Revista Chapingo Serie Zonas Áridas
E-ISSN: 2007-526X
rchsza@chapingo.uruza.edu.mx
Universidad Autónoma Chapingo
México

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Revista Chapingo Serie Zonas Áridas, vol. XI, núm. 1, 2012, pp. 45-50
Universidad Autónoma Chapingo
Durango, México

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METHANE EMISSIONS CAUSED BY CATTLE AND MANURE IN THE LAGUNA REGION: ENVIRONMENTAL IMPACT AND OPORTUNITIES FOR BIOGAS PRODUCTION

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RESUMEN. La Comarca Lagunera representa el 0.03 % del territorio mexicano y cuenta con el 0.2 % de la población lechera nacional, la cual cuenta con aproximadamente 430,000 cabezas de ganado. La industria ganadera produce metano de dos formas. La más importante es la fermentación entérica, derivada de la alimentación de rumiantes, y la segunda es debida al manejo del estiércol. Una vez que el metano es liberado a la atmósfera, se reconoce su importancia como un gas del efecto de invernadero, que es 58 veces más efectivo que el dióxido de carbono. Para estimar la cantidad de metano liberado en esta región, se realizó la estimación de las emisiones de CH_4 originadas por el ganado de la Comarca Lagunera empleando el modelo del Grupo Intergubernamental del Cambio Climático (IPCC). Se determinó la liberación 55 Gg de CH_4 por año, lo cual representa un 2.5 % de las emisiones nacionales de origen ganadero, una gran cantidad considerando el área de la región (0.03 %). El ganado fue responsable del 83 % de la fermentación entérica liberada a la atmósfera, y el restante 17 % se originó de los sistemas de manejo del estiércol. Entre las alternativas para aminorar las emisiones de CH_4, se cuenta con mejorar la calidad de la dieta para una mejor utilización de los insumos proporcionados, por ejemplo, la reducción en la pérdida de energía en las formas de metano y empleo de subproductos del girasol (aceite) o monesina además de raciones basadas en maíz, todo lo cual puede disminuir las emisiones hasta en un 20 %. Sin embargo, posteriores investigaciones requieren precisar este fenómeno y realizar análisis de costo-beneficio y factibilidad a gran escala.
Palabras clave: Metano, biogás, gases de invernadero, cambio climático, establos.

SUMMARY. The Laguna region represents 0.03 % of the Mexican territory and holds 0.2 % of the national milking cow population, with approximately 430,000 heads. Livestock produce methane from two ways. The most important source is enteric fermentation of feed by ruminants, and the second is manure management. Once methane is released to the atmosphere, it is well known to be an important Greenhouse Gas (GHG), 58 times more efficient than carbon dioxide as an Infrared (IR) radiation trap. CH_4 emissions from cattle origin in the Laguna region have been estimated using the IPCC model. Fifty five Gg of CH_4 are produced per year which represents 2.5 % of national CH_4 emissions from livestock origin, a high amount considering the area of the region (0.03 %). For cattle, enteric fermentation is responsible for 83 % of CH_4 released in the atmosphere and 17% comes from manure management systems. Among the existing alternatives for mitigating those CH_4 emissions, improvements in diet quality toward better utilization of ingested energy, i.e. reduction of energy losses in the form of methane, and utilization of supplements such as sunflower oil or monensin in addition to maize based ration may decrease CH_4 emissions up to 20%. However, further investigation is needed to better understand these phenomena and find out cost effective and large scale feasible alternatives.
Keywords. CH_4, biogas, greenhouse gases, climatic change, livestock farming.

INTRODUCTION

The Laguna region, located on the states of Coahuila y Durango in the northern México, is the most important milk production region in the country. This area extends over 44,887 km², and is located at 101° 40´ W Long, 25° 05´ N at an altitude of 1,120 meters over the sea level (Anonymous 2006 www.inegi.gob.mx). The Laguna region represents 0.03 % of the Mexican territory and holds 0.2 % of the national milking cow population, with

Recibido: marzo 15, 2011
Aceptado: julio 11, 2011

425,960 heads in 2005 (Anonymous, 2005 www.siap.gob.mx). This cattle is mainly reared in an intensive way in order to supply the needs of an industrialized milk production, such as the LALA or the Bell companies, which are the leaders in the region with a production of about $1.8x10^9$ litters/year (Anonymous, 2006 www.siap.gob.mx) mainly intended for exportation out of the Laguna region.

