their suppression of fiber-digesting bacteria and toxicity to protozoa closely associated with methanogens (Hristov et al., 2009). Johnson et al. (2002) tested the ability of canola and whole cottonseed to reduce CH_4 and found no difference in emissions when compared with a control diet, whereas other researchers have found crushed canola seed to have a CH_4-suppressing effect (Beauchemin et al., 2009a). The inconsistency of the effect of dietary lipids on CH_4 is due, in part, to the variation in diets, the fatty acid profile, amount and form of the lipid source, and the length of the feeding trial, because the rumen ecosystem may adapt to lipid supplementation (Martin et al., 2008; Beauchemin et al., 2009a). Although lipids do have the potential to reduce CH_4 emissions, consideration must be given to their adverse side effects of reducing DMI or decreasing milk fat when fed at levels over a critical threshold (Giger-Reverdin et al., 2003; Martin et al., 2008). Furthermore, the source and availability of lipids must be considered, because price will dictate their commercial adoption, and long-distance transport of lipid sources may defeat their emission-reducing potential by increasing fossil fuel combustion.

Forage quality and management can affect both air quality and GHG emissions per kilogram of FCM. Fermented feeds are a major source of Volatile Organic Compounds (**VOC**) (Alanis et al., 2008) and require substantial fossil fuel inputs during their production (de Boer, 2003; Schils et al., 2007); therefore, minimizing dry matter loss throughout the production, storage, and feeding of these feedstuffs will decrease the air quality and climate change impact of each kilogram of feed. Higher quality forages, produced by ideal crop production, harvesting, and preservation practices, maximize DMI and milk production (Oba and Allen, 1999). Additionally, forages with higher digestibility and higher rates of passage out of the rumen have the potential to reduce enteric CH_4 emissions for each unit of feed consumed (Johnson and Johnson, 1995).

So-called precision feeding that closely matches the nutrients needed by the dairy cow for maintenance, growth, lactation, and gestation to the supplied dietary nutrients can minimize the environmental impact of the cow's excreta (Tylutki et al., 2008). Precision feeding requires nutritional models with sufficient accuracy and a level of management that can reduce the feeding system's variation (Wang et al., 2000). By constantly monitoring the dry matter and nutrient composition of feedstuffs, dairy producers can avoid expensive overfeeding and minimize nutrient excretion that can lead to emissions. The potential reduction in NH_3 emissions by more tightly managing the crude protein content of the diet to match the animal's needs is substantial because most of the N fed over requirements is excreted as urinary urea-N. Castillo et al. (2001) found that cows with intakes of 419 g of N/d had similar milk production as cows consuming 516 g of N/d; however, 74% of the extra 94 g of N/d was excreted as urinary urea-N, which could be lost to the environment as NH_3 emissions. Moreover, a precision feeding strategy decreases the amount of refusals, which may become waste on a dairy or be fed to other production groups (e.g., lactating cow refusals fed to heifers) that have dissimilar nutrient needs, thereby increasing the likelihood for higher nutrient excretion (St-Pierre and Thraen, 1999). Additionally, closely monitoring and ensuring the correct nutrition of individual groups of animals can minimize the risk of other nutritionally influenced diseases and conditions, such as ketosis, lameness, and prolonged anestrous (Lucy, 2001; Roche, 2006). Overall, managing feed and feeding programs to minimize waste while maximizing milk production can improve farm profitability and decrease the life-cycle emissions per kilogram of FCM.

Reproduction

Perhaps not as apparent as nutrition, reproductive performance greatly affects emissions per kilogram of FCM. Dairy cows that have extended calving intervals because of conception failure spend more time out of peak milk when feed conversion into milk is most efficient. The total productive lifetime of many dairy cows is determined by reproductive performance, because reproductive problems are responsible for 26.3%

of the selective culls in the United States (USDA, 2007). Over the past 30 yr, the reproductive performance and productive lifetime of dairy cattle have substantially decreased while milk production has increased (Lucy, 2001; Dechow and Goodling, 2008). The negative effect per kilogram of FCM emissions caused by declining reproductive efficiency has likely been offset by increases in milk production per cow. However, restoring reproductive performance in combination with increased milk yield would further reduce emissions per kilogram of FCM. Garnsworthy (2004) modeled the environmental impact of reproductive performance and milk production in the United Kingdom. The model found that both higher milk yield and improved reproductive performance (better estrus detection and conception rates) contributed to reduced CH_4 and NH_3 emissions because of the smaller lactating and replacement herd population required to meet UK production quotas (Garnsworthy, 2004). The cause of the decline in reproductive efficiency of dairy cattle is multifaceted and is not completely understood currently (Ingvartsen et al., 2003), because reproductive success is influenced by nutrition, genetics, health disorders during transition, management, and the environment (Lucy, 2001). The level of reproductive success across all US herds is variable by region, breed, and management (Norman et al., 2009), suggesting that improvements are achievable. Encouragingly, recent data show that the long-term trend of decreasing reproductive performance and survivability may be slowing or reversing (Hare et al., 2006; Norman et al., 2009). Extensive research in dairy cattle reproduction is needed to identify the factors impeding fertility and to further develop strategies to improve reproduction on commercial herds. Wide adoption of these successful reproductive strategies could potentially lengthen the productive life of the US dairy cow and lower emissions per kilogram of FCM.

Sexed semen is a reproductive technology that has the potential to both help and hurt the impact of the dairy industry on air quality and climate change per kilogram of FCM. If used selectively, sexed semen can increase the rate of genetic gain in dairy cattle, allowing advantageous traits to become ubiquitous in the entire dairy cattle population (De Vries et al., 2008). Furthermore, on average, heifer calves are smaller than bull calves and cause fewer dystocias, which may allow for earlier breeding of heifers, and fewer mortalities and health problems (Weigel, 2004). However, if all animals are bred with sexed semen (or even all heifers), the replacement population for the US dairy herd will increase in size. To keep the total population of dairy cattle at a level that does not create an oversupply of milk, the lactating cow cull rate must increase. Again, this can be advantageous, because poor performing animals and those with poor genetic merit would likely be culled, but in the context of environmental impact per kilogram of FCM, the widespread use of sexed semen could increase emissions per kilogram of FCM by shortening the total productive lifetime of dairy cows. Furthermore, a larger replacement herd size means more nonproductive emissions for each kilogram of FCM produced.

Overall, this paper shows that some of the most important gains that can be achieved in mitigation of dairy environmental impacts are tightly connected to efficiencies around feeds and feeding as well as reproductive management.

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SESSION NOTES