INVITED REVIEW

THE SIGNIFICANCE OF LIVESTOCK AS A CONTRIBUTOR TO GLOBAL GREENHOUSE GAS EMISSIONS TODAY AND IN THE NEAR FUTURE

Thakshala Seresinhe

Emeritus Professor, Department of Animal Science, Faculty of Agriculture, Mapalana, Kamburupitiya, Sri Lanka.

ABSTRACT

In animal agriculture, the greatest contributors to methane emissions are enteric fermentation and manure management. Enteric methane emissions were higher with ruminant animals while manure storage methane was higher with swine and poultry. The main course of agricultural nitrous oxide emissions is from the application of nitrogen fertilizers and animal manures. The most cost-effective way to reduce CH_4 production is to improve feed efficiency. In low-intensity systems, CH_4 production per unit product can be markedly reduced by improving feed quality and feeding intensity. Inhibition of methanogens, involvement of other H_2 alternative sinks e.g. inclusion of dietary fat, can result in a reasonable reduction in CH_4 production. Generally, some feed additives such as condensed tannins (CTs), fibrolytic enzymes and other factors e.g. methane inhibitors, vaccines, defaunating agents etc, have the potential to mitigate CH_4 production from ruminants. However, there are also some disadvantages, e.g. they are costly and not economical to apply at the farm level, and many have only short-term effects on CH_4 production thereby diluting the maintenance costs. The range of global mitigation potential to improve carbon sequestration and other factors are documented. Global and Sri Lankan scenarios on emissions and emission intensities from dairy production and the mitigating options are discussed. It is highlighted that removing animal agriculture is not a good solution to reduce greenhouse gas emissions. It is also suggested that combining productivity increases in crop and livestock sectors appears to be the most efficient way to exploit mitigation and food security co-benefits.

Keywords: Dairy cows, Enteric methane, Emission intensity feed efficiency, Mitigating ability, Ruminant

INTRODUCTION

Livestock production contributes greenhouse gases (GHG) to the atmosphere both directly and indirectly (IPCC 2007). The emissions can be classified based on the source of the emission; 1) Mechanical, and 2) Non-mechanical. The majority of direct CO_2 emissions from animal agriculture are usually from fossil use; for example, the use of propane or natural gas in furnaces or incinerators and the use of fuel to operate farm equipment and generators results mostly in CO_2 emissions (Dunkley and Dunkley 2013), This type of emission can be described as "mechanical emissions." The use of electricity on animal production farms results in indirect emissions since the emissions do not occur on site. For non-mechanical emissions, methane from enteric fermentation and manure management are the main sources of CH_4 emissions from agricultural activities and

of all domestic livestock, dairy and beef cattle are the largest emitters of CH_4. Enteric fermentation produces methane as a natural part of digestion in ruminant animals. It accounts for 33 percent of the total GHG emissions in agriculture and 71 percent of all agricultural sources of methane. Activities related to the storage and land application of manure releases 12 percent of the total agricultural methane emissions, and represent 25 percent of all agricultural sources of methane. Other significant sources on farms and ranches include rice cultivation and the burning of agricultural residues.

The majority of the N_2O emission from animal agriculture is from manure management which is the second largest (a far second to cropping practices) N_2O emitter in the agricultural sector. Application of nitrogenous fertilizers and cropping practices are estimated to

Corresponding author: tseresinhe@googlemail.com

cause 78% of total nitrous oxide emissions (IPCC 2006). Indirect emission of N_2O occurs when nitrogen is lost from the system through volatilization as NH_3 and N_2O (Dunkley and Dunkley 2013). Also, indirect emissions can result from nitrogen that is runoff or leached from manure management systems in a form other than N_2O and is later converted to N_2O offsite (IPCC 2006). Nearly 53 percent of agricultural GHG emissions are from nitrous oxide. Ninety-two percent of nitrous oxide is from agricultural soil management. Other significant sources include manure management and the burning of agricultural residues.

The degree to which human activities, including animal agriculture production, contributes to climate change is largely unknown. However, efforts are underway to identify all major sources of GHGs to determine strategies aimed at reducing these emissions. While animal agriculture contributes only a small amount (about 3 percent) of all GHG emissions, producers should know the issues and consider alternatives to reduce their overall carbon footprint.

Emissions from enteric Fermentation

Methane in the rumen is produced by methanogenic bacteria and protozoa. The role of protozoa in methane formation is interesting. It has been established that virtually all of the bacteria attached to protozoa are methanogens (Vogels *et al*. 1980) and that these bacteria are responsible for between 25 and 37 percent respectively of the total methane produced (Newbold *et al*. 1995).

By removing the protozoal population through defaunation, the ruminal bacterial population can be modified, volatile fatty acid (VFA) production shifted from acetate and butyrate towards propionate, and methane emissions decreased. However, there is a negative impact on fiber digestion (Demeyer 1991).

Hindgut fermentation differs from rumen fermentation by a substantially lower methane production and the presence of reductive acetogenesis or dissimilatory sulfate reduction. Sulfate reduction and methanogenesis seem to be mutually exclusive, while methanogenesis and reductive acetogenesis may occur simultaneously in the hindgut (Immig 1996).

