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Possibilities for mitigating the environmental footprint of dairy ruminants

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Abstract

Livestock industry, with dairy sector as one of the fastest growing, largely contributes to the atmospheric/soil pollution and greenhouse gases emissions (i.e. methane, carbon dioxide, and nitrous oxide) on the global scale. The goal of this paper is to present a short synthesis of published scientific works aiming to reduce dairy ruminants' environmental footprint by mitigating land degradation, water pollution and depletion, and greenhouse gasses emissions (GHG) by implementing novel nutritional, biotechnological, microbiological, animal management, and manure management strategies. In order to mitigate land degradation, suggested strategies include the introduction and adjustment of grazing fees and lease rents, and addressing pollution by establishing a "provider gets - polluter pays". Improving water use efficiency is the most important in animal feed production. Contamination of water with microorganisms and parasites from manure should be prevented to avoid a public health hazards. With respect to methane and nitrous oxide emissions, the most common nutritional strategy for mitigating GHG emissions is using forages with lower fiber and higher soluble carbohydrates content or grazing less mature pastures. Although many of feed additives (organic acids, secondary plant components, and lipids) can be effective to some extent in reducing rumen methanogenesis, much *in vivo* research is still needed to clarify which amounts and combinations of additives are the most effective in mitigating methane emission. In order to successfully respond to the increasing global demand for raw milk and milk products, the dairy industry will have to mitigate future negative impacts on the environment, modifying the current production systems, and maintain at the same time high quality of final products at an economic price acceptable for the consumers.

Key words: methane, nitrous oxide, greenhouse gases, milk production

Introduction

Over the past few decades, the livestock sector has become increasingly demand-driven and it is now in further competition for the same natural resources as other agricultural sectors. Facing problems in the dairy industry and in the attempts to solve them, the livestock sector is constantly leaving a mark on the environment. Growing populations and other demographic factors (i.e. urbanization, age structure, growing economies, and individual incomes) are the main driving forces for increased demand of animal protein, which is particularly driven by changes in diets in developing countries (Delgado, 2005). With the projected rise in dairy production, there will be an equally strong relationship of pressure applied to the environment (FAO, 2018). The emphasis of this paper will be on dairy ruminants, particularly the most globally important ones (i.e. - cattle, buffalos, goats and sheep), and their general influence on the environment with a special emphasis on atmospheric pollution and greenhouse

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gas emissions (i.e. methane, carbon dioxide, and nitrous oxide). This paper will give a short review of published scientific work in the field of dairy production and environmental management with a full view of current possibilities for mitigating ruminant's environmental footprint in addition to future prospects on approaches to improve production processes in order to successfully respond to global demands in a sustainable way.

Current trends in ruminant livestock production worldwide

According to the Food and Agriculture Organization (FAO) report released in 2017, the number of the most important ruminant livestock species on a global basis for production continues to rise. To put the importance of ruminants in a global perspective, the FAO reported in 2014 a total population of 194.5 million buffalos, 1.01 billion goats, 1.47 billion cattle and 1.19 billion sheep (FAO, 2017).

The rising trend in global dairy production is expected to continue in the next decade and have a severe impact on livestock and crop production systems, the environment, public health, trade flows, and on the world food economy (Pica-Ciamara and Otte, 2011). Estimates express that approximately half a billion of the world's extreme poor that depend on livestock to survive may potentially economically benefit from the expanding market for animal origin products, but on the other hand, an unregulated growth of the livestock sector may have significant negative influences on their environment and public health (Pica-Ciamara and Otte, 2011).

Despite the fact that the majority of ruminant animals are housed in developing regions, they account for less than half of the global production. Developing regions account for around 40 % of milk production and among these developed countries, the USA is a leader in cattle dairy production even though Brazil has a greater number of cattle per capita (FAO, 2017). According to FAO (2017) India is the global leader in goat milk and buffalo milk production (which was produced only in Asia), while the largest quantity of sheep milk is produced in China (Table 1).

Ruminant production systems vary a lot depending on the environment, country they are managed, and their purpose. For example, Brazil is one of the largest beef producers and exporters in the world, and most of its production is based on pasture grazing (Ferraz and De Felicio, 2010). On the other hand, Indian agriculture is characterized by a mixed farming system (Kumar and Singh, 2008) and their cattle production is primarily for dairy while China has significantly increased in milk production over the last 20 years with a very diverse breeding practices due to the size and diversity of country (Han et al., 2016).

Strategies and possibilities for mitigating dairy ruminant environmental footprint

The influence of livestock to the environment are mutually connected and interwoven. Land degradation and depletion has a direct impact on water quality by nutrient leaching or direct erosion to water bodies. In addition, deforestation and overuse of land in feed production systems releases large amounts of carbon dioxide stored in plant biomass and soil into the atmosphere. Carbon dioxide, an important greenhouse gas along with methane and nitrous oxide, is playing a big role in increasing the greenhouse effect which results in global increase of temperature (Herrero et. al., 2011).