Such a production in a semi arid area is an ecological paradox regarding to the water availability in the region. Indeed, many rivers in the region have been dried due to field irrigation for forage production and the levels of underground water are decreasing dramatically since high yields irrigated crop productions have been started in the Laguna. The region also suffers soil fertility problems on account of maize (*Zea mays*) and alfalfa (*Medicago sativa*) monoculture practices. Sustainability for livestock agroecosystems is thus in at critical point. Cattle rearing and especially large milking cow feedlots are criticized for their contribution to air pollution, i.e. unpleasant smell and methane (CH_4) production. Livestock produce methane from two ways. The most important source is enteric fermentation of feed by ruminants, and the second is manure management (Ruiz-Suárez & Gonzalez-Ávalos 1997), that varies according to storage systems and composting methods at work (Hao *et al*., 2001; Umetsu *et al*., 2005). Once methane is released to the atmosphere, it is well known to be an important Greenhouse Gas (GHG), 21 or 58 times more efficient -by molecule or by mass, respectively - than carbon dioxide as an Infrared (IR) radiation trap (Stedd & Hashimoto, 1993). Methane also contributes to the deterioration of the ozone layer (Rhoderick & Dorko 2004). It is the second GHG involved in the global warming (after CO_2 O_3) and its global participation to climate forcing in the past 150 years is 0.57 Wm^{-2}, which is about 35 % of the climate change caused by carbon dioxide (1.6 Wm^{-2}) (Lelieved *et al*., 1998). The importance of global warming for environmental stability does not need to be proved nowadays as it has already been the topic of numerous investigations. However, a huge uncertainty remains on its consequences on human and natural ecosystems (Penman *et al*., 2000).

Methane presence in the atmosphere is also a source of health problems due to its capacity to produce ozone while decomposing in the troposphere. Increase in tropospheric of ozone is associated with premature mortality, respiration y cardiovascular problems, as well as ecosystem perturbations. Mitigation of ozone pollution with better methane emission management brings global health benefits for human societies and the environment (Weast *et al*., 2006). Methane effects on global warming and human health raise the problem of the sustainability of methanogenic activities such as cattle rearing. Although many other sectors contribute to methane emissions (industry, transports, etc.), improvements in livestock management - both for enteric fermentation and for manure management -have to be considered seriously. Several ways are available today to influence CH_4 impact on ecosystems, among which are diet improvement toward better utilization of ingested energy (Beachemin & McGinn, 2005) and biogas production. Indeed, methane is an important renewable energy source. Anaerobic digestion (AD) processes for cattle manure composting offer an interesting alternative for farm owners to reduce methane emissions on a local scale while generating bio energy (biogas). Comparing traditional manure management methods AD process presents advantages such as odor elimination, nutrient recovery and mitigation of lixiviation, reduction of pathogen risks and diminution of GHGs emissions (Wilkie, 2005a, 2005b). The Laguna region represents a non negligible potential for biogas production because of its important cattle population, and the availability of both simple y complex biogas production systems gives farmers all the possibilities to get into such a progress.

The objective of this paper is to examine and quantify methane emissions from cattle in the Laguna region, using models given by the Intergovernmental Panel on Climate Change (Hougthon *et al*., 1997; Dong *et al*., 2006). Further, we will see in more detail how methane impacts on climate and human health, and to explore the existing ways to reduce methane emissions from cattle and finally estimate the biogas potential of the region.

Methane emissions from livestock in the Laguna region

Livestock and especially ruminants (bovine and ovine) produce methane in two ways. The first and most important one is enteric fermentation, where methane originates from carbohydrate reduction by anaerobic micro organisms during the digestion process. CH_4 quantity depends on animal type, age, weight and diet (Carmona *et al*., 2005). The second way results from anaerobic decomposition of manure, and its intensity increases when an important cattle population is kept in closed areas, i.e. feedlots and “loose-housing” systems (Hougthon *et al*., 1997).

