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Technological innovations in animal production related to environmental sustainability[1]

Inovações tecnológicas na produção animal relacionadas à sustentabilidade ambiental

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SUMMARY

According to FAO, meat production will double by 2050 to meet the demand of growing and more affluent population. The soaring demand presents an environmental challenge for intensive animal production. Greenhouse gas emissions (GHG), particularly methane (CH_4) increases as animal numbers increase, however, mitigation strategies such as dietary manipulation (e.g., lipid supplementation), ionophores, defaunation and biotechnologies can be used to reduce emissions per animal. Emissions from manure storage can also be reduced using biological and thermochemical conversion technologies with added benefit of producing bio-energy while treating livestock wastes. At the animal level, reduction of overfeeding protein and balancing the amounts of protein degraded in rumen and those allowed to bypass the rumen will reduce N excretion. Synchronizing energy and protein supply to animals also offers better utilization of nutrients with concomitant decrease in urine N, which contains high levels of urea that can be converted into ammonia when mixed with feces. Phosphorus in manure represents a significant renewable resource and there are several technologies that remove and recover P from manure including chemical precipitation, biological P removal and crystallization. The development of technologies for GHG and nutrient reduction offers the opportunity for environmental sustainability.

Keywords: entenic fermentation, methane, ruminants.

RESUMO

De acordo com a FAO, a produção de carne deve duplicar até 2050, devido à grande demanda e enriquecimento da população. Essa crescente necessidade apresenta um desafio ambiental para a produção intensiva de animais. A emissão de gás do efeito estufa, particularmente metano (CH_4), se eleva com o aumento do número de animais, entretanto, estratégias de mitigação, tais como a manipulação da dieta, por exemplo, suplementação lipídica, ionóforos, defaunação e biotecnologias podem ajudar a reduzir a remessa por animal. Emissões por armazenamento de esterco também podem ser reduzidas se utilizarem tecnologias biológicas e termoquímicas com o benefício adicional de se produzir bio-energia durante o tratamento de resíduos animais. No que diz respeito ao animal, a redução da superalimentação proteica e a manutenção do equilíbrio entre proteína degradada no rúmen e proteína *bypass* podem reduzir a excreção de nitrogênio. Balanceamento de energia e suplementação proteica dos animais também podem oferecer melhor utilização dos nutrientes e, concomitantemente, diminuir o nitrogênio na urina, que contém altos níveis de ureia que, por sua vez, pode ser convertida em amônia quando misturada às fezes. Fósforo nos resíduos (estrume) representa um importante recurso renovável, e várias tecnologias existem para remover e recuperar esse mineral sem excluir precipitação química, remoção biológica e cristalização. O desenvolvimento de tecnologias relacionadas ao efeito estufa oferece oportunidade para a sustentabilidade ambiental.

Palavras-chave: fermentação entérica, metano, ruminantes.

INTRODUCTION

Globally, there has been an increase in public concern about environmental damage instigated by intensive animal feeding operations. This increased public concern has led some countries such as the Netherlands to introduce legislation (JONGBLOED & LENIS, 1998). The main concerns related to large scale animal production are the production of Greenhouse gas emissions (GHG) and ammonia (NH_3), which are linked to air quality degradation and global warming as well as the impact of nutrient losses on water quality. For example, the global dairy sector contributes 4.0% of globally produced anthropogenic GHG, with the majority of these gases produced on the dairy farm (FAO, 2011). Methane (CH_4) is the main GHG gas eructated from dairy farms, which is 25 times more effective in trapping heat in the atomsphere than carbon dioxide over 100 year period (IPCC, 2006). The main source of nutrient pollution from animal production is N and P excretion in excess of crop removal. Although N is a central element for plants and animals, it is highly mobile and high concentrations can be toxic and cause environmental degradation. Phosphorus is an essential nutrient that contributes to agricultural development. However, its release in the environment is associated with depletion of non-renewable inorganic P sources and causing eutrophication. Steen (1998) estimates global phosphate reserves to be depleted in 50 to 100 years.