Possibilities for mitigating land degradation

Organic carbon retained in agricultural areas worldwide has been severely depleted due to intensive farming practices, especially by shifting cultivation or "slash and burn" agriculture in the tropics. Steinfeld et al. (2006) stressed the adequate pricing of natural resources and preservation of

Table 1. Largest producers and production quantities of milk from different ruminant species in 2014

	Buffalo milk	Cattle milk	Goat milk	Sheep milk
Largest producer	India	USA	India	China
Quantity (million t)	74.7	93.4	5.1	1.5

Source: FAO (2017)

ecosystems as key strategies for reaching a sustainable balance, especially if humanity wants to produce as much as today, or even more to accommodate population increases. They are emphasizing that the current prices of natural resources used for livestock production do not reflect true scarcities, which leads to overuse. With respect to land, suggested strategies include the introduction and adjustment of grazing fees and lease rents, and addressing pollution by establishing a "provider gets - polluter pays", which was successfully introduced and conducted by EU's Common Agricultural Policy. This policy's goal was to direct farmers to management choices which are less costly for the environment and thus would mean benefits for farmers who are promoting good ecological practices as well as punishments for the ones who do not (Rosso Grossman, 2007). Carbon sequestration is the main option in capturing the additional carbon dioxide from the atmosphere. Since carbon sequestration is a naturally occurring process in the agricultural sector, a great amount of hope is put into improved pastures especially in the tropics as carbon release to the atmosphere is very high due to bad management practices, higher temperatures, increased precipitation, and destruction of forests (Amezquita et al., 2007). Research on the capacity of pastures and special silvopastoral systems in the tropics was conducted over the period between 2002 and 2007 and showed that if managed correctly, pasture systems can sequester the same and even higher amounts of carbon from the atmosphere than the native forest, which was once covering the same location (Amezquita et al., 2007). Steinfeld et al. (2006) recommend silvopasture (combining forestry and grazing of livestock in a mutually beneficial way) as a practice in combating climate change with carbon sequestration and rehabilitating degraded land along with better management of especially dry, degraded pasture soils.

It is difficult to generalize the mitigating options for land degradation because there are many different factors that need to be taken into consideration such as the area's production systems, climate, type of animal, and others. Therefore, we will focus on examples from European Union countries to present strategies and methods used in prevention of land degradation by livestock production. Livestock production systems currently occupy around 28 % of the land surface of the European Union (EUROSTAT, 2017). Beef and dairy farming is the most prevalent in Central and Northern Europe while sheep production is concentrated in the western part of the European Atlantic region and the Mediterranean countries (Bowyer et al., 2009). The main land degradation problems associated with beef and dairy systems are erosion, compaction, soil contamination, and the pollution and eutrophication of water systems. Erosion and compaction are caused directly by stocking densities higher than the carrying capacity of the land, and by the associated intensive crop production (often monoculture) for feed. Although many of the incentives for overstocking has been removed with the introduction of decoupled payments through the Common Agricultural Policy (CAP) in 2005, high stocking densities continue to cause problems within intensive beef and dairy systems as well as grazing systems within the Mediterranean where the soils are more fragile. According to European Parliament (2009), there is a large number of different actions that can be undertaken by farmers to improve the health of their soils, which include reducing the intensity of management, applying new cropping techniques, and introducing new forms of machinery and technological equipment (Bowyer et al., 2009). For example, wiser management of livestock rearing on farms would include an appropriate stocking density on permanent pasture, which should depend on the carrying capacity of the particular habitat and the way it is managed (Bowyer et al., 2009). Reducing the length of the grazing season, grazing intensity, and more appropriate manure storage and application are other strategies available for mitigating pressure on land by livestock. In periods of wet weather, grazing should be minimized due to increased structural damage of the soil. Establishing the shifting systems between a few pieces of land in order to enable the overgrazed parts of meadow to recover is especially important because of the economic pressure to reduce the cost of silage and animal feed. With respect to manure management, the European Union has implemented 12 different regulations to minimize salinization, saturation, leaching of nutrients from the soil, and storage methods of soil. Of these 12 regulations, the following three are the most important: The Nitrate Directive (1991), The Water Framework Directive (2000), and Animal By-Products Regulations (2009).

Possibilities for mitigating water pollution and depletion

Pollution from livestock production comes from several sources and results in polluting the water in many different ways. Pollution by nutrients from fertilizers used in feed production is very common due to leaching of nitrates to groundwater, but also by nutrients from poorly managed manure storage and application. Furthermore, contamination of water with microorganisms and parasites from manure can pose a public health hazard risk. Another problem with waste water from farms is the drug residues used in production as well as heavy metals used in small quantities as growth promotors. Steinfeld et al. (2006) reports that mitigation options usually rely on three main principles: reduced water use, reduced depletion process, and improved replenishment of water resources. Improving water use efficiency is the most important in feed production since cultivation of feed crops uses the largest proportion of water. Improved irrigation efficiency would lead to better control of the water supply as well as increase in yields and water productivity if precision irrigation is used.