The methane emissions level in a region is an excellent way for identifying mitigation options. Hougthon *et al* (1997) developed a general model to estimate GHGs emissions from anthropogenic sources. The agriculture section presents methods to evaluate methane emissions from cattle, taking in account data such as cattle population, climate characteristics and manure management practices, and emission factors for both enteric and manure anaerobic fermentation. The IPCC Tier 2 models suffer a lack of precision when applied to the case of Mexico (González-Ávalos & Ruíz-Suárez, 2001). They have determined country-specific emission factors for the national inventory closer to the reality. Those emission factors are used in the present paper for methane emission calculations in the Laguna region. The results show that CH_4 emissions from domestic livestock in the Laguna region are about 55 Gg yr^{-1} (Table 1), which represent 2.5 % of national emissions, concentrated in 0.03 % of national territory. The biggest part (83 %) is due to enteric fermentation of dairy cattle, i.e. dairy cows (~46 Gg yr^{-1}). The emissions from manure management (17 %), are imputable to poultry farming with ~0.5 Gg yr^{1}.

The lack of regional data about CH_4 emissions from fuel combustion, industrial processes and waste treatment makes impossible comparison with those sectors, but national data from the national inventory of GHGs 1994-1998 shows that methane from livestock origin is about 25% of the total CH_4 released. Any reduction in this sector would thus have an important impact on these emissions.

Effects of CH_4 on global warming

The emission of CH_4 in the atmosphere presents direct and indirect effects. The direct effect consists in the contribution to climate forcing of the CH_4 molecules. One added CH_4 molecule absorbs infrared radiation about 25 times more efficiently than one added CO_2 molecule (Lelieveld *et al*., 1993), which can be partly explained by the fact that CO_2 levels are about 200 times higher y therefore its absorption lines are already saturated (Lelieveld *et al*., 1998). This makes CH_4 being one of the two most important today's greenhouse gas in the atmosphere after CO_2 (with ozone) (Ramaswamy, 2001). Further, decomposition of CH_4 generates formation of other radiatively active gases which increase its direct effect on climate forcing by aproximatively 30 % (Lelieveld *et al*., 1998),. Thoses gases are tropospheric ozone (O_3), CO_2 and water vapour.

Impacts of CH_4 emissions and of its decomposition products

Importance of greenhouse gases on climate change has not anymore to be demonstrated, as it is commonly accepted as one of most serious impacts of human activities on the environment, both by the scientific community (Hougthon *et al*., 1997) and today, by the wide public. However, besides this primordial aspect, some of the greenhouse gases may procure additional negative effects. It is the case of increasing tropospheric ozone. If global ozone ranks with CH_4 only behind CO_2 as the most important greenhouse gas, its increase in the troposphere implies also other consequences. West *et al*. (2006), identify two main ones. First, premature mortalities can be linked to the high presence of ozone, and especially in the case of cardiovascular and respiratory mortalities. Secondly, increased global ozone affects ecosystems by reducing the net primary productivity of plants. This reduction has for both incidences to diminish plants uptakes of CO_2 - and therefore increasing climate forcing - and to modify agricultural cultures productivity, while changing plants development.

Although CH_4 has greater potential for ozone abatement, it has not been considered for air quality management, contrary to nitrogen oxides (NOx) and nonmethane volatile organic compounds (NMVOCs)(West & Fiore, 2005). Reason for this is that ozone is traditionally considered to be a local and regional problem and that the effects of CH_4 mitigation on surface O_3 are delayed and widespread, offering small local benefits, whereas NOx and NMVOCs affect ozone more rapidly and thus more locally. However, West & Fiore (2005) calculate that a 17 % reduction of current global CH_4 anthropogenic emissions, apart from reducing the radioactive forcing level by ~0.12 W m^{-2}, would decrease ozone by ~1 ppb. Ozone reduction would prevent about 370 000 all-cause mortalities between 2010 and 2030 and about 30 000 for the year 2030 only. Suppressing about 20 % of the anthropogenic CH_4 emissions in therefore considered as a cost-effective process, as the money saved by avoiding this amount of premature mortalities exceeds the money engaged to implement the CH_4 reduction. Moreover, if this quantity of CH_4 is captured for energy purpose, it would provide ~2 % of current global natural gas production (West *et al*., 2006). As CH_4 emissions present negative consequences and potential reduction benefits that are globally shared, it seems that their control should be organized at an international level (West & Fiore 2005; West *et al*., 2006). This does not mean that it prevents to look forward how reduced CH_4 emissions can be implemented at a local scale.