Factors affecting enteric methane production

Johnson and Johnson (1995), suggested that a range of factors such as feed intake, type of carbohydrate fermented, forage processing and lipid addition affect enteric methane emissions. These factors have their effects by two different mechanisms. The first mechanism described is the amount of carbohydrate that is fermented in the reticulo-rumen. The second mechanism is the amount of available hydrogen and the consecutive methane formation through the ratio of VFA produced. The relation between the production of propionic and acetic acids has a relevant impact on methane production. The VFA's regulate the hydrogen supply which controls the production of methane. If carbohydrates would be fermented to acetic acid only, the energy loss from methane formation would be 33% (Wolin and Miller 1988). If the ratio of acetic and propionic acid was 0.5, the loss of energy as methane would be 0%.

Methane production from Livestock

Fig.1 illustrates that the enteric methane emissions are higher with ruminant animals while manure storage methane is higher with swine followed by poultry. On the contrary manure storage, nitrous oxide was highest with poultry followed by swine. Both parameters were low with ruminant animals.

Feed characteristics and methane production

There are some feed characteristics which influence CH_4 production, as the rumen-fermented organic matter has a close relationship with CH_4 production. Diets containing highly digestible fiber tend to lead to an increase in digestibility and consequently promote CH_4 production. Factors such as forage maturity and its physical form also influence CH4 production (Moss *et al*. 2000). For example, CH_4 production is lower in animals fed milled and pelleted forages compared with chopped forages (Hironaka *et al*. 1996).   It was reported that a diet with high content of pea/oat silage decreases the amount of enteric
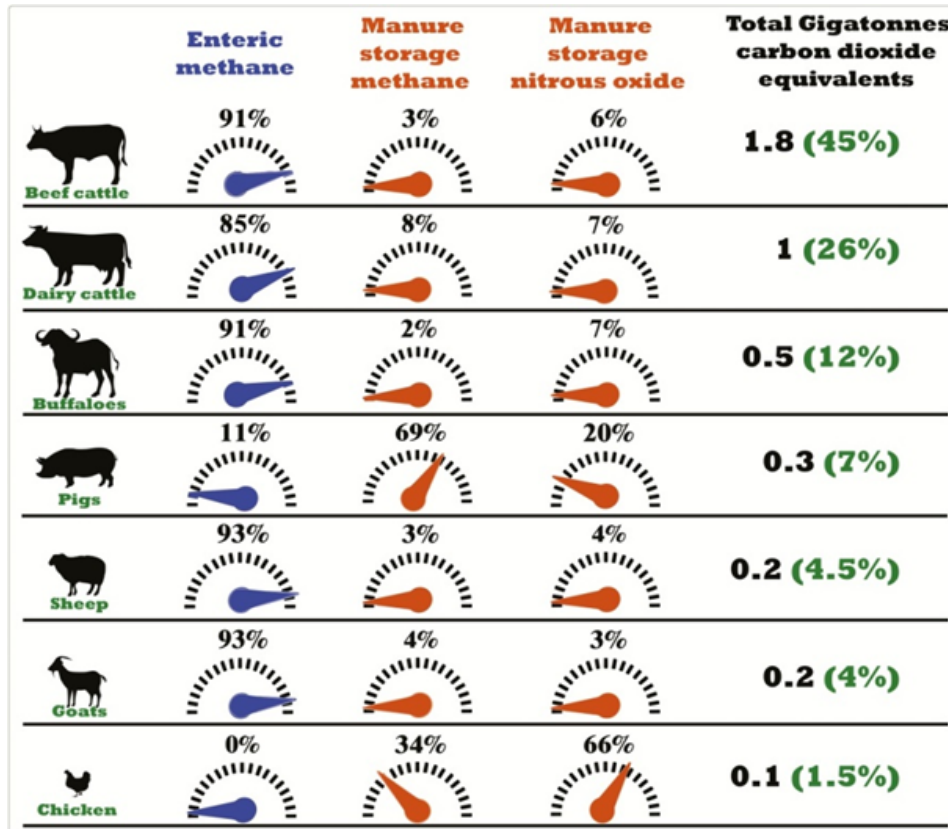
Figure 1: Livestock and climate change: impact of livestock on climate and mitigation strategies. Source: Giampiero Grossi *et al*. 2019.

methane compared to a diet with grass silage. Diets with pea/oat silage contain as expected, significantly higher amounts of starch than diets with grass silage. It was however not shown that a diet with high content of pea/oat silage generates less methane per kg of ingested starch than a diet with grass silage (Wirsenius *et al*. 2011)

Digesta passage rate and ambient temperature
It has been suggested that a cold environment may influence CH_4 production, mainly because the rumen passage rate increases in the cold climate, thereby decreasing CH_4 production (McAllister *et al*. 1996). Lower temperature decreases the ratio of acetate/propionate in sheep, resulting in a shift to propionate production instead of CH_4 production (McAllister *et al*. 1996). It has also been reported by Shibata and Terada, (2010) that in natural tropical environments, the content of components in the cell wall of plants such as

acid detergent fiber (ADF) and lignin tends to increase. These increases result in lower digestibility of feed and higher energy losses, causing an increase in CH_4 production per unit of product through the decrease in the efficiency of animal production (Shibata and Terada 2010).