In the same way as for land degradation mitigation practices, the policies and rules given by national or regional governments play a big role in water protection and mitigation of negative impacts. Reverting focus back to the EU, a good example of these policies is a case study within the EU legal framework conducted in the Netherlands (Dai, 2014). As a result of past tendencies to increase and intensify the livestock production in order to make EU self-sufficient, the Netherlands is nowadays known for a relatively large scale dairy production. All related agricultural practices resulted in a four times higher nitrogen pollution than other European countries. The Dutch agriculture sector was forced to mitigate further leaching and release of nutrients, especially nitrogen and nitrogen compounds, in the environment and subsequently implemented "The Water Framework Directive (2000)" and "The Nitrates Directive (1991)" on their whole territory with great success. The most significant and important measure they took were "buffer-zones", which are green stripes along the water bodies with restrictions of application of fertilizers and pesticides. This would mean the reduction in surface of production area for farmers, but the government offered financial compensation in exchange for ecosystem services which was supported by the Rural Development Regulation under the EU. This is a good example of how to approach the problem in a sustainable way.

Possibilities for mitigating greenhouse gases emissions

Greenhouse gases (GHG) emissions, in particular methane and nitrous oxide, are the main example of ruminants' negative impact on the environment regarding accumulation of gases in the atmosphere. Methane (CH_4) is the most important greenhouse gas emerging from ruminant livestock. Cattle produce about 7-9 times as much methane as sheep and goats, respectively (Broucek, 2014). Around 90 % of methane is produced in the rumen and 98 % of that is released through the nose or mouth (Thorpe, 2009).

With respect to methane and nitrous oxide emissions, before proposing any of the available mitigation methods, detailed life cycle assessments should be considered because each ruminant system is unique. Mitigation strategies such as genetic selection, use of chemicals and vaccines, and the capture of GHG emitted have been proposed; however, dietary manipulation is considered the most promising strategy for the reduction of GHG emission from ruminant production systems (Meale et al., 2012). There are three approaches when discussing dietary manipulation: nutrition (feeding), biotechnology and microbiology, and management strategies (Mirzaei-Aghsaghali et al., 2015). By taking into account all changes in GHG emissions associated with implementing a mitigation practice, it will reveal whether a change in management aimed at reducing enteric methane production will actually lower net farm GHG emissions. Describing the farming system can be very complex because of numerous components that interact with each other such as soils, crops, feeds, animals, and manure. Therefore, whole-farm models should be able to give an accurate representation of the internal cycling of materials and its constituents as well as the exchange between the farming system and its environment (Schils et al., 2007).

Nutrition strategies

Adjustment of nutrition is the most effective and easiest option when it comes to strategies for GHG emission reduction; however, a good understanding of methanogenesis is vitally important. Enteric fermentation is a naturally occurring fermentation of feed that takes place in the digestive systems of ruminant animals. The microbial fermentation that occurs in the rumen enables ruminant animals to digest coarse plant material and plant polymers that monogastric animals cannot, with methane occurrence as one of by-products. The basic idea behind the process of methanogenesis is utilization of hydrogen by methanogens in the energy-yielding reduction of carbon dioxide to methane, which prevents accumulation of hydrogen in the rumen and allows normal fermentation process to occur (Meale et al., 2012). If fermentation patterns are shifted from acetate to propionate both hydrogen and methane production will be reduced (Maheri-Sis and Mirzaei-Aghsaghali, 2011). A lot of feeding strategies based on this fact have been successful, but only over the short term. The livestock sector consumes annually around 6 billion tons of feed material on a dry matter basis, which accounts for one third of global cereal production. While monogastric animals consume 72 % of the global livestock grain intake, grass and leaves represent more than 57 % of the ruminants' intake (FAO, 2010).

Forage-rich diets result in acetic type of fermentation, which increases methane production. Generally, ruminants consuming grass forages are considered to produce more methane per unit of dry matter intake compared to those of grazing legumes (Hegarty, 1999). The most common nutritional strategy for mitigating GHG emissions is using forages with lower fiber and higher soluble carbohydrates content or grazing less mature pastures, which promotes production of propionate and may lower ruminal pH to a level that inhibits methanogens (Maheri-Sis and Mirzaei-Aghsaghali, 2011). On the other hand, an increase in fiber content can reduce forage intake, elevate ruminal residence time and reduce fermentability that leads to increased methane production (Meale et al., 2012).

