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2. Decreasing environmental impacts from cattle through nutrition: what may be the best available techniques?

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Environmental impacts attributed to livestock have various origins; they can be due to animal physiology, through direct emission of pollutants, to upstream processes (feed production) or downstream processes (manure). Life cycle assessments from cradle to farm gate show that more than 50% of greenhouse gases (GHG) emissions, expressed in carbon dioxide (CO₂)-eq, are due to enteric methane (CH₄) in dairy and beef cattle systems (e.g. Nguyen et al., 2012). Although of lower extent for other environmental impacts, the role of animal physiology and nutrition is one of the key factors which control emission of pollutants.

Defining the best available techniques for mitigating environmental impacts is a major challenge. These techniques must have a proven effect, which often requires a change in practices (and not “business as usual” even if it has a mitigating effect) within the same production system, and should be implemented from now on. In addition, interactions between techniques and, in the case of GHG, between the different GHG (i.e. CH₄, nitrous oxide (N₂O), CO₂) for each of them, should not reduce the mitigating effect. This paper will be focused on GHG net emissions, taking into account carbon sequestration in soils, and on pollutants related to N losses by animals. Nutritional strategies and management changes, especially for grassland use, will be considered.

Mitigating enteric methane production

Methane is produced in the rumen by carbohydrate fermentation. Starch and cellulose are degraded by a consortium of microbes, mainly bacteria and protozoa, and produce hydrogen together with volatile fatty acids (VFA). Hydrogen is converted into CH₄ by archaea methanogens; most methane is eructated. Methane production is thus positively related to fermentable carbohydrate intake. Among VFA, acetate and butyrate production releases hydrogen whereas propionate production takes up hydrogen, so that concentrate diets, which increase propionate proportion in VFA, produce less CH₄ than forage diets. The replacement of carbohydrates by lipids allows reducing CH₄ because lipids are not hydrogen producers in the rumen. Different additives or biotechnologies have been tested for CH₄ mitigation; their mode of action may be one or several of the following: i) reducing hydrogen production; ii) reducing archaea methanogens; shifting VFA towards propionate; iv) utilizing hydrogen in other pathways than CH₄ production (Morgavi et al., 2011). In addition, when dry matter intake (DMI) increases, CH₄ produced per kg DMI decreases due to lower retention time of nutrients in the rumen. Methane expressed per kg of product, milk or meat, decreases when animal level of production (milk yield, liveweight gain) increases, because their level of intake is higher, and because the ratio between the percentage of feed used for production vs. maintenance increases.

Among numerous available techniques to mitigate CH₄ emissions, few can be considered to be implemented at large scale. The increase in genetic merit is a constant trend for many years, and has become “business as usual” technique. The genetic improvement of productive efficiency is a stimulating way of progress, but research is too recent to allow evaluating the global effects, on fertility, longevity of animals for example. The decrease in CH₄ with high-concentrate diets is partially compensated for by an increase in other GHG due to higher upstream inputs, and one can wonder whether increasing concentrates in ruminant feeding is ethically sound. The use of lipids is a promising solution and does not present the same drawbacks. Most additives and biotechnologies tested for methane mitigation have not been proven to have a consistent and long-term effect for reducing CH₄ (essential oils, most plant extracts, vaccine against methanogens, direct-fed

microbes); in some cases they are expensive (synthetic organic acids), or their use is banned or may be banned in many countries such as in EU (antibiotics, chloroform) (Doreau et al., 2011). Some compounds may be interesting in the future. Tannin extracts or tanning-rich plants may be efficient but do often decrease animal performances. Tea saponins have been shown to be efficient, but need more research. One promising additive, shown to be efficient in short- and long-term experiments, is nitrate (Van Zijderveld et al., 2012).

According to literature analysis, efficient and available techniques are thus lipids and nitrate. Several sources of lipids can be used. Unsaturated lipids, especially from linseeds, are recommendable as they modify microbial ecosystem resulting in an additional decrease in CH₄ production from carbohydrates. Lipids rich in medium-chain fatty acids such as coconut oil, palm kernel oil or palm oil derivatives have the same effect, but their high content in non-desirable saturated fatty acids may enrich milk or meat in these components, so that they are not considered. Concerning application of lipids, distribution as extruded seeds is a good solution, due to the significant amounts of lipids that can be easily included in the diet; on the contrary the incorporation of high amounts of oils in concentrates is limited by technological constraints. Moreover, a large-scale use is possible and lipids may be fed to most ruminants, provided they receive concentrates in their diet. However, CH₄ mitigation is partially compensated for by higher N₂O and CO₂ emissions linked to the production of oleaginous seeds compared to cereals, as shown by life cycle assessment method.

