RELATIONSHIP BETWEEN SELECTION FOR FEED EFFICIENCY AND METHANE PRODUCTION

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Where Does Methane Come From?

Enteric methane is a product of fermentation in the gastro-intestinal tract of ruminants. A group of archaea bacteria collectively called “methanogens” are responsible for the synthesis of methane. Methanogens live in environments that are void of oxygen and are frequently involved with the fermentation of organic material. In addition to being found in the gastro-intestinal tract of animals, they are found in other sites where fermentation occurs such as bogs, marshes (marsh gas), landfills, waste water containment ponds, and feedlot surfaces. Methanogens typically use acetate or carbon dioxide and hydrogen as substrate to grow and produce methane as a by-product. In ruminants, the majority of the methanogen species use carbon dioxide and hydrogen. In ruminants, the methanogens grow in the reticulum-rumen complex and in the cecum. Most of the methane that a ruminant produces is in the reticulum-rumen (87%), and is released into the environment through the mouth (Murray et al., 1976). Most of the methane produced in the cecum (89%) is absorbed in the blood and travels to the lungs where it is exhaled during respiration (Murray et al., 1976). About 3% of the methane is released from the rectum (Murray et al., 1976; Muñoz et al., 2012). Methanogens live in a symbiotic relationship with the other bacteria in the rumen; however, they make up a relative small proportion of the total rumen microbes (Krause and Russell, 1996; Mosoni et al., 2011). Methanogens help maintain a zero net hydrogen balance in the rumen by releasing hydrogen in the form of methane rather than other microbes producing longer chained volatile fatty acids such as propionate.

The Problem

Methane is a greenhouse gas. Depending on the size and level of feed intake, cattle will produce 10 to 16 kg of methane per year (Hristov et al., 2013).

Methane represents a lost opportunity to capture feed energy. If captured, this lost energy could potentially be used for maintenance, growth, and lactation. There is a lot of variation in the fraction of intake energy released as methane (Johnson and Johnson, 1995). This variation can partially be explained by the composition of the diet. About 3% of intake energy consumed by steers fed a high-corn diet is lost as methane energy (Archibeque et al., 2007). The percentage increases when cattle are eating a high-forage diet. Increasing the forage:concentrate ratio increased methane production (Reynolds et al., 1991; Sauvant and Giger-Reverdin, 2007). Methanogens are sensitive to low rumen pH and their prevalence decreases (Van Kessel and Russell, 1996). Pregnant beef cows eating a corn silage based diet will release 5 to 7% of their gross energy intake as methane (Freetly et al., 2008). A number of strategies have been used to reduce methane production including chemical inhibitor, ionophores, and manipulation of the rumen ecology. A potential approach for reducing methane production is to select for increased feed efficiency.

Methane and Feed Efficiency

The relationship between methane production and feed efficiency is dependent on how feed efficiency is defined. Selecting cattle for greater residual gain or greater gain:feed ratios may result in an increase in methane production. Residual gain is the difference in amount of body weight gain an animal achieves compared to what it is predicted to gain for a given feed intake. Cattle that more completely digest their feed will get more nutrients per unit of feed and produce more methane. In our studies in cattle not selected for feed efficiency, methane production increased with increased gain:feed ratios when they were fed a roughage diet, but there were no differences when they were fed a concentrate diet (Freetly and Brown-Brandl, 2013). The different response in the two experiments may have been due to the relative digestibility of the two diets. The concentrate diet was highly digestible and the variance in the rate of digestibility may have been lower than compared to cattle consuming the less digestible roughage diet. Goopy et al. (2014) found that methane production increased with increased rumen retention times. They also determined that sheep that produced more methane had greater rumen volume.

Residual feed intake (RFI) is the difference in amount of feed consumed by an animal from that predicted for its rate of body weight gain and size. Negative RFI are more efficient since they ate less feed than is predicted to be needed for a given rate of production. Residual feed intake has been used as a measure of feed efficiency and has been used in selection programs to improve feed efficiency. Selection on RFI decreases feed intake (Herd et al., 2002). Methane production increases with increased feed intake; however, the methane per unit of feed decreases (Blaxter and Clapperton, 1965). Hegarty et al. (2007) reported that cattle selected for low RFI have a reduced daily methane production, and Nkrumah et al. (2006) found that steers that ranked low for RFI had a reduced methane production. Zhou et al. (2009) determined the relative proportion of different species of methanogens differ between cattle classified as having less or greater RFI which may influence the potential to produce methane. The studies of Nkrumah et al. (2006) and Hegarty et al. (2007) differ when methane productions are expressed per unit of feed fed. Hegarty et al. (2007) found that cattle selected for a low RFI also had a reduced total feed intake, but they did not differ in the amount of methane produced per unit of feed. In our studies, we found RFI did not account for differences in methane production when we adjusted for feed intake (Freetly and Brown-Brandl, 2013). Nkrumah et al. (2006) found that steers with a low RFI produced less methane per unit fed than other steers. Collectively, these studies suggest that selection for low RFI does not inherently mean that methane production per unit of feed is decreased, but methane production is reduced by decreasing the amount of feed consumed.