Unlike forages, the nutrition of ruminant animals consuming higher grain content will promote the production of propionate in the rumen due to higher starch content, which will lower ruminal pH and therefore inhibit methanogenesis (VanKessel and Russell, 1996). For example, feedlot cattle in North America are typically fed high grain diets (> 90 % grain on a dry matter basis) to achieve the maximum profit. In these systems, methane energy emitted can be as low as 2 to 3 % of the gross energy intake (Johnson and Johnson, 1995). Nevertheless, high level of grain feeding can compromise the health of cattle by promoting acidosis and bloat, and with higher grain prices, the use in livestock nutrition will be limited by financial constraints particularly in developing countries (Meale et al., 2012). Another concern is that increasing the concentrate proportion in the diet above certain levels will negatively impact fiber digestibility (Agle et al., 2010; Hristov et al., 2013), which in addition to a potential loss of production, will result in an increased concentration of fermentable organic matter in manure and most likely increase methane emissions from the stored manure (Lee et al., 2011; Hristov et al., 2013). With respect to energy loss through methane emission, Giger-Reverdin and Sauvant (2000) published a meta-analysis that classifies feeds into four categories based on their generating potential (Table 2). Enteric methane emission may be reduced when corn silage replaces grass silage in the diet. Legume silages may also have an advantage over grass silage due to their lower fiber content and the additional environmental benefit of replacing inorganic nitrogen fertilizer to a certain extent (Hristov et al., 2013). Regarding distiller's grains,

Table 2. Categories of feed with respect to their generating potential (Giger - Reverdin and Sauvant, 2000)

Category	Gross energy loss as CH_4	Feed
High-CH_4 producing feed	>12 %	Peas, faba beans
Medium-CH_4 producing feed	10-12 %	Wheat, corn, barley, sorghum, soybean meal
Low-CH_4 producing feed	5-9 %	Wheat offal, oats, maize and grass silage, dry grasses
Very low-CH_4 producing feed	<4 %	Distiller's grains

Stock et al. (1999) reported that fermentation of starch to produce dried distillers grains with solubles (DDGS), increases the nutritional concentration of protein, fat, neutral-detergent fiber, and phosphorus up to 3x's compared to traditional grains. Feeding triticale distiller's grains reduced the ruminal acetate to propionate ratio, which is considered to result in reduced methane production as explained earlier (Wierenga et al., 2010). The greatest concern is high protein and phosphorus concentrations, which increases manure ammonium (NH_4^+) and ammonia (NH_3) concentrations. However, an increase in the ammonium content in manure can occur without increased nitrous oxide emissions, which is further evidence that ruminant life cycle assessments are necessary to determine the impacts of distiller's grains in GHG budget (Meale et al., 2012).

Supplementations with small amount of concentrate feeds will most likely increase animal productivity and therefore decrease GHG emission intensity. In spite of these potential gains, concentrate supplementation cannot be a feasible substitute for high-quality forage for ruminants because in many parts of the world, this may not be economically viable and socially acceptable mitigation option. Therefore, the best mitigation option when discussing general ruminant nutrition would be to increase the forage digestibility in order to improve intake and animal productivity. One of the ways by which digestibility can be increased in ruminants is feed processing. Forage particle size reduction through mechanical processing or chewing, is an important component of enhancing forage digestibility, thus providing greater microbial access to the substrate, reducing energy expenditures, increasing passage rate and feed intake, and ultimately animal productivity (Gerber et al., 2013; Hristov et al., 2013), which would reduce enteric methane emissions.

Feed additives

Apart from balancing forage and concentrate ratios, a lot of research has been done on food supplements, which could potentially reduce enteric methane production. Some of the proposed substances are ionophores and naturally occurring antibiotics isolated from the bacteria *Streptomyces cinnamonensis*. These substances are commonly used in North America, but prohibited for use in European Union since 2006 (Beauchemin, 2009). The most widely used ionophore is monensin, which has different modes of action. Primarily, it decreases the number of rumen protozoa, which consequently causes the reduction in methane production due to rumen protozoa accommodating methanogens on their cell surface and within the cell. Therefore, the number and activity of methanogens are indirectly reduced by ionophores (Kobayashi, 2010). Monensin also increases proportion of propionate by selectively inhibiting gram-positive bacteria, which enables *Selenomonas ruminantium* to decarboxylate succinate to form propionate (Duffield et al., 2008). Methane reduction by ionophores occurs only at the early stage of feeding since rumen protozoan populations that are depressed by ionophores tend to restore their numbers when ionophores are administered for a long time (Kobayashi, 2010). Despite this, the use of ionophores is considered as an effective method of methane production reduction especially in the United States due to methane emission reduction that are more consistent with grain-based diets than in forage-based diets (Meale et al., 2012). On the other hand, effectiveness of ionophores is dose dependent. Beauchemin et al. (2008) concluded that inclusion of 24-35 mg/kg of feed caused a 4-13 % reduction in methane, while supplementing less than 20 mg/kg of feed won't result in any reduction.