Diet composition
The inclusion of concentrate is suggested to be a solution for mitigation purposes, as it shifts the fermentation towards propionate production. However, Sveinbjörnsson *et al*., (2006) found that the effect of starch on propionate production was small. McGinn *et al*., (2006) found the opposite effect, i.e. that increased concentration in the diet increased CH_4 production per unit dry matter intake (DMI). The inclusion of concentrate generates a higher amount of fermentable organic matter per unit of feed than with roughage alone, resulting in increased CH_4 production. The effect mainly depends on the inclusion level,

the effect on fiber digestibility and the type of grain used (Hristov *et al.* 2013). The inclusion of high sugar grasses can increase the efficiency of microbial growth in the rumen, by directing feed N into microbial protein and diverting H_2 to microbial cells rather than CH_4 production (Hristov *et al.* 2013). Stoichiometric fermentation equations published by Bannink *et al.* (2000) show concordantly that fermentation of sugar results in higher production of butyrate and lower production of propionate than fermentation of starch. On this basis, replacement of sugar by starch in the feed ration is expected to decrease methane production as actually shown by simulation with dynamic, mechanistic models (Mills *et al.* 2001; Kebreab *et al.* 2004) in which the fermentation equations of Bannink *et al.* (2008) were applied.

Dietary fat supplements

Supplementation of the ruminant diet with fat (oleic, linoleic and linolenic) is an effective method of suppressing CH_4 production (Beauchemin *et al.* 2009; Grainger and Beauchemin 2011). However, supplementation with fat is not always effective, as reported by Johnson *et al.* (2002). Using high levels of fat to reduce CH4 production can decrease DMI and productivity (Hristov *et al.* 2013). In most cases, the diet costs also increase, since feed energy is usually more expensive in fat than in cereal grains. However, according to a metaanalysis of a large data set from production trials, the optimal concentration of concentrate fat is 30-40 g/kg diet dry matter (DM) (Huhtanen and Nousiainen 2012). Consequently, small amounts of supplementary fat can both increase productivity and reduce CH_4 production. A summary of feeding man-

Table 1: Summary of feeding management approaches to altering rumen fermentation and reducing CH_4 emissions per unit of energy corrected milk (ECM)[1].

Feeding alteration	CH_4/ECM	Assumption(s) and comments
Increased DMI	Decreased 2 to 6% for each kilogram increase in DMI	(a) Increased fill; (b) increased rate of solids passage; (c) decreased rumen neutral detergent fiber (NDF) digestibility will be compensated by increased hindgut NDF digestibility; (d) decreased rumen starch digestibility; (e) increased starch digestion in the small intestine; (f) no difference in total-tract starch digestion; (g) increased production
Decreased forage particle size	Neutral	(a) Increased passage of forage particles from the rumen; (b) decreased rumen NDF digestibility will be compensated by increased hindgut NDF digestibility
Grain processing	Decreased 1 to 2.5% with a 5% increase in apparent total-tract starch digestibility	(a) Decreased grain particle passage from rumen; (b) increased VFA yield with the increased proportion of propionate; (c) no increase in intake of digestible DM (which may or may not be true)
Rumen pH <5.5	Decreased 15 to 20%	(a) Decreased rumen NDF digestibility not fully compensated for by hindgut fermentation; (b) assumes 50% reduction in apparent total-tract NDF digestibility; (c) milk yield reduced 10 to 15%; (d) no change in rumen starch digestibility and no effect on DMI

Table 1 Continued

Feeding alteration	CH₄/ECM	Assumption(s) and comments
Increased concentrate feeding	Decreased 2% for every 1% increase in ration NFC; maximum reduction ~15%	(a) Effects manifested by less NDF fermented in the total tract, the shift of starch digestion from the rumen to the small intestine, and possibly lower rumen pH; (b) potential to increase intake; (c) higher proportions of propionate
Increased forage quality achieved by better management of harvesting and storage or pasture management	Decreased up to 5% with a 5 percentage unit increase in apparent total-tract NDF digestibility	(a) Increased yield of VFA (energy) is greater than increases in CH4; (b) increased milk yield
Forage type/strain selection and genetics (eg. brown midrib corn)	Decreased 0 to 4%	Improvements in digestibility lead to increased DMI, energy availability, and milk yields
Lipid feeding	Decreased 5% per unit of ether extract in ration	Potential for (a) decreased DMI, (b) decreased NDF digestibility, (c) decreased lactation performance, and (d) decreased milk components

[1]Many of the biological effects are interrelated and interdependent and, accordingly, the changes in enteric CH4 emissions per unit of ECM (CH4/ECM) are not likely to be additive. Expected decreases in CH4/ECM range from 0 to 15%. These changes are modest because the range of alterations was restricted to what might reasonably be implemented or occur in commercial dairy production without compromising milk yield significantly (except as noted for rumen pH) compared with previously published reviews where the manipulations ranged from all-forage to all-concentrate diets for nonlactating and lactating animals. Manipulations that alter carbohydrate digestibility and thus energy availability will affect milk yield as well as CH4 emissions.
Source: Knapp *et al.* (2014)

agement approaches to altering rumen fermentation and reducing CH₄ emissions per unit of energy corrected milk (ECM) are shown in the Table 1.