Other Factors to Consider

Factors other than feed efficiency contribute to the methane footprint of cattle. Hristov et al. (2013) has reviewed several management strategies used to reduce methane production. These include the feeding of inhibitors, electron receptors, ionophores, plant bioactive compounds, enzymes, yeast products, and oils. Other approaches have included decreasing the rumen protozoa and manipulating the rumen archaea and bacteria ecology. One of the biggest factors that determine the lifetime methane production of calves is the number of days from birth to harvest. If we assume a 160-day finish period and cattle consume 35 Mcal/day and 3% of the consumed energy is released as methane, then total methane release is 168 Mcal. Using the same assumptions on a 150-day finishing period, methane production is 158 Mcal. The 10-day decrease on feed results in a 6% drop in methane production. Similarly, backgrounding programs that prolong the age at harvest will increase lifetime methane production. Management and selection programs that decrease the age at harvest will reduce lifetime methane production.

The bulk of the annual methane production from cattle can be attributed to the cow herd. If we consider the measure of methane efficiency to be the amount of calf marketed per unit of methane produced in a cow's lifetime, then factors that make a cow economically efficient are the same that makes her efficient with regard to methane production. Selecting and managing cattle for prolonged lifetime productivity, and pounds of calf marketed per unit of feed consumed will improve methane efficiency.

Literature Cited

Archibeque, S. L., H. C. Freetly, N. A. Cole, and C. L. Ferrell. 2007. The influence of oscillating dietary protein concentrations on finishing cattle. II. Nutrient retention and ammonia emissions. *J. Anim. Sci.* 85:1496-1503.

Blaxter, K. L. and J. L. Clapperton. 1965. Prediction of the amount of methane produced by ruminants. *Br. J. Nutr.* 19:511-522.

Freetly, H. C., J. A. Nienaber, and T. Brown-Brandl. 2008. Partitioning of energy in pregnant beef cows during nutritionally induced body weight fluctuation. *J. Anim. Sci.* 86:370-377.

Freetly, H. C., and T. Brown-Brandl. 2013. Enteric methane production from beef cattle that vary in feed efficiency. *J. Anim. Sci.* 91:4826-4831.

Goopy, J. P., A. Donaldson, R. Hegarty, P. E. Vercoe, F. Haynes, M. Barnett, and V. Hutton Oddy. 2014. Low-methane yield sheep have smaller rumens and shorter rumen retention time. *Br. J. Nutr.* 111:578-585.

Hegarty, R. S., J. P. Goopy, R. M. Herd, and B. McCorkell. 2007. Cattle selected for lower residual feed intake have reduced daily methane production. *J. Anim. Sci.* 85:1479-1486.

Herd, R. M., P. F. Arthur, and R. S. Hegarty. 2002. Potential to reduce greenhouse gas emissions from beef production by selection to reduce residual feed intake. Communication 10–22 in Proc. 7th World Congr. Genet. Anim. Prod., Montpellier, France.

Hristov, A. N., J. Oh, J. L. Firkins, J. Dijkstra, E. Kebreab, G. Waghorn, H. P. S. Makkar, A. T. Adesogan, W. Yang, C. Lee, P. J. Gerber, B. Henderson, and J. M. Tricarico. 2013. Special topics--Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. *J. Anim. Sci.* 91:5045-5069.

Johnson, K. A., and D. E. Johnson. 1995. Methane emissions from cattle. *J. Anim. Sci.* 73:2483-2492.

Krause, D. O. and J. B. Russell. 1996. Symposium: Ruminal microbiology. How many ruminal bacteria are there? *J. Dairy Sci.* 79:1467-1475.

Mosoni, P., C. Martin, E. Forano, D. P. Morgavi. 2011. Long-term defaunation increases the abundance of cellulolytic ruminococci and methanogens but does not affect the bacterial and methanogen diversity in the rumen of sheep. *J. Anim. Sci.* 89:783-791.

Muñoz, C., T. Yan, D. A. Wills, S. Murray, and A.W. Gordon. 2012. Comparison of sulfur hexafluoride tracer and respiration chamber techniques for estimating methane emissions and correction for rectum methane output from dairy cows. *J. Dairy Sci.* 95:3139-3148.

Murray, R. A. A. M. Bryant , and R. A. Leng. 1976. Rates of production of methane in the rumen and large intestine of sheep. *Br. J. Nutr.* 36:1-14.

Nkrumah, J. D., E. K. Okine, G. W. Mathison, K. Schmid, C. Li, J. A. Basarab, M. A. Price, Z. Wang, and S. S. Moore. 2006. Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. *J. Anim. Sci.* 84:145-153.

Reynolds, C. K., H. F. Tyrrell, and P. J. Reynolds. 1991. Effects of dietary forage-to-concentrate ratio and intake on energy metabolism in growing beef heifers: Whole body energy and nitrogen balance and visceral heat production. *J. Nutr.* 121: 994-1003.

Sauvant, D., and S. Giger-Reverdin. 2007. Empirical modeling meta-analysis of digestive interactions and CH4 production in ruminants, pp. 561-563 in Energy and Protein Metabolism and Nutrition. I. Ortigues-Marty, N. Miraux, and W. Brand-Williams, ed., Wageningen, The Netherlands.

Van Kessel, J. A., and J. B. Russell. 1996. The effect of pH on ruminal methanogenesis. FEMS Microbiol. Ecol. 20:205-210.

Zhou, M., E. Hernandez-Sanabria, and L. L. Guan. 2009. Characterization of variation in rumen methanogenic communities under different dietary and host feed efficiency conditions, as determined by PCR-denaturing gradient gel electrophoresis analysis. *Appl. Environ. Micro.* 75:6524-6533.