The organic acids such as malate, fumarate, citrate, and succinate are propionate precursors and it has been demonstrated both *in vitro* and *in vivo* that their dosage and addition to the diet reduces methane production (Maheri-Sis and Mirzaei-Aghsaghali, 2011). Meale et al. (2012) reported that a methane reduction of 23 % in steers and 49 % in sheep were accomplished, but with large amounts of fumarate (20 g/kg of dry matter and 100 g/kg of dry matter, respectively). Thus it is clear that relatively high levels of organic acids are required in order to show some results regarding methane production reduction that has a negative impact on dry matter (DM) intake and ruminal pH, which drops with negative consequences for fiber digestion (Meale et al., 2012). Besides DM intake and reduced pH, using organic acids as dietary supplements is also restricted due to their cost. However, as organic acids, they can be found in forages, especially in early stages (Martin, 1998). Maheri-Sis and Mirzaei-Aghsaghali (2011) noted that other factors may be involved in the methane reduction such as high rate of intake, high rate of passage, and presence of saponins.

There is a growing interest in the use of secondary plant components as a potential strategy for methane mitigation and in particular, tannins and saponins are among the components in focus due to their natural origin, however, most trials were done *in vitro* with highly variable results (Maheri-Sis and Mirzaei-Aghsaghali, 2011). The effect of saponins is similar to that of ionophores with rumen protozoa being particularly sensitive to saponins that reduce their level in the rumen, thus resulting in the depression of methanogens associated with protozoa, which could be the main mechanism by which saponin feeding reduces methanogenesis (Kobayashi, 2010). However, the effectiveness of saponins on methane mitigation also depends on forage type and content of basic nutrient components (i.e. crude protein and crude fiber). There are several studies (Cieslak et al., 2014; Cieslak et al., 2016; Pisarčíková et al., 2016) that demonstrated probable antagonistic interactions between basic dietary compounds and phytochemicals resulting in reduced potential to inhibit rumen methanogenesis. Patra and Saxena (2009) and Cieslak et al. (2013) also confirmed these findings, since they showed that the effect of phytochemicals depends on diet composition, microbial structure and microbiota adaptation to the rumen environment.

On the other hand condensed tannins have two modes of action: reducing methane production by reducing fiber digestibility that indirectly decreases hydrogen production (Tiemann et al., 2008); and a direct inhibiting effect on methanogens *in vitro* (Bhatta et al., 2014) and *in vivo* (Cieslak et al., 2012). Jayanegara et al. (2012) published a meta-analysis which showed a close relationship between dietary tannin concentrations, decreased feed intake, and decreased digestibility. However, tannins make complexes with soluble proteins, making them insoluble in the rumen, but release them under acidic conditions in the small intestine, thus reducing bloat and increasing amino acid absorption (Maheri-Sis and Mirzaei-Aghsaghali, 2011). Essential oils, as other naturally occurring secondary metabolites, were also used in researches due to their ability to interact with microbial cell membranes and inhibit the growth of some bacteria that causes a reduction in methanogenesis, ammonia nitrogen, and acetate, with increased concentrations of propionate (Calsamiglia et al., 2007). Patra and Yu (2012) conducted an *in vitro* experiment with five different essential oils (clove oil, eucalyptus oil, garlic oil, oregano oil, and peppermint oil) for their effect on methane production, fermentation, and selected groups of ruminal microbes. The authors concluded that all tested oils reduced methane production with increasing doses, but degradability of dry matter and neutral detergent fiber also decreased linearly with increased doses of essential oils except in the case of garlic oil. Most of the essential oil effect on methane production research was also conducted only *in vitro*, and there is no evidence that they can be used successfully to inhibit rumen methanogenesis (Hristov et al., 2013). However, *in vitro* and *in vivo* experiment conducted using dairy cows showed synergistic effect of condensed tannins (originating from lingonberry shrub - *Vaccinium vitis idaea*) and a blend of fish-soybean oils on the rumen methanogens population consequently lowering methane production (Szczechowiak et al., 2016). The above mentioned feeding strategy also showed beneficiary effect on blood parameters of dairy cows such as a significant decrease in triglyceride and the saturated fatty acid proportion and a significant increase in C18:1t11 and n-3 fatty acids proportion, finally resulting in more n-3 PUFA reaching the mammary gland and is secreted in milk (Szczechowiak et al., 2018). After using pelleted and ensiled grape pomace in dairy cows nutrition, Moate et al. (2013) reported a decrease of approximately 20% in methane emission and total enteric methane yield.