Condensed Tannins (CTs)
The effect of CTs on rumen fermentation show that CTs exhibit strong antibacterial activity on fibrolytic species often resulting in reduced digestibility of NDF and ADF. Responses of methanogens to CT have been noted to be type and dose-dependent. Jayanegara *et al*. (2009) reported an inverse relationship between dietary tannin concentration and CH₄ production per unit of digestible organic matter (OM) in rumen fermentation. Tavendale *et al*. (2005) reported both bacteriostatic and bactericidal properties of Lotus pedunculatus on the common rumen methanogen Methanobrevibacter ruminantium in vitro. Waghorn *et al*. (2002) evaluated the potential of Lotus pedunculatus and reported a 16% reduction in

methane production (in g CH₄ kg-1 dry matter intake) in lambs due to the presence of CTs in the forage.   Similarly, Carulla *et al*. (2005) observed a 13% reduction in CH₄ emissions when Acacia mearnsii CT extract was administered at 25g/kg feed DM to sheep. Condensed tannin forage and condensed tannin extract used in literature have however shown wide variation in their anti-methanogenic effect, which according to Mané *et al*. (2007), is related to their average molecular weight and the degree of polymerization of the CTs. The chemical structure and molecular weight of CTs have been observed to play a significant role in their biological activity (Naumann *et al*. 2014) and 26 condensed tannin-protein interactions (Soares *et al*. 2007).

Use of fibrolytic enzymes
Sujani and Seresinhe (2015), reviewed that fibrolytic enzyme application showed inconsistent but positive responses on feed intake,

nutrient digestibility, growth performance, production parameters and manure nutrient excretion etc. in the studies done with ruminants like cattle both dairy and beef, goat, sheep and less with buffalo. Mohamed (2013), found that supplementation of early lactating dairy cow diet with fibrolytic enzymes (Enzyme was added to the total mixed ration at the time of feeding), did not cause any significant changes in dry matter intake but milk yield was improved significantly. Soltan *et al.* (2013) reported that the use of exogenous enzymes, particularly cellulases, increases CH_4 production, indicating that there is a forage-enzyme interaction. The above results are consistent with the findings of Gemeda and Hassen (2015) who observed an increasing volume of methane gas with increasing levels of enzyme application for the feeds treated with enzymes, compared to the control samples. Likewise, Arriola *et al.* (2011) observed that, in cows fed high concentrate diets, enzyme supplementation decreased the acetate: propionate ratio in rumen fluid, and hence a reduction in methane production (calculated from VFA profiles, using a fermentation balanced approach). The results of Seresinhe *et al.* (2017) concur with those of Giraldo *et al.* (2008) who found that methane production was not influenced by fibrolytic enzyme supplementation. In an in-vitro study conducted by Togtokhbayar *et al.* (2015)

Table 2: Use of methane inhibitors in reducing enteric methane production.

Name of inhibitor	Action	Adverse / desirable effects	Source
Chloroform, amichloral and 2-25 bromoethanesulphonic acid (BES)	Suppress methanogenesis	Liver damage and even death	Dong *et al.* 1999
2-25 bromoethanesulphonic acid (BES)	Effect of BES is momentary and CH_4 production rapidly returns to its original level of emission within some days		McAllister and Newbold 2008
Fungi	Reduction in total gas production after fermenting palm kernel cake	The reduction could be due to the production of some special compounds such as statins during the fermentation, thereby inhibiting the emission of gases	Ramin *et al.* 2010
HMG-CoA (mevastatin) in vitro to a co-cuture comprising CH_4-producing bacteria and other eubacterial species.	Mostly cellulolytic, inhibited the growth of Methano-brevibacter.	Without causing any growth inhibition on other bacterial species.	Wolin and Miller, 2006
Lonophores (lipid-soluble molecules)	To reduce CH_4 production.		Moss *et al.* 2000
	It promotes the production of propionate at the expense of acetate and reduces feed intake.		Johnson and Johnson 1995; Baker 1999; Hegarty 1999

Table 2 Continued

Name of inhibitor	Action	Adverse / desirable effects	Source
Monensin	Gram-negative bacteria are resistant.	CH_4-producing Grampositive bacteria are not resistant to ionosphere antibiotics.	Wolin and Miller 2006
Monensin	Causes high intracellular NADH/NAD+, which reoxidises NADH while limiting the H_2-yielding acetate pathway.	Lonophoric antibodies (eg. monensin and related compounds) are prohibited within the European Union countries.	Hegarty 1999
Commercial allicin products originating from garlic	Effective in inhibiting CH_4 production at a dose of 20g/mL without any adverse effect on daily VFA production.	The inhibitory effect was mainly a direct effect on methanogen DNA.	McAllister and Newbold 2008
Hops acid	Increasing the concentration of hops acid from 50 to 400g/mL in an in vitro gas production system, CH_4 production quadratically decreased per unit DM digested.		Narvaez *et al.* 2011
Egg Albumin (EA), chitosan (CH) and polyethylene glycol (PEG).	Supplementing EA, CH and PEG are beneficial in terms of In Vitro Gas Production, Short Chain Fatty Acids and Ammonia nitrogen (NH_3-N) production but no significant effect on methane production.		Sujani *et al.* 2017
Polyethylene glycol (PEG)	Good relationship between PEG binding and the improvement of In Vitro Dry Matter Digestibility of C. calothyrsus as a result of lower invitro gas production		Seresinhe and Iben, 2003

where they have used Xylanase supplemented to wheat straw in goat rumen fluid, they observed increased CH_4 production, linearly at 24 h of incubation. Table 2 summarized the use of methane inhibitors in reducing enteric methane production.