Regarding CO_2 and water vapor emission caused by CH_4 decomposition, it appears that their contribution to the direct radioactive forcing effect of CH_4 increase only about 5 % (Lelieveld *et al*., 1998). Moreover, the contribution of CO_2 shall not be considered since most of it (~80%) comes from biogenic CH_4, so that it is in fact recycled CO_2 and therefore does not accentuate climate forcing. Concerning water vapor, this one is only relevant when considered in the stratosphere.

CH_4 reaction in the atmosphere

According to Lilieveld *et al*. (1998), CH_4 is mainly removed from its reaction with hydroxyl radicals (OH) in

Recibido: marzo 15, 2011
Aceptado: julio 11, 2011

the atmosphere (-90 %). Hydroxyl radicals, as for them, are formed via the action of solar radiation on ozone and water vapor (R1 y R2), and their removal is almost totally ensured by CO y CH_4.
Reaction between CH_4 and OH leads first to formation of CH_2O and HO_2 (R3-R5). Further, CH_20 degradation generates apparition of carbon monoxide (CO) and then of CO_2 (CO + OH + O_2 HO_2 + CO_2), while the HO_2 radicals suffer several reactions leading to the formation of O_3 molecules as well as new OH radicals that contribute to renew their presence in the atmosphere (R6-R8). However, this production is dependent on the presence of nitrogen oxides (NO_X). Indeed, when levels of NO_X in the atmosphere are low (less than 25-50 pmol/mol), the hydroperoxy radicals (HO_2) (produced from CH_4 breakdown) cannot react with NO but destroy O_3 and limit the regeneration of OH radicals. Thus, methane oxidation in the atmosphere is a net source of O_3 and OH radicals if NO_X levels are high, whereas net destruction of O_3 and OH prevails if NO_X levels are low. As a consecuence of this, the more NO_X in the atmosphere, the more OH and O_3 y the less important is CH_4 lifetime, when knowing that CH_4 lifetime is the quotient of CH_4 burden in the atmosphere and the annual CH_4 breakdown (Lelieveld, 1998).

Reduction pathways

Reducing emissions from enteric fermentation
The most important source of CH_4 emissions from livestock comes from enteric fermentation, it appears primordial to consider alternatives to mitigate the phenomena. According to Carmona *et al*. (2005*)*, methane emissions can vary a lot with the diet submitted to cattle.

Improvements in diet quality can lessen CH_4 emissions by giving to the fermentative process in the rumen better physical chemical conditions and by the way reduce digestive energy loss, which is the cause of methanogenesis. Recent studies in Canada (Beauchemin & McGinn 2005; 2006; McGinn *et al*., 2004) show that diets supplemented with sunflower oil, ionophores (e.g. monensin), and possibly some yeast products, as well as a corn-based diet during the finishing phase of the production cycle of feedlot cattle can significantly reduce enteric methane production in the rumen, which represent an improvement in feed efficiency. Thus, mitigating CH_4 losses from cattle has both long-term environmental and short-term economic benefits.

Reducing emissions from manure management origin: biogas production
Biogas production from anaerobic digestion of cattle manure appears to be an interesting solution to combine prevention of global warming, preservation of ozone layer and reduction of health risks due to tropospheric O_3. At the same time it provides bio-energy (methane), as well as a high quality fertilizer for field use. Anaerobic digestion is an engineered methanogenic decomposition of organic matter under oxygen-free conditions (Wilkie, 2005a). The biogas produced in the digester is primarily composed of methane (~60 %) and carbon dioxide (~40 %) (Borole *et al*. 2006), with traces of hydrogen sulphide and ammonia. The quality of the feedstock used in the digester will determine how much gas is produced (British-Biogen, 2000).

The CH_4 generated can be used as a fuel for an engine connected to a generator to produce electricity that can be used on site or marketed to the network. The latter possibility is by far the most interesting one for big scale anaerobic digestion units as it leads to an additional net income for the farm owner. Biogas can also be used to produce heat or merely be burned for kitchen use in the case of small-scale farm production (Laichena & Wafula, 1997). The electricity generated can cover totally or partially the needs of farm machinery such as milking or maintaining machine, depending on the far size.

In contrast with classical storage and aerobic composting techniques, whose methane production escape in the atmosphere and suffers a loss of nutrients (nitrogen) in the form of gas or by lixiviation (Hao *et al*., 2001; Umetsu *et al*., 2005), anaerobic systems save those products inside the closed system of the biodigestor and provide them as mineralized and more soluble nutrients for field use (Wilkie, 2005).