Lipid supplementation is the most effective method with respect to short term food supplementation (Meale et al., 2012). The biggest problem with this method is avoiding the impairment of animal production because the addition of unprotected fats to the diet can have negative effects on feed intake, carbohydrate digestion in the rumen, protein and fat content of milk, and organoleptic quality of milk. Therefore, to prevent these negative effects the amount of lipid added to the diet must be limited to 3-4 % so that the total lipid content does not exceed 6 % of dietary dry matter (Beauchemin et al., 2009). A review by Meale et al. (2012) also reported that dietary lipids have multiple modes of action and examples of these modes are as follows: they decrease amount of fermented organic matter in the rumen, lipids can have a direct inhibitory effect on methanogens and protozoa, and lipids rich in unsaturated fatty-acids act as a hydrogen sink through hydrogenation of fatty acids, which favours a shift in ruminal fermentation towards propionate with a potential reduction in methane production. Bayat et al. (2018) found that plant oils supplemented to a grass silage-based diet reduce ruminal CH_4 emission and milk saturated fatty acids, and increase the proportion of unsaturated fatty acids and total conjugated linoleic acid while not interfering with digestibility, rumen fermentation, rumen microbial quantities, or milk production. With respect to the form of feed supplementation, pure oils are usually more effective in suppressing methane than supplying the same amount of lipid via unprocessed or processed oilseeds; but in general, oilseeds are preferred over refined oils because of lower cost and the fact that they evoke fewer adverse side effects on intake and fiber digestibility (Beauchemin et al., 2009). Furthermore, since oilseed and refined vegetables oils are more expensive compared to forages and grains, the use of distiller's grains and meals from biodiesel industry are recommended as more cost-effective methane mitigation measure. There are a few further techniques regarding feed additives published and tested *in vitro* as promising possibilities such as supplementation with microalgae, yeast, organic acids, and enzymes; however, all the authors agree that further research is needed to confirm their beneficial effect on methane production reduction (Meale et al., 2012).

Biotechnological and microbiological strategies

Animals have been bred throughout history with a focus on production traits and resistance to different environmental conditions. More recently, the emphasis of breeding has been focused on widening the range of traits in breeding programs such as product quality, animal health, efficiency, and environmental impact (Mirzaei-Aghsaghali and Maheri-Sis, 2016). However, methane emission is not yet included among breeding goals for dairy cattle worldwide (de Haas et al., 2017). According to Kandel et al. (2017) CH_4 emissions could be mitigated by direct selection on CH_4 intensity in dairy cows (CH_4 g/kg of milk), but response to selection will be faster if environmental traits are added on selection index. Indeed, de Haas et al. (2016) stated that it is important to make measurements on commercial farms as a precondition for moving on with a genetic evaluation and ranking of animals for methane emission. Waghorn and Hegarty (2011) concluded that there was not enough evidence that efficient animals have a different methane yield per unit of dry matter intake and mentioned the need to select high-producing animals because this reduces emissions per unit of product. On the other hand, animal breeding and environmental conditions all have been shown to affect ruminal microbial diversity, which could potentially be used to select animals with lower methane emitting potential or manipulate the ruminal ecosystem to raise animals producing less enteric methane per unit of digested feed (Hristov et al., 2013). However, the emphasis should be on maximizing the feed efficiency which is more compatible with existing breeding objectives than breeding for reduced methanogenesis (Eckard et al., 2010). Selection for productivity and efficiency helps mitigate greenhouse gases in two ways. Firstly, the higher productivity generally leads to higher gross efficiency as a result of diluting the maintenance cost of the productive and non-productive animals; and secondly, a given level of production (i.e. farm milk quota) can be achieved with fewer higher yielding animals and their followers (Wall et al., 2009). A good example demonstrating the importance of the genetic merit is the use of Holstein genetic material from the USA on native European breeds, which resulted in increased efficiency of feed utilization and higher milk yield. Another benefit is fewer cows to maintain since fewer cows are needed to achieve the desired quantity (Mirzaei-Aghsaghali and Maheri-Sis, 2016). One of the traits attracting more and more attention in research is the residual feed intake. Residual feed intake is the difference between the actual feed intake and the expected feed requirements for maintenance of body weight and for weight gain (Sainz and Paulino, 2004). Since feed intake is heritable, genetic selection aimed to reduce the residual feed intake can result in offspring that eat less, and consequently reduce methane production without compromising an animal's productivity (Mirzaei-Aghsaghali and Maheri-Sis, 2016).

In addition to the extensive research on animal genetics and their role in methane production, a lot of research has been focused in modifying the rumen environment. Modification of rumen microbial composition and their activity was attempted by using chemical additives that selectively effect rumen microbes, introducing naturally occurring or genetically modified foreign microbes into the rumen, and genetic manipulation of existing microbes in the rumen ecosystem (Santra and Karim, 2003). The best-known technique regarding microbial modification is defaunation. Defaunation is the process of making the rumen of animals free of rumen protozoa. Apart from using feed additives to achieve defaunation (e.g. ionophores, organic acids, and plant secondary components), defaunation can be accomplished by using different chemical agents (Gebeyehu and Mekasha, 2013). The main problems associated to chemical additives are their often toxicity to the animal or the rumen microflora and therefore reduce digestion and food intake. The additives are also expensive, volatile and thus difficult to administer or would fail to meet consumer product acceptance (Ulyatt and Clark, 2002). In addition, results reported by different researchers on the effect of defaunation are still contradictory. Due to all of the previously listed reasons in conjunction with current data, chemical defaunation cannot be recommended as a methane mitigation practice (Hristov et al., 2013).