Defaunation
Protozoa are microorganisms living in the rumen that contribute up to 50% of fibrolytic activity within the rumen (Coleman, 1986). Defaunation is an effective mitigation strategy, i.e. elimination of protozoa from the rumen results in a decrease in CH_4 production (Moss *et al.* 2000; McAllister and Newbold 2008). Defaunation can be done by lowering the pH in the rumen (feeding grain) or giving oils such as highly unsaturated C_{18} fatty acids (linseed oil) to the animal (Hegarty 1999). Defaunation is a process that disrupts the cross-

feeding between ruminal protozoa and Archaea in the rumen. Defaunation increases the proportion of propionate in the rumen improves the efficiency of microbial cell synthesis and decreases diet digestibility (Eugène *et al.* 2008), all of which can contribute to reduced CH_4 production.

Vaccines and other factors

Vaccination is a novel strategy to reduce CH_4 production in ruminants. It is based on a continuous supply of antibodies to archaea through the saliva in the animal. However, attempts to use vaccines in vivo against methanogens have not been successful (Wright *et al.* 2004). One reason could be the growth of other methanogenic strains in the rumen to replace those methanogens against which the antibodies are generated (McAllister and Newbold 2008). However, the vaccination strategy to reduce CH_4 production is an attractive method, as it can be applied to all types of ruminants. Biological strategies to control methanogens is one approach for influencing CH_4 production. Archaeal viruses and bacteriocins, eg. nisin produced by Lactococcus lactis, are safe natural feed additives that can be used to control rumen methanogens. Archaeal viruses (eg. bacteriocins) are biological treatments that raise the H2 pressure sufficiently in the rumen to initiate acetogenesis (Klieve and Hegarty 1999).

Table 3: Description of livestock waste deposition and storage pathways. Source: Dunkley and Dunkley (2013)

Manure Management System	Description	Relative Emissions	
		CH$_4$	N$_2$O
Pasture/range/paddock *Ex. beef cattle*	Manure and urine from pasture and grazing animals is deposited directly onto soil.	Low	High
Daily Spread	Manure and urine are collected and spread on fields (little or no storage prior to application).	Low	Minimal
Solid storage *Ex. poultry*	Manure and urine with or without litter are collected and stored long term in bulk	Low	High
Dry lot *Ex. Beef cattle*	Manure and urine are deposited directly on unpaved feedlots where it is allowed to dry. It is periodically removed.	Low	High
Liquid/slurry *Ex. Swine/dairy cattle*	Manure and urine are collected and transported in liquid form to tanks for storage. The liquid/ slurry may be stored for long periods.	Moderate to high	Low
Anaerobic Lagoon *Ex. Swine/dairy cattle*	Manure and slurry are collected using a flush system and transported to lagoons for storage. It remains in lagoons for 30-200 days.	Variable	Low
Pit Storage *Ex. Swine/poultry layers*	Combined storage of manure and urine in pits below livestock confinements.	Moderate to high	Low
Poultry with litter *Ex. Broiler/pullet/ breeders*	Enclosed poultry houses utilize bedding material (ex. Wood shavings, peanut hull, rice hulls etc.). The bedding absorbs moisture and dilutes manure. Litter is cleaned out typically once per year.	Low	High
Poultry without litter *Ex. Poultry layers/ broiler breeders*	In high-rise cages or scrape-out/belt systems, manure is excreted onto the floor below with no bedding to absorb moisture. The ventilation system dries the manure as it is stored.	Low	High

Emissions based on manure management systems.

According to Dunkley and Dunkley (2013), (Table 3) the type of manure management system that is used in livestock production can affect the amount of emissions and the type of gases that are emitted. Manure management systems practiced in different farms are; pit storage, poultry with/without litter (that is, poultry raised on a bedding material or poultry raised in cages), dry-lot, anaerobic lagoon, pasture, etc.

The role of dung beetles in reducing GHG emissions from cattle farming

A study was done in Finland, (Slade *et al.* 2016) assessed GHG emissions at three scales: the dung pat, pasture ecosystem, and whole lifecycle of milk or beef production. At the first two levels, dung beetles reduced GHG emissions by up to 7% and 12% respectively, mainly through large reductions in methane (CH_4) emissions. However, at the lifecycle level, dung beetles accounted for only a 0.05–0.13% reduction of overall GHG emissions. This mismatch derives from the fact that in intensive production systems, only a limited fraction of all cow pats end up on pastures, offering limited scope for dung beetle mitigation of GHG fluxes. In contrast, they suggested that the effects of dung beetles may be accentuated in tropical countries, where more manure is left on pastures, and dung beetles remove and aerate dung faster. These considerations give a new perspective on previous results and suggest that studies of biotic effects on GHG emissions from dung pats on a global scale are a priority for current research (Slade *et al.* 2016)

The global scenario on GHG emissions and mitigation

Herrero *et al.* (2016) emphasized that the livestock sector supports about 1.3 billion producers and retailers, and contributes 40-50% of agricultural GDP. They estimated that between 1995 and 2005, the livestock sector was responsible for GHG emissions of 5.6-7.5 $GtCO_2e$ yr^{-1}. Livestock accounts for up to half of the technical mitigation potential of the agriculture, forestry and land-use sectors, through management options that sus-

tainably intensify livestock production, promote carbon sequestration in rangelands and reduce emissions from manure, and reductions the demand for livestock products. The economic potential of these management alternatives is less than 10% of what is technically possible because of adoption constraints, costs and numerous trade-offs.