The use of nitrate in diet, although efficient as calcium nitrate, is controversial due to an effective risk of animal intoxication by nitrites in case of over-dosing, and of a potential rejection of this technique due to the negative image of nitrates. Nevertheless, this technique provides advantages as nitrates combined with hydrogen result in ammonia (NH₃) production in the rumen; it may contribute to spare other sources of ruminal NH₃, such as urea or a small part of oleaginous meals. The cost of the product is difficult to evaluate but may be reasonable, because of the present use of calcium nitrate as fertilizer.

Decreasing organic matter and nitrogen losses

Manure CH₄ production highly depends on manure storage conditions and application, but is proportional to undigested carbohydrates. When concentrate-rich diets are fed, undigested carbohydrates are lower than with forage-rich diets. When lipid supplements are fed, part of carbohydrates are replaced, leading to less undigested carbohydrates are present in faeces. Additives which may reduce CH₄ enteric production do not change or slightly modify carbohydrate digestibility. As a consequence, techniques which reduce enteric CH₄ production either reduce or do not change the potential CH₄ production from manure.

Nitrogen losses result in various pollutions: N₂O as GHG, drainage of nitrates leading to eutrophication (Vertès et al., 2007) and NH₃ involved in acidification and human health, and responsible of unpleasant odours. Organic N is lost in faeces and urine. Most urinary N is as urea, which is rapidly transformed into NH₃ by faecal urease (Vaddella et al., 2010). Moreover, after redeposition NH₃ can also be transformed in nitrates and N₂O and it is generally assumed that 1% of the N-NH₃ is converted in N₂O. For this reason, one major objective is to reduce N losses, and especially urinary N. Indeed, mineral form of N (i.e. ammonia) result, in addition to NH₃ volatilisation, in higher N₂O emissions than organic forms (Eckard et al., 2010). However, it should be noted that this specific decrease in urine compared to urea is not taken into account by IPCC (2006) which considers urine and faeces as global manure.

Faecal N can be reduced when dietary N is highly digestible as for example protein from concentrates. The use of synthetic amino acids (AA) improves milk protein synthesis, and so, can reduce urinary N. In dairy cows, the use of the most limiting AA for milk production, methionine and lysine, increases the AA metabolic efficiency. This was known for high-N diets and has recently been demonstrated with low-N diets (Haque et al., 2012). This technique is now more expensive in

ruminants than in monogastric animals, especially because of the need to protect AA against ruminal degradation, but could be considered in the future. Also the use of formaldehyde-treated meals (principally from soybean and rapeseed) can limit the excess of ruminal fermentable nitrogen, and thus limit urinary N excretion and thus ammonia emission (Van Duinkerken et al., 2005). Formaldehyde-treated meals are generally combined with urea in order to adjust dietary fermentable N supply. In spite of this, this technique is not frequent, and may be questioned in the future because they contain formaldehyde. The most promising technique is the reduction of protein content in diet, provided this does not reduce milk production. Accordingly, a replacement it has been suggested to replace grass-based systems by maize silage-based systems (Schils et al., 2013). However, this technique will put into practice a major change in production systems; moreover GHG emissions and nitrate leaching per ha are not reduced. An analysis of available data of N intake, excretion and secretion in milk using the whole-farm model MELODIE (Chardon et al., 2012) shows that diets with 14% protein do not limit milk production, on average. Hence, a reduction of dietary protein within a same production system can be seen as an available technique for limiting N losses of dairy systems.

The implementation of a reduction of dietary protein content is considered only for dairy systems. For beef systems, to date, our knowledge on existing practices using techniques such as improved dietary N efficiency is too limited to recommend an application. In addition, about 90% of total GHG emissions of beef systems are related to the cow-calf herd, of which the diet is generally low in protein content. In dairy systems, this technique is only considered for winter diets, as protein nutrition is not easy to monitor when cows are on pasture. This technique is rather easy to implement, because the measurement of milk urea is an excellent indicator of an excess of dietary N and is very well related to urinary N (Faverdin and Vérité, 1998). Moreover, contrary to many other mitigation techniques, the decrease in dietary N results in a spare of money for the farmer, especially by decreasing purchased concentrates. This is thus a win-win technique. Dissemination of this technique would need advertisement to assure farmers that a controlled limitation of dietary N does not compromise herd performances.