The objective of this study is to review and discuss technological innovations that are used to mitigate environmental pollution and increase sustainability of animal production.

GREENHOUSE GAS EMISSIONS

Greenhouse gases absorb solar radiation reflected from earth’s surface, contributing to the global warming effect. Greenhouse gas emissions from the agricultural sector that are related to animal production comprise CH_4 directly emitted from domestic animals, CH_4 and N_2O emitted from manure and grazed lands, and N_2O emitted from soils after application of manure (KEBREAB et al., 2006).

Livestock production, especially ruminants, contributes to CH_4 emissions worldwide significantly. Methane is also associated with dietary energetic losses, which are generally between 2 and 12% of the ingested gross energy (JOHNSON & JOHNSON, 1995). Carbohydrates are fermented in the rumen, producing relatively large quantities of CH_4 when compared to non-ruminant animals. Agriculture accounts for 50% of anthropogenic CH_4 emissions in the world (IPCC, 2006) and beef cattle were the largest contributor of enteric CH_4 emissions in the United States, accounting for 71%. Dairy cattle accounted for 25%, and the remaining were produced by enteric fermentation of other animals (EPA, 2007).

Enteric fermentation. Methane in ruminants is produced during the fermentation process of substrates in the rumen, especially structural carbohydrates, by the action of a group of Archaea denominated methanogens. Methanogens are composed basically of *Methanobrevibacter*, *Methanobacterium*, *Methanosarcina*, and *Methanomicrobium* (BALCH et al., 1979). Most of methanogens utilize hydrogen originated in the production of volatile fatty acids (VFA) in rumen fermentation process, to reduce CO_2 to CH_4. However some methanogens can utilize other substrates to produce CH_4, such as the utilization of formate as a hydrogen source (HUNGATE et al., 1970). Protists (commonly referred to protozoa) also have an important role in the CH_4 ruminal production since methanogens can bind to protozoa and transfer hydrogen (SHARP et al., 1998).

Mitigations strategies to reduce CH_4 emissions from ruminants have become an important tool to decrease environmental impacts of livestock production and also to increase energetic efficiency of feed utilization. Hook et al. (2010) and Martin et al. (2010) reviewed mitigation strategies focused on dietary manipulation and biotechnological and management techniques. According to Martin et al. (2010), ideal CH_4 mitigation strategies should decrease emissions by modifying hydrogen production and utilization without decreasing nutrient digestibility. Hydrogen utilization should be shifted towards the formation of other biochemical compounds to maintain rumen pH and not decrease the rate of carbohydrate fermentation. Also, mitigation strategies should be economically feasible to be adopted by producers. Methane abatement technologies can be divided into four main categories: dietary manipulation, use of ionophores and other compounds such as organic acids, defaunation, and use of biotechnologies.

Dietary manipulation. Diet composition plays an important role in CH_4 production in the rumen. The profile of VFA produced in the rumen is dependent on the form of dietary carbohydrates fermented. Ruminal fermentation of structural carbohydrates promotes a greater production of acetate, in which hydrogen is formed and can be used by methanogens to produce CH_4. The fermentation of non-structural carbohydrates favors the production of propionate, which acts as a proton sink to sequester hydrogen. Forages usually have a higher composition of structural carbohydrates, therefore, are likely to increase the proportion of acetate and availability of hydrogen for CH_4 production. However, dietary manipulation only has a limited role in reducing CH_4 emissions, especially for lactating dairy cows, because a minimum amount of fiber in the diet is required for maintenance of chewing activity, stimulation of saliva production and buffering the rumen pH. Structural carbohydrate's physical form is also important because fiber from grains and by-products are usually not as effective as fiber from forages in stimulating chewing activity and maintaining milk fat percentage (ARMENTANO & PEREIRA, 1997) by maintaining acetate levels in the rumen. Excessive levels of dietary non-structural carbohydrates can lead to greater VFA production that may exceed the absorption capacity of the rumen wall. The increased VFA production decreases rumen pH and promotes the formation of lactate which further decreases rumen pH, impairing rumen bacterial activity and increasing the incidence of ruminal acidosis (PLAIZIER et al., 2008).

