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MANURE TREATMENT STRATEGIES: AN OVERVIEW

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Abstract

A treatment strategy is a combination of processes leading to the fulfillment of a given objective. There are many objectives that could be fitted, such as energy production, nutrients recovery or removal, odors abatement, transportation cost decrease by removing water, etc. Since the problem to be solved depends on livestock production methods, farming density and intensity, the nutrients management planning adopted, and many other local or global constrains, there is not a unique technological strategy suitable for all situations. Although biogas production through anaerobic digestion can fit the objective of renewable energy production, its combination with other processes enhances the global efficiency for many other purposes, such as odors abatement, mineralization, nutrients recovery and partial hygienization, among others, and clearly represents a unitary process to be considered in any sustainable manure treatment strategy.

Keywords: anaerobic digestion, emerging pollutants, hygienization, manure treatment technologies, nitrogen removal, nutrients recovery.

Introduction

Organic wastes which are potentially valuables as fertilizers or soil amendments are resources that need to be managed adequately. According to this simple concept, manure must be handled as a by-product of livestock production and when required processed, just for fitting the objective of an optimal management within the context of the farm and considering local conditionals (Table 1).

A nutrient management planning (NMP) is a set of actions performed to adequate manure production to the demand of quality products for the agricultural soils (Teira-Esmatges and Flotats, 2003). This set of actions must include on-site minimization of volumes and limiting components (i.e.: nutrients, heavy metals, etc.); the enhancement of animal diets and management practices; a fertilization planning depending on available soils and crops characteristics; the analysis of economical costs; and the assessment of feasible treatments, adopted in order to fit the objectives defined by the local constrains and opportunities (Table 1).

Table 1. Factors to be considered when designing Nutrient Management Plans (NMP) and possible objectives to be fitted by manure treatments.

Factors to be considered
o Availability of accessible soils and crops to be fertilized
o Nutritional requirements and productivity of the crops
o Presence of other competitive/synergic organic fertilizers in the area
o Mineral fertilizers price
o Climatic factors
o Density and intensity of farming
o Property structure of farms and agricultural lands
o Distances and transportation costs
o Energy prices
Possible objectives of the adopted treatment strategy
o To adjust manure production to seasonal crop requirements
o Facilitation of transportation by reducing the volume
o Transformation of manure into valuable products
o Adjustment of manure composition to the agricultural demand
o Nutrients recovery
o Nitrogen removal
o Removal of easily biodegradable organic matter
o Hygienization
o Removal of xenobiotics and other emerging pollutans
o Production of renewable energy
o Decreasing gaseous emissions (ammonia, methane and nitrous oxide)
o Prevention of pollution due to run-off or spillage

The general trend of animal protein production is the concentration and specialization in regional clusters (Hegg, 2008). This fact can become responsible for higher productions of manure than the fertilizing requirements in the area, and to an excess in the availability of nutrients. Problems caused by nutrients surplus have been described profusely (Burton and Turner, 2003). Of increasing concern are emissions to the atmosphere of ammonia and greenhouse gases (GHG), water resources pollution through leaching, and soil accumulation of undesired elements. By the establishment of Good Agricultural Practices, farmers have been prompted to design and follow NMP. This planning can be individual or collective, being the transportation cost and the density and intensity of farming some of the limiting factors for adopting centralized or on-farm treatment strategies (Flotats *et al.*, 2009).

Transportation may become an important bottleneck when planning manure management. In the case of liquid manures, pumping through a pipeline can represent an interesting alternative (Ghafoori *et al*., 2006; Dauden *et al.*, 2010). Transportation cost also provides a simple criterion to decide when a manure treatment strategy can be adopted. Treatment may become feasible if the global net cost of treatment, transportation and soil application of effluents is less than the cost of transportation and application of raw manure at an adequate nutrients dosage (Campos *et al*., 2004).

The objective of this work is to overview manure treatment alternatives in the framework of the decision making scheme of a nutrient management planning.

Treatment technologies

A treatment strategy is a combination of unitary processes leading to the fulfillment of a given objective. Such objective must be determined by applying a NMP methodology and considering local constrains. A clear definition of what a treatment is expected to provide is basic for a successful implementation. There is not a unique technological strategy suitable