Moreover, anaerobic digestion can reduce the potential for global warming in two ways. First, the use of biogas as an energy source replaces the consumption of fossil fuels such as coal, oil and natural gas, and thus CO_2 emissions related to that combustion is avoided. Indeed, CO_2 emitted from biogas burning comes from carbon of cattle feed, which originates from photosynthesis processes in feed or forage production, and is part of a closed carbon cycle and, therefore, does not contributes to increasing atmospheric CO_2 levels. The second way is that anaerobic digestion reduces CH_4 release in the atmosphere and by the way mitigates potential global warming, as CH_4 is 21 times more efficient as CO_2 for climate forcing (Wilkie, 2005a).

Furthermore, CH_4 reduction also influences O_3 production in the troposphere to prevent premature mortality and other diseases at a local scale (Lelieveld *et al*. 1998).

Biogas potential in the Laguna region for electricity production
The cattle population, for the Laguna region represents a great potential for energy production. Electricity

produced from biogas has an average yield of 30 % as the biggest part of the energy is converted by the generator into heat. Nevertheless, this heat can be recovered to warm water or directly to the digester to improve its performance (British-Biogen, 2000). Taking in account cattle population, average slurry and biogas production, we can estimate the electricity potential of the Laguna region. If all the slurry produced were digested by AD process and converted to electricity, it would generate around 61 GW h^{-1} . It is evident that this level of electricity production will never be reached because all farms are not going to set up biogas plants in the next few years, but many projects have already begun in the Laguna region with the support of the United Nations and Ag Cert Company. A project of installing 28 biodigestors in the region in the next two months, totally financed by the United Nations, is ongoing in collaboration with big farm owners (more than 700 cows). On the other hand, the Universidad Autónoma Agraria “Antonio Narro” (UAAAN) is working on biogas application to small scale farms and rural communities in order to bring this technology to the countryside and give to rural community the opportunity to produce their own energy and by self sufficient.

DISCUSSION

CH_4 emissions from cattle origin in the Laguna region have been estimated using the IPCC model (Hougthon *et al*., 1997). Fifty five Gg of CH_4 are produced per year which represents 2.5 % of national CH_4 emissions from livestock origin, a high amount considering the area of the region (0.03 %). Indeed, cattle rearing in the region are large and suffer serious sustainability problems. For cattle, enteric fermentation is responsible for 83 % of CH_4 released in to the atmosphere and 17 % comes from manure management systems. The greenhouse potential of methane as well as the negative effects of its decomposition by-products on human health and air pollution turns CH_4 into a threat for global climate balance and natural and human ecosystems stability. As CH_4 emissions from livestock is about 25 % of total CH_4 emissions, any reduction on this sector would be environmentally effective and a path toward more sustainability and consciousness of our surroundings. Among the existing alternatives for mitigating those CH_4 emissions, improvements in diet quality toward better utilization of ingested energy, i.e. reduction of energy losses in the form of methane, and utilization of supplements such as sunflower oil or monensin in addition to maize based ration may decrease CH_4 emissions up to 20 %. However, further investigation is needed to better understand these phenomena and find out cost effective and large scale feasible alternatives. Considering the manure management issue, utilization of AD technology to control manure fermentation may avoid the majority of CH_4 emissions due to manure decomposition and of the same time generate a renewable and environmentally friendly energy: biogas. Utilization of biogas on farms can reduce or eliminate electricity consumption due to farming activity. Digesting animal slurry makes the farming system more sustainable and self sufficient, and helps farmers and rural communities being aware of their impact on the environment and of the power they have to convert this problem into damage-free activities.

In the case of the Laguna region, if a process carries several advantages but, one should not forget that the main problem still remains: the high concentration of animals for intensive production. Utilization of AD technologies and especially the biogas production make it possible to diminish some negative effects of high concentrations of domestic animals, but do not represent a solution to the whole problem. Dramatic decrease in water availability, high level of soil erosion and widening social gaps are some of the actual indicators that show that the presence of intensive production in the region is not compatible with the wish to reach sustainable and long-term development. AD technologies represent interesting tools for future development only if considered as a part of the greater and radical changes that have to be implemented in the agricultural sector and in the society in general.

Acknowledges.

We acknowledges to the project support by Universidad Autónoma Agraria “Antonio Narro” with register number 02-03-1510-2798.

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