Lipid supplementation has been studied as a mitigation strategy for CH_4 production in the rumen due to distinct forms of action (JOHNSON & JOHNSON, 1995). The first hypothesis is that the supplemented unsaturated fatty acids utilize hydrogen through the biohydrogenation process in the rumen, in which unsaturated fatty acids are reduced to partially or completely saturated fatty acids (WU & PALMQUIST, 1991). Therefore, the fatty acid chain length and the degree of unsaturation would have an important role in determining the amount of hydrogen utilized in biohydrogenation. A second hypothesis is that the inclusion of lipids in the diet can shift VFA production to propionate, increasing the utilization of hydrogen thereby reducing its availability for CH_4 production. A third hypothesis is that lipids would have a negative impact in rumen protistan-methanogen associations (CZERKAWSKI, 1966) inhibiting CH_4 production and protist activity in the interspecific hydrogen transfer reactions. A meta-analysis by Eugene et al. (2008) found that emissions decreased by 9% when the dietary ether extract increased from 2.5 to 6.4%. Beauchemin et al. (2008) found that CH_4, in g/kg of DMI, was reduced by 5.6% for each additional percent of supplemental fat based on dairy, beef, and sheep data. Lipid supplementation can be a promising technique to reduce enteric CH_4 production; however, the modification of ruminal environment by the fat supplementation is an important point because excessive dietary fat (greater than 6-7%) can compromise fiber digestion.

Ionophores and other compounds. The use of ionophores in ruminant diets has been studied in relation to improvement of feed utilization (RUSSELL & STROBEL, 1989) and manipulation of ruminal fermentation, decreasing the incidence of acidosis (TUNG & KUNG, 1993). However, with increased concern of GHG emissions, the ability to reduce CH_4 emissions in the rumen by ionophores, especially monensin, is of interest. Monensin alters the transport of ions, especially sodium, through the cell wall membrane, causing an inhibitory effect in gram positive bacterial population. The reduction of CH_4 emissions with the use of monensin has been attributed to the inhibitory effect on ruminal methanogens and in the decrease of hydrogen supply for methanogenic population. Hook et al. (2009) studied the long term effect of monensin and after 6 months, the quantity and diversity of ruminal methanogens was not affected by monensin. Therefore, the reduction in CH_4 emissions with monensin supplementation seems to be more a result of the inhibition of gram positive bacteria in the rumen, shifting VFA from acetate to propionate and also decreasing the supply of hydrogen to the methanogenic population. Odongo et al. (2007) reported a 7% decrease in CH_4 emissions without compromising intake or milk yield after 6 month supplementing monensin at 24mg/kg of diet DM. Similar results were reported by McGinn et al. (2004) with a decrease of 8.6% of CH_4 emissions per kg of DM intake with the use of monensin in beef cattle. The quantity of monensin supplied has an important role in CH_4 reduction. Doses lower than 1 ppm (WAGHORN et al., 2007) and 20ppm (VAN VUGT et al., 2005) did not decrease CH_4 emissions per unit of DM intake of dairy cows in the reported studies. Guan et al. (2006) found that monensin supplementation reduced CH_4 emissions up to 30% when 33 mg/kg of diet DM was fed to beef cattle, however, the reduction in CH_4 emissions was only observed for 2 months. Johnson & Johnson (1995) discussed the persistency of the reduction in CH_4 emissions, stating that reductions in CH_4 emissions usually last for 2 weeks and returns to previous levels probably due to the adaptation capacity of methanogen population or the hydrogen producers. These results suggest that monensin can be used to reduce CH_4 over a short period of time, such as early lactation, but this reduction in CH_4 cannot be sustained for longer periods.