Optimizing grassland use

A part of GHG emissions from ruminants can be compensated for by a sequestration of carbon by grassland soil. This is an efficient way of GHG mitigation, known for a long time, but is barely taken into account. Recent studies show that soil C storage has been underestimated for methodological reasons such as neglecting storage in deep soil layers (Soussana et al., 2011). However, there is a large variability in C sequestration estimate, with wide inter-annual variations related to climatic conditions and agricultural practices (i.e. grazing, cut, sown grassland) (Soussana et al., 2007, Klumpp et al., 2011). The use of natural grasslands by livestock is not a mitigation technique *per se*, because it is “business as usual”, but changes in grassland management may have considerable consequences: fertilization and animal stocking rate act on N₂O emission and nitrate leaching, draining wet soils reduce CH₄ emissions from grasslands. Given the a large diversity of grassland management among beef and dairy cattle systems, several ways of reduction of environmental impacts can be suggested.

One option is to increase grazing compared to production of conserved forage as hay or silage; these latter result in a more extensive exportation of biomass by cut, leading to *lower* C storage and *higher* GHG emissions (Soussana et al., 2007, Allard et al., 2007). Moreover, a prolongation of grazing period is possible if climatic conditions are favorable, and if soils are load-bearing and not too humid (Schils et al., 2013). For example, in plain areas of France, grazing period may be extended in many farms for at least 20 days, which may reduce emissions (NH₃, N₂O and CH₄) linked to barn (i.e. manure storage and spreading) and increase on-site C sequestration as more carbon is recycled at the paddock. A comparison of 9 European grassland sites confirmed that cutting vs. grazing was more beneficial for the net GHG balance (Soussana et al., 2007). In addition, faecal and urinary losses may produce less NH₃ on pasture than in building because they are excreted in separated places, with a slower conversion of urea to NH₃.

Also changes relative to temporary sown grasslands are promising, as an increase in lifetime (i.e. until 5 years) of temporary grassland will increase C storage due to less frequent ploughing. Moreover, a less frequent renewal of grasslands not only increases the net C sequestration but also reduces N₂O and NH₃ emissions and nitrate leaching, due to mineralization of N bound to soil organic matter. Other techniques such as composition of sown grasses (i.e. tannin rich grasses, sugar-rich grasses and legumes) may be used to reduce enteric CH₄. However to date there is no proven effect of nature of grasses on CH₄ emission: the interest of ryegrass rich in soluble carbohydrates is controversial, and a lower CH₄ emission with lucerne has been observed but remains to be confirmed (Doreau et al., 2011). Nevertheless, increasing the proportion of legumes in temporary sown grasslands contributes to the reduction of N₂O and NH₃ emissions, and of nitrate pollution related to lower use of mineral fertilizers (Rochette and Janzen, 2005).

Grassland management may be another mitigation option to decrease environmental impacts of livestock production systems. A reduction of N fertilization of permanent and temporary grasslands offers thereby the most promising techniques. In France, mineral N fertilization varies annually from zero unit per ha to more than 200 units per ha depending on regions and expected biomass, and a reduction of 10-20% may be considered at the highest application rates. Such a decrease, especially for high fertilized grasslands, does not impair animal performances when it contributes to avoid excess of dietary N. For example, Peyraud and Astigarraga (1998) showed that a strong decrease in grass N annual fertilization, which results in a decrease in grass N content and grass growth, may not change milk production of dairy cows using efficient N recycling, but drastically reduces urinary N; however milk production per ha is decreased. Sparing fertilizer while reducing environmental impacts is often a win-win technique. However, this option does not work for low-input, low-producing grasslands, where on the contrary, an increase in stocking rate may enhance C sequestration due to a stimulation of vegetation and a higher input of organic N supply.

Conclusions

Many techniques have been proposed for reducing environmental impacts by optimizing animal nutrition or management, in interaction with grassland use. A first step has been to select the most promising, or the more efficient techniques to be implemented from now on or in a near future. Additional work is needed to quantify the extent of mitigation and the cost of these techniques, which may be a key factor for their success or failure.

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