Animal husbandry and manure management strategies

Gerber et al. (2013) gave an overview of technical options for mitigation of enteric methane emissions and their effectiveness regarding their interactions with other categories of emission (Table 3). For example, the effectiveness of lipids as a food supplement is strong; however if the source is oilseed, it can lead to an increased content of nitrogen in the feed and ultimately in excreta thus potentially causing problems with the volatilization of greenhouse gases from manure. Ionophores would also potentially increase emissions of nitrous oxide from urine while tannins would have the opposite effect. Authors agree that the best option is precision feeding (Gerber et al., 2013; Hristov et al., 2013). The idea behind precision feeding is matching the animal requirements with dietary nutrient supply which would result in reduced feed waste, maximizing production and minimizing GHG emissions per unit of animal product. However, this kind of feeding strategy requires infrastructure and investment, which may not be available in many production systems especially in the developing world (Hristov et al., 2013).

Methane from manure is produced in manure fermentation which is an anaerobic process (Monteney et al., 2006). Manure from grazing animals produce small quantities of methane since it remains largely aerobic, which leads us to the conclusion that one of the possibilities to reduce methane production from manure management is preventing anaerobic conditions during storage or capturing the produced methane if the conditions of storage are anaerobic (Hristov et al., 2013).

The simplest method for mitigation of greenhouse gases emissions in animal husbandry is improving animal health and reducing the mortality, thus enhancing the efficiency of production systems as previously explained in this paper. Improvement in animal health is especially important in livestock production systems where the application of technology is difficult (Hristov et al., 2013). All the effort put in the activities towards better performance of animals will result in lower manure production, therefore lowering emission of greenhouse gases from both enteric fermentation and manure management.

Table 3. Technical options for the mitigation of enteric methane emissions and their interactions with other categories of emissions (Gerber et al., 2013)

Mitigation technique	Effectiveness	Domain of relevance	Interactions with other categories of emissions	Overall effectiveness
Ionophores	Low	Landless systems, outside of EU	Potential increase of N_2O from urine	Yes
Tannins	Low	All systems	Decrease in urine N	Yes
Dietary lipids	Medium	All systems	Can reduce digestibility - increase of CH_4	Yes
Concentrate inclusion in diet	Low to medium	All systems	Higher emission of CH_4 from manure	Yes
Precision feeding	Low	All systems	Reduction of manure CH_4 and N_2O emissions	Yes

Diet manipulation is also recommended as one of the abatement of greenhouse gases from manure strategies. In particular, diet affects the amount, form, and partition of nitrogen excretion between urine and faeces; and the amount of fermentable organic matter excreted (Gerber et al., 2013). Dietary manipulation strategies are focused on reducing dietary crude protein concentrations which would reduce nitrogen excretion thus reducing urea and ammonium concentrations, and consequently may reduce nitrous oxide emissions. However, meta-analysis done by Montes et al. (2014) reported another antagonistic relationship between methane and nitrous oxide production. This inverse relationship of decreasing dietary protein concentration will most likely result in an increased concentration of fermentable carbohydrates in the diet, which in turn increases methane production. Reduced protein nitrogen in animal nutrition can also have some negative consequences such as slower nitrogen mineralization rate, which releases less plant available nitrogen, and low-protein diets have to be carefully formulated otherwise they can lead to reduced fiber digestibility which would influence dry matter intake and animal performance (Montes et al., 2014). Another promising method for reduction of nitrogen oxide emissions is shifting nitrogen excretions from urine (as main source of volatile nitrogen emissions) to faeces, which would result in lower emissions due to lower concentrations of available nitrogen in manure, but this would depend on storage methods and management (Hristov et al., 2013). Usage of tannins as feed supplements or tanniferous forages can be used for this purpose and Carulla et al. (2005) showed that these practices reduce urinary nitrogen as proportion of total nitrogen losses by 9.3 %.

Apart from diet manipulations, there are several technical options for mitigating greenhouse gases emissions. The first step in proper manure management occurs in animal houses. Structures used to house livestock animals do not directly affect the processes resulting in greenhouse gases emissions, but they do determine the method used to store and process manure and eventual litter. Housing systems with solid floors that use hay or straw for bedding accumulate manure that has higher dry matter and is commonly stored in piles, creating conditions conducive for nitrous oxide emissions (Gerber et al., 2013). Thus, animal housing may affect greenhouse gases emissions through the method of manure and litter management. Farm yard manure, deep litter manure handling systems, straw-based bedding, and solid manure handling systems tend to produce higher nitrous oxide emissions than slurry-based systems (Hristov et al., 2013). In general, manure systems in which manure is stored for prolonged periods of time produce greater ammonia and methane emissions compared with systems in which manure is removed on a daily basis. Biofiltration can be of some help in closed animal stables. This technique includes filtration of air through biological filters to control odour, absorb ammonia, and convert ammonia into nitrates (Montes, 2014). However, the processes of nitrification and denitrification including the conversion of ammonia to nitrate oxide can occur in the biofiltration media (Gerber et al., 2013).