The search for specific compounds in animal diets that could decrease CH_4

production in ruminal fermentation has increased over the years. Plant extracts such as essential oils, tannins and saponins have been studied as natural compounds that could assist in the reduction of enteric CH_4 emissions. The reduction of CH_4 emissions with condensed tannins may be caused by an inhibition of rumen methanogens and by a decrease in the hydrogen available for methanogens (TAVENDALE et al., 2005). However, most of the trials utilizing tannins were conducted in vitro and the reported in vivo trials present different results regarding changes in feed digestibility (MARTIN et al., 2010). Puchala et al. (2005) measured CH_4 emissions, in an open circuit respiration calorimeter from goats fed a high tannin forage (17% DM) vs. a forage with 0.5% DM condensed tannins and CH_4 emissions were reduced from 16.2 to 6.9 g/kg of DM intake respectively. VFA production in the rumen was not altered nor was feed digestibility. However, results are not consistent. Beauchemin et al. (2007) reported that Angus steers fed up to 2% of dietary DM of quebracho tannin extract did not result in a reduction of CH_4 emissions and apparent crude protein digestibility decreased 15%. The reports for tannin research shows promise but there is inconsistency in the results which may be due to the form that the tannins are fed. Also, the effects of tannins on protein digestibility can impair the utilization of the compound in animal diets. Compounds present in essential oils also have been examined as rumen fermentation modifiers. Antimicrobial properties present in these oils are thought to reduce hydrogen supply for rumen methanogenic population as discussed by Hook et al. (2010). Busquet et al. (2005) found a decrease in CH_4 emissions when garlic oil was added at 300mg/L of rumen fluid in lactating dairy cows fed rations with 50:50 forage concentrate ratio. McGinn et al. (2004) reported that sunflower oil reduced CH_4 emissions by 22%, however, NDF digestibility also was reduced by 20% in growing beef cattle. Therefore, results with these compounds show promise but are not consistent and require further investigation before practical implementation.

Defaunation. Complete or partial elimination of protists from the rumen is termed defaunation. The role of defaunation in reduction of CH_4 emissions is based on the supply of hydrogen to methanogenic population by rumen protists, through the hydrogen transfer process (SHARP et al., 1998). Defaunation of ciliate protists in the rumen of steers increased propionate concentration, whereas steers with a normal protist population had a greater concentration of butyrate in the rumen (WHITELAW et al., 1984). Methane emissions were reduced from 11.5 to 6.68 MJ/100 MJ of GE with defaunation. Several additives and substances can promote rumen defaunation, as discussed above (monensin, lipid supplementation) and results are usually dependent on diet composition (HEGARTY, 1999). The viability of rumen defaunation can be compromised with the adaptation capacity of rumen protists (as discussed for monensin). Moreover, the maintenance of defaunated animals can be a difficult process (BIRD et al., 2010) and nutrient digestibility can be impaired with the reduction of rumen protists.

Biotechnologies. Several biotechnologies have been tested to reduce CH_4 production in the rumen. Wright et al. (2004) reduced CH_4 production by 8% with the use of a vaccine to suppress methanogens. The development of such vaccines rely on the identification and cultivation of different strains of methanogens, however, not all methanogens have been identified or cultivated (WHITFORD et al., 2001). Differences in rumen methanogens due to feeds, climate and other aspects in different parts of the world could limit the action of vaccines in different regions in which the vaccines were developed (WRIGHT et al., 2007). Cooprider et al. (2011) achieved 31% reduction in CH_4 emissions from feedlot cattle by implanting them with 100 mg trenbolone acetate and 14 mg estradiol benzoate and also adding monensin to the diet. Other technologies, such as passive immunization, bacteriocins were discussed by Martin et al. (2010) and generally results are not persistent over time or consistent between experiments.