O'Mara (2011) reported that as assessed by IPCC, Animal agriculture is responsible for 8-10.8% of global GHG emissions. However, on the basis of lifecycle analysis, the contribution of livestock is up to 18% of global emissions. Asia is the source of the most enteric CH_4 emissions with Latin America, Africa, Western Europe and North America being significant sources. These emissions are dominated by emissions from cattle. When GHG emissions are related to food production, the four most efficient regions are Eastern and Western Europe, North America, and the non-EU former Soviet Union which produced 46.3% of ruminant meat and milk energy and only 25.5% of enteric CH4 emissions in 2005. In comparison, the three least efficient producers (Asia, Africa, Latin America) produced an equivalent amount (47.1%) of ruminant meat and milk energy and almost 69% of enteric CH_4 emissions in 2005. Livestock related emissions will increase as world population and food demand increases; enteric CH_4 emissions were projected to grow by over 30% from 2000 to 2020. There are mitigations available now, but it is imperative to develop new mitigations and ways to implement existing technologies more cost-effectively.

GHG emissions from the EU livestock sector

According to Lesschen *et al.* (2011), there are increasing concerns about the ecological footprint of global animal production. They reported regional variations in dairy, beef, pork, poultry and egg production, and related GHG emissions in the 27 Member States of the European Union (EU-27), based on 2003–2005 data. Analyses were made with the MITERRA-Europe model which calculates annual nutrient flows and GHG emissions from agriculture in the EU-27. The dairy sector had the highest GHG emission in the EU-27, with an-

nual emission of 195 Tg CO_2-eq, followed by the beef sector with 192 Tg CO_2-eq. Enteric fermentation was the main source of GHG emissions in the European livestock sector (36%) followed by N_2O soil emissions (28%). On a per kg product basis, beef had by far the highest GHG emission with 22.6 kg CO_2-eq/kg, milk had an emission of 1.3 kg CO_2-eq/kg, pork 3.5 kg CO_2-eq/kg, poultry 1.6 kg CO_2-eq/kg, and eggs 1.7 kg CO_2-eq/kg. However large variations in GHG emissions per unit product exist among EU countries, which are due to differences in animal production systems, feed types and nutrient use efficiencies. These results provide insight into differences in GHG sources and emissions among animal production sectors for the various regions of Europe.

Likewise, Weiss and Leip (2011) presented detailed product-based net emissions of main livestock products (meat, milk and eggs) at the national level for the whole EU-27 according to a cradle-to-gate life-cycle assessment, including emissions from land use and land-use change (LULUC). Total GHG fluxes of European livestock production amounts to 623-852 Mt CO_2-eq; 182-238 Mt CO_2-eq (28-29%) is from beef production, 184–240 Mt CO_2-eq (28–30%) from cow milk production and 153-226 Mt CO_2-eq (25-27%) from pork production. According to IPCC classifications, 38-52% of total net emissions are created in the agricultural sector, 17–24% in the energy and industrial sectors. 12–16% Mt CO_2-eq are related to land use (CO_2 fluxes from the cultivation of organic soils and reduced carbon sequestration compared to natural grassland) and 9-33% to land-use change, mainly due to feed imports. The results suggest that for effective reduction of GHG emissions from livestock production, fluxes occurring outside the agricultural sector need to be taken into account. Reduction targets should address both the production side as defined by IPCC sectors and the consumption side. An LCA assessment as presented here could be a basis for such efforts.

Bustamante *et al*. (2012) in a study estimated, for the first time, the GHG emissions associated with cattle raising in Brazil, focusing on three principal sources: 1) portion of deforestation resulting in pasture establishment and subsequent burning of felled vegetation; 2) pasture burning; and 3) bovine enteric fermentation. Deforestation for pasture establishment was only considered for the Amazon and Cerrado. Emissions from pasture burning and enteric fermentation were accounted for the entire country. The consolidated emissions estimate lies between approximately 813 Mt CO_2eq in 2008 (smallest value) and approximately 1,090 Mt CO_2eq in 2003 (greatest value). The total emissions associated with Amazon cattle ranching ranged from 499 to 775 Mt CO_2eq, that of the Cerrado from 229 to 231 Mt CO_2eq, and that of the rest of the country between 84 and 87 Mt CO_2eq. The full set of emissions originating from cattle raising is responsible for approximately half of all Brazilian emissions (estimated to be approximately 1,055 Mt CO_2eq in 2005), even without considering cattle related sources not explicitly estimated in this study, such as energy use for transport and refrigeration along the beef and derivatives supply chain. The potential for reduction of GHG emissions offered by the Brazilian cattle industry is very high and might constitute Brazil's most important opportunity for emissions mitigation. The study offers a series of policy recommendations for mitigation that can be implemented by public and private administrators at a low cost relative to other GHG reduction options.