Concluding comments

Agricultural pressure on the environment is expected to rise with increased demand for food especially proteins from animal origin. Livestock production currently has a huge negative impact on the environment with an emphasis on enhancing global warming by emitting large quantities of greenhouse gases with higher global warming potential and higher persistence in the atmosphere than carbon dioxide. There are numerous technological, chemical, and biological possibilities for the reduction of greenhouse gases emission throughout the whole life cycle of certain animal products like ruminants. Better utilization of existing agricultural land is crucial, which should include prevention of desertification and shifting to different agroecological systems (e.g. silvopastoralism wherever possible). Regarding direct emissions from animals, the reviewed literature identifies that the most promising methods for mitigation are those related to animal nutrition and usage of feed additives because they are less invasive, simpler to conduct, and also are more acceptable by consumers than chemical or biotechnological methods, which directly interfere with genetics of animals or an animal's digestive system. Enhancing an animal's productivity is also a widely accepted method which results in better utilization of feed and higher yields, and consequently lower amounts of greenhouse gases emitted per product unit. However, with respect to feed additives, a lot of research is still needed because current available data is primarily from *in vitro* experiments.

With all the recommendations on how to properly storage manure to avoid additional emission of gases, the most noted recommendation is the use of biogas (methane) as a sustainable and clean raw material in electricity production. Besides that, methane emissions from manure can be effectively controlled by shortening storage duration and ensuring aerobic conditions. The important factor to observe when choosing the mitigating strategy is interaction between two or more chosen strategies due to their complex nature. Some examples of this could be one practice may successfully mitigate enteric methane production, but increase methane emission from stored manure or nitrogen availability for increased nitrous oxide emission from land application of manure, while other mitigation practices are synergistic and are expected to decrease both enteric and manure greenhouse gases emissions. A common feature of researchers whose papers were used to write this synthesis was their agreement that there is a lot work to be done with respect to finding the most feasible, economically justifiable, and easiest option depending on the production system and other important factors for mitigation of ruminant footprint on the environment.

Mogućnosti ublažavanja utjecaja mliječnih preživača na okoliš

Sažetak

Stočarska proizvodnja, osobito mliječni sektor kao jedan od najbrže rastućih, u velikoj mjeri doprinosi onečišćenju atmosfere/tla i emisijama stakleničkih plinova (tj. emisiji metana, ugljičnog dioksida i dušičnog dioksida) na globalnoj razini. Cilj ovog rada je dati sažet pregled objavljenih znanstvenih radova na temu istraživanja mogućnosti smanjenja utjecaja mliječnih preživača na okoliš kroz ublažavanje degradacije zemljišta, smanjenje onečišćenja i osiromašenja kvalitete voda te smanjenja emisija stakleničkih plinova (GHG) primjenom suvremenih hranidbenih, biotehnoloških i mikrobioloških strategija, kao i strategija upravljanja farmom te upravljanja otpadnim tvarima na farmi. Kako bi se ublažila degradacija zemljišta, predložene su strategije uvođenja i prilagodbe naknada za ispašu i najamnine te rješavanje onečišćenja uspostavom odnosa "dobavljač dobiva - zagađivač plaća". Poboljšanje učinkovitosti korištenja vode najvažnije je u proizvodnji stočne hrane. Zagađenje vode mikroorganizmima i parazitima iz stajskog gnoja treba spriječiti kako bi se izbjegla ugroza javnog zdravlja. S obzirom na emisije metana i dušičnog dioksida, najčešća hranidbena strategija za ublažavanje emisija stakleničkih plinova je korištenje krme s nižim sadržajem vlakana i višim sadržajem topljivih ugljikohidrata ili ispašom manje zrelih pašnjaka. Iako mnogi dodaci hrani za životinje (npr. organske kiseline, sekundarne biljne komponente i lipidi) mogu djelovati u određenoj mjeri na smanjenje metanogeneze buraga, još uvijek je potrebno provesti brojna *in vivo* istraživanja kako bi se pojasnilo koje su količine i kombinacije dodataka najučinkovitije u ublažavanju emisije metana. Da bi se uspješno odgovorilo na povećanu globalnu potražnju za sirovim mlijekom i mliječnim proizvodima, mliječna industrija morat će ublažiti buduće negativne utjecaje na okoliš mijenjajući postojeće proizvodne sustave i istodobno održavajući visoku kvalitetu gotovih proizvoda cjenovno prihvatljivih potrošačima.

Ključne riječi: metan, dušični dioksid, staklenički plinovi, proizvodnja mlijeka

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