Manure management and land application. Alternative uses of manure can be separated into three categories: conversion and use as an energy source; conversion to value-added products; and innovative and emerging products. Many technologies and strategies already exist for converting animal manure into energy and other valuable products. New technologies are also being developed with better efficiencies and new products. Energy products that can be derived from manure include heat and biofuels, which includes gaseous (e.g. biogas from anaerobic digestion), liquid (e.g. alcohols from fermentation) and solid (e.g. densified pellets made from fibers) fuels. Biological and thermochemical conversion technologies can be applied to produce bio-energy while treating livestock wastes.

Anaerobic Digestion. Animal manure has complex chemical composition and high moisture content, therefore, biogas production from anaerobic digestion appears to be the most energy-efficient choice (CAES, 2008). A properly functioning anaerobic digester can provide numerous benefits at farm, local, and environmental levels. These benefits include: odor control; reduction of nuisance gas emissions; potential pathogen kill; reduction of wastewater strength (oxygen demand); onversion of organic N into plant available NH_3-N; preservation of plant nutrients (e.g., N, P, K) for use as a high quality fertilizer; and production of a renewable energy source-biogas, which typically contains 50-70% CH_4 with the rest being primarily CO_2 and impurities. Biogas can be upgraded to biomethane by removing moisture, CO_2 and impurities and supplied to existing and future natural gas distribution systems (CANTRELL et al., 2008). The disadvantages include high initial capital investment; and high standards of maintenance and management.

Covered lagoon. The most common way to store manure from large animal facilities is using open-air, anaerobic lagoons. Although these are low maintenance systems, they results in emissions for GHG such as CH_4 and CO_2, and other odorous intermediate compounds such as hydrogen sulfides and NH_3. Covering the lagoon using a floating impermeable cover can reduce GHG and air pollutants, and harvest biogas (DESUTTER & HAM, 2005). The Alberta government recognizes covering lagoon as GHG reducing technology and farmers can get carbon credit for covering their manure lagoons and flaring the biogas trapped under the cover (CLIMATE CHANGE CENTRAL, 2011).

Therochemical conversion (TCC). The technique is a high-temperature chemical reforming process that breaks apart the bonds of organic matter and reforms these intermediates into char, synthesis gas and highly oxygenated bio-oil. In addition to TCC being a mass consumer of a manure’s organic portion that extracts all available energy, TCC processing has a number of other benefits and advantages: small footprint; efficient nutrient recovery; no fugitive gas emissions; short processing time in the order of minutes; capability of handling a variety feedstocks and blends; and high-temperature elimination of pathogens and pharmaceutically active compounds (CANTRELL et al., 2007). One of the processes identified for converting livestock manures into a value-added renewable energy product are pyrolysis (CANTRELL et al., 2007). Pyrolysis uses heat and a non-oxygen atmosphere to convert the organic portion of a feedstock into a mixture of char and volatile gases containing both non-condensable vapors and condensable tars (oxygenated hydrocarbons), which form a combustible pyrolytic oil or bio-oil (MOHAN et al., 2006). Slow pyrolysis converts animal wastes into char, providing farmers with potential economic benefits due to energy production and carbon credits generated from carbon sequestration. Char can also be applied to soil as a soil amendment to improve fertility (ANTAL & GRØNLI, 2003).

Algal CO_2 removal. Carbon dioxide is a major component in the product gases from anaerobic digestion and thermochemical conversion processes. Since an increased atmospheric concentration of CO_2 is considered one of the main causes of global warming (SCHNEIDER, 1989), it is important to recover CO_2 to limit short-term release. By naturally fixing atmospheric CO_2 via photosynthesis 10 times more efficiently than terrestrial plants (USUI & IKENOUCHI, 1997), algae can rapidly generate both algal biomass and intracellular oil (MIAO & WU, 2006). These algal products can then be harvested and converted into multiple value-added products.