Mitigation of GHG emissions at the global level
In the Fig 2, red represents the range for each practice, where available. The range of mitigation potentials for carbon sequestration due to improved grazing management is defined by Smith *et al*. (2008) and Clough *et al*. (2009). The mitigation potentials for 10% improved digestibility in all ruminants in the developing world are shown, obtained by up-scaling values from Thornton and Herrero (2010). Direct application of this option to developed country situations was assumed to be too small to be considered. Full adoption of the practice across all ruminants was assumed to obtain the technical mitigation potential for this practice, hence no range is pre-
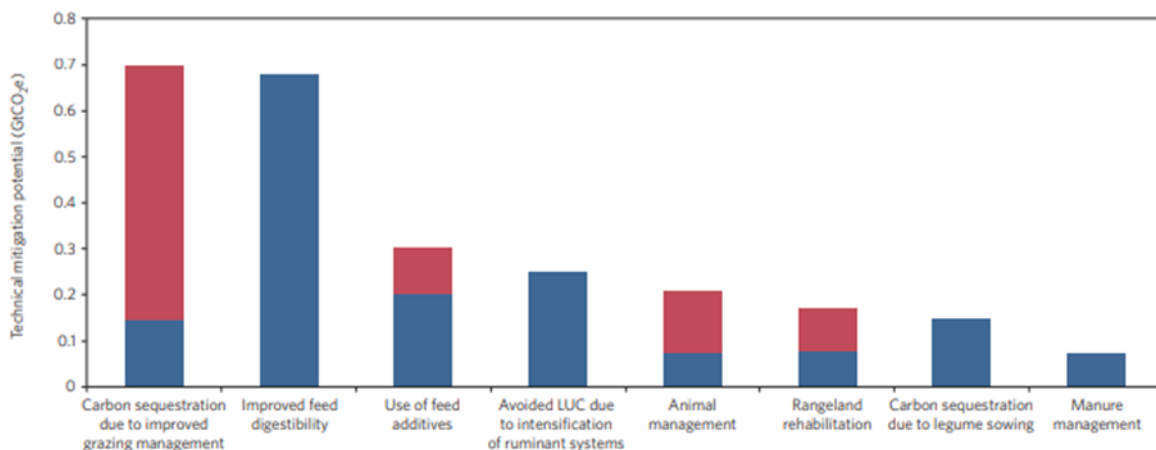
Figure 2: Technical mitigation potentials of supply-side options for reducing emissions from the livestock sector. Source: Herrero *et al.* 2016.

sented. The mitigation potentials for use of feed additives are from Hristov *et al*. (2013) and include inhibitors, ionophores, electron receptors, enzymes, plant bioactive compounds, lipids and manipulation of rumen microflora. These potentials are applied to breeding herds of cattle globally with effects on ECH_4 as described in Hristov *et al*. (2013). The mitigation potentials of avoided land-use change from transitions from grazing to mixed crop-livestock systems are from Havlík *et al*. (2014). The mitigation potentials

for animal management practices such as improved health and reduced mortality are from Hristov *et al*. (2013). and the effects applied as for feed additives. Rangeland rehabilitation mitigation potentials are from Henderson *et al*. (2015). Manure management mitigation potentials are from Smith *et al*. (2008).

Sri Lankan Scenario on GHG emission and mitigation options.
The report published by the Food & Agriculture Organization & New Zealand Agricultur-
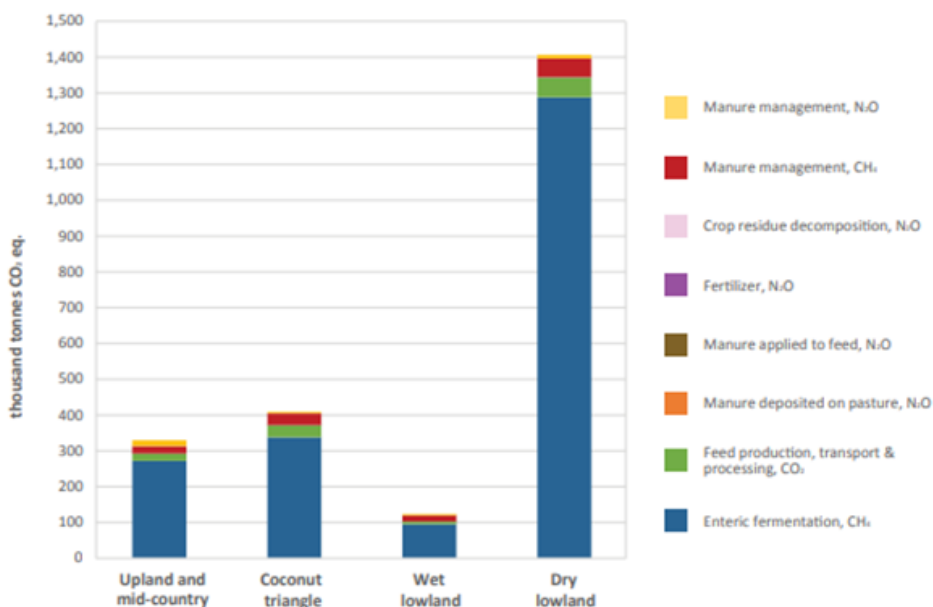
Figure 3: Emission intensity per kg FPCM, by production system in Sri Lanka (FAO & NZAGGRC 2017).

al Greenhouse Gas Research Center (FAO and NZAGGRC) in 2017, the dairy cattle sector produces about 0.32 million tons of milk; of this 43 percent of the milk is produced by the intensive systems in the Upland and Mid-country production zones, while 31 percent, 18 percent and 8 percent are produced in the Dry Lowland, Coconut Triangle and Wet Lowland zones, respectively. Milk production from the dairy cattle sector in Sri Lanka emits about 2.3 million tons CO_2eq (Fig.3). The emission's profile of milk is dominated by methane (93.2 percent), while nitrous oxide (N_2O) and carbon dioxide (CO_2) contribute 1.6 percent and 5.2 percent of the total emissions, respectively. Three sources of emission contribute to the bulk of emissions from dairy cattle. Approximately 88 percent of the emissions arise from methane produced by the rumination of cows and 5 percent from the management of stored manure. CO_2 emissions associated with feed production,

Table 4: Summary of selected interventions to mitigate GHG emission in livestock systems in Sri Lanka. Source: FAO & NZAGGRC 2017.