NUTRIENT EXCRETION

Reduce overfeeding and balancing (RUP). Reducing N excretion from livestock is one way to reduce nutrient loading in the environment. Urea excreted in urine, if mixed with feces, is converted to NH_3 and volatilized because of high urease activity in feces (MUCK, 1982). Indigestible dietary protein is excreted in feces and can be leached to water sources promoting eutrophication (TAMMINGA, 1992). Animal N requirements are based on metabolizable protein (MP) concept, which is defined as the quantity of true protein and amino acids available for absorption by the animal in the small intestine (VAN SOEST, 1994). Metabolizable protein in feeds is calculated as the sum of rumen synthesized microbial crude protein (MCP), rumen undegradable feed crude protein (RUP) and endogenous crude protein (ECP). The MCP values are a function of the amount of the dietary crude protein that is degradable in the rumen (RDP). Requirements are met by adding RDP and RUP because animal N requirements for high producing animals cannot be met only by MCP produced from RDP and non-protein N (NRC, 2001).

Urinary N excretion is highly correlated with N intake (KEBREAB et al., 2010) since urea excreted in urine is composed of excess absorbed N, and therefore, is highly correlated with RDP intake and animal N requirements. However, N excreted in feces is usually less affected by dietary N content (KAUFFMAN & ST-PIERRE, 2001; COLMENERO & BRODERICK, 2006) because it is composed of indigestible protein. One approach to reduce N excretion would be to match N intake with requirement, because most diets formulated for high producing animals usually have excess N. A reduction of dietary crude protein from 19 to 15% did not affected milk yield and reduced urinary N excretion significantly in early to mid-lactation cows (CASTILLO et al., 2001a). Similar results were presented by Broderick et al. (2003) who fed lactating cows diets containing crude protein varying from 15.1 to 18.4% and found that beyond 16.7% CP, milk yield was not affect by dietary protein content and from 15.1 to 16.7%, the increments in milk yields were modest. However, urinary N decreased linearly from 35 to 23% of dietary N when dietary CP was decreased from 18.4 to 15.1% (BRODERICK, 2003). Groff and Wu (2005) found no reduction in milk yield and small differences in milk fat and protein contents when Holstein cows were fed diets varying from 15.7 to 19.2%. Urinary N concentration decreased from 7.3 to 5.8 g/L of urine (GROFF & WU, 2005). Børsting et al. (2003) suggested that if dietary RDP contents were reduced to a level equivalent to the maximum capacity of microbes to synthesize protein, dietary N could be reduced, and RUP would be balanced to meet the rest of N animal requirement. This approach would reduce N urinary excretion, because most of RDP would be utilized by microbial production and RUP would be balanced to meet animal amino acid requirements. This hypothesis agrees well with the results of Castillo et al. (2001a), in which urinary N excretion increased with increased dietary protein degradability and apparent fecal N excretion was not affected by protein degradability. However, two main problems are evident with this approach. Firstly, RUP sources are generally expensive and can increase diet costs significantly. Secondly, the estimation of RDP and RUP content of feeds are based on digestion and passage rate of protein assumptions, which can have high animal variability and are difficult to measure simultaneously. Therefore, the estimation of amino acid contents of RUP can have a high variability, decreasing the accuracy in estimating amino acid composition of RUP in feeds.