Intervention	Objective and constraint addressed	Mitigation mechanism
Supplementation with fodder trees and low-cost concentrate	•Minimize quantitative and qualitative deficiency of basal diet to address feed seasonality and quality constraints	•Lower CH_4 observed with legumes is attributed to lower fiber content and faster rate of passage of feed through the rumen and therefore intakes are higher with regular forages
Supplementation with rice straw concentrate mixture	•Supplementation of diet with good quality concentrates helps overcome problem of palatability and digestibility	•A high proportion of concentrate in diet reduces rumen pH and consequently affects the protozoa population
Use of total mixed ration	•Increase efficiency of dietary nutrient use by providing critical nutrients that are deficient in the diet and therefore balancing nutrient availability with animal requirements	•Alters human fermentation towards more production of microbial protein and lower volatile fatty acid production improves efficiency of nutrient utilization, improves productivity and reduces methane emission
Supplementation of forage diet with Gliricidia blocks	•Improve the quality of low basal diets and addresses feed availability during periods of scarcity	•Provides rumen fermentable nitrogen and by-pass protein to fibrous diets. •Promotes high dry matter intake and have a faster rate of passage through the rumen and reduction of CH_4/ FPCM
Under health management (prevention of mastitis)	•Improve health status of animals, increase productivity •Reduce economic losses for farmers and reduce human health risks, High morbidity •Reduced milk production and milk wastage	•Enhanced animal productivity and reduced GHG emission intensity.
Animal comfort (heat stress management)	•Improve productive and reproductive performance of animals •Addresses reduced milk production, decreased reproductive efficiency	•Enhanced animal productivity and reduced GHG emission intensity.

transport and processing contribute an additional 5 percent to total emissions. At the national level, the emission intensity of milk produced in Sri Lanka is on average 6.9 kg CO_2eq./kg FPCM; the highest values were estimated for the low input-output dairy systems in the Dry Lowland zone and the lowest in in the intensive systems in the Upland and Mid-country production zone. Emissions were on average, 13.8, 6.8, 4.8 and 2.3 kg CO_2eq./kg FPCM (fat and protein corrected milk) for the Dry Lowland, Coconut Triangle, Wet Lowland and Upland and Mid-Country systems, respectively. A summary of selected interventions to mitigate GHG emission in livestock systems in Sri Lanka are shown in Table 3.
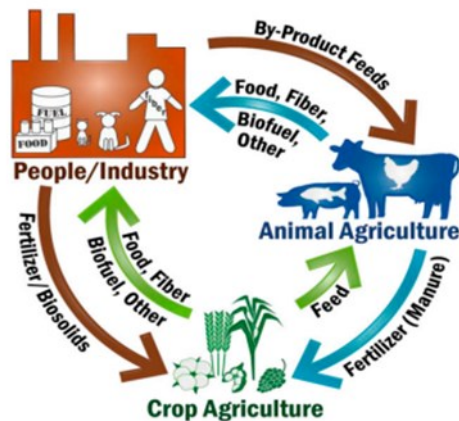
Figure 4: United States food production as an ecosystem with transactions between components (White and Hall (2017).

Nutritional and GHG impacts of removing animals from agriculture

White and Hall (2017), suggests that removing animals from US agriculture would reduce agricultural GHG emissions, but would also create a food supply incapable of supporting the US population's nutritional requirements (Fig. 4). US agriculture was modelled to determine the impacts of removing farmed animals on food supply adequacy and GHG emissions. The modelled system without animals increased total food production (23%), altered foods available for domestic consumption, and decreased agricultural US GHGs (28%), but only reduced total US GHG by 2.6 percentage units.

Compared with systems with animals, diets formulated for the US population in the plants-only systems had greater excess of dietary energy and resulted in a greater number of deficiencies in essential nutrients. The results give insights into why decisions on modifications to agricultural systems must be made based on a description of direct and indirect effects of change and a dietary, rather than an individual nutrient, basis.

Valin *et al*. (2013) investigated the effects of crop yield and livestock feed efficiency scenarios on GHG emissions from agriculture and land-use change in developing countries. The results confirmed that yield increase could mitigate some agriculture-related emissions growth over the next decades. Closing yield gaps by 50% for crops and 25% for livestock by 2050 would decrease agriculture and land-use change emissions by 8% overall, and by 12% per calorie produced. However, the outcome is sensitive to the technological path and which factor benefits from productivity gains: sustainable land intensification would increase GHG savings by one-third when compared with a fertilizer intensive pathway. Reaching higher yield through total factor productivity gains would be more efficient on the food supply side but halve emissions savings due to a strong rebound effect on the demand side. Improvement in the crop or livestock sector would have different implications: crop yield increase would bring the largest food provision benefits, whereas livestock productivity gains would allow the greatest reductions in GHG emission. Combining productivity increases in the two sectors appears to be the most efficient way to exploit mitigation and food security co-benefits.

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