Energy and Protein Synchronism. The synchrony of energy and protein supply in the rumen has been studied to account for optimal microbial protein synthesis (NOCEK & RUSSELL, 1988). Castillo et al. (2001b) studied urinary and fecal N excretions of dairy cows fed isoenergetic diets with energy sources varying in digestibility. Dairy cows fed high digestible carbohydrate sources had increased urinary N excretion. The increased urinary N excretion was explained by increased ruminal absorption of NH_3 and also by increased amino acid deamination (CASTILLO et al., 2001b). Fecal N in the same study was not affected by carbohydrate rumen digestibility. Castillo et al. (2001b) also reported that efficiency of N utilization improved with an intermediate digestibility (corn based starch) carbohydrate source due to the change in the site of starch digestion from the rumen to the large intestine, shifting N excretion from urine to feces. Weiss et al. (2009) fed multiparous lactating cows with diets varying in proportions of alfalfa and corn silage. Fecal N increased with higher levels of alfalfa and urinary N excretion represented 41% and 48% of N excretion when dietary alfalfa was 75% and 25% of dietary forage, respectively. Changes in urinary and fecal N excretion were explained by changes in N and carbohydrate digestibility. Broderick (2003) fed lactating cows with varying levels of protein and energy. They found that fecal N excretion was not affected by source of dietary carbohydrate, however, they observed linear decreases in urinary excretion of urea N and total N when dietary NDF was reduced from 36% to 28%. Reductions in urinary N excretion were explained by a higher non-fiber carbohydrate content of diets with reduced dietary NDF that caused a higher efficiency of N utilization in cows fed increased levels of energy. Kebreab et al. (2010) showed that as metabolizable energy increased, milk N increased at the expense of urinary N. Therefore, the synchrony of dietary energy and protein sources and digestibility seem to be a promising way to reduce N excretion, because microbial utilization of N is optimized and absorption of urea and NH_3 are reduced.

Phosphorus is second only to calcium in abundance in the body of animals, with about 80% of the body P located in the skeleton, the remaining 20% having essential metabolic function in cell contents and cell walls (VEUM, 2010). Phosphorus requirements for various species of farm animals is periodically reviewed and summarized in publications such as the NRC (2001). The requirements are calculated based on P digestibility of feedstuff and absorbed P requirement to support maintenance, growth, pregnancy and lactation.

Livestock utilize P inefficiently, excreting 60 to 80% of that consumed. When animals are fed above the requirement, most of the P will be excreted to the environment. Kebreab et al. (2005) found that there is a linear relationship between P intake and excretion in feces. Several surveys (e.g., SATTER & WU, 1999) have revealed that dairy producers in the United States feed 0.45 to 0.50% dietary P, which is in excess of recommendations by NRC (2001). Increased P excretion creates challenges for environmental sustainability. For example, concentrated animal agriculture has been identified as a significant source of P contamination of surface water in the United States (SMITH & ALEXANDER, 2000). Apart from dietary strategy such as reduced P content in diet and increased energy density to reduce P loading in the environment (KEBREAB et al., 2005), there are several P removal technologies available. These technologies include chemical precipitation, biological P removal, constructed wetlands, ion-exchange, and crystallization (MORSE et al., 1998). We will limit the discussion to crystallization methods because it is the most promising technology for removing P from animal manure.

Crystallization. The technique not only removes high levels of P, but it recovers it as useful products such as struvite, calcium phosphate, and hydroxyapatite (WANG et al., 2005). Struvite is the common name for magnesium ammonium phosphate hexahydrate, or MAP (MgNH4-PO4·6H2O), and its constituent ions are among the most predominant in anaerobic swine lagoon effluent (NELSON et al., 2003). Struvite is a promising slow-release fertilizer, with higher purity and lower heavy metal content than commercial phosphate fertilizer. Struvite has been successfully recovered from swine and dairy operations and used as fertilizer in Japan, USA and Belgium (UENO & FUJII, 2001; MOERMAN et al., 2009). Jordaan et al. (2010) achieved 80% P removal with high pH in manure and suggested that struvite precipitation is a

viable method of P removal from anaerobically digested swine manure.
The soaring demand for animal products will have serious implications for environmental sustainability in the next few decades. Therefore, it is imperative that technological innovations in animal production cope with increases in production to reduce the carbon footprint and ensure sustainability of animal agriculture. The paper reviewed current practices that offer reductions in GHG emissions, N, and P excretions to the environment. The technologies need to be implemented on a wider scale to ensure their effectiveness and research into new innovations should continue hand in hand with increasing efficiency and production of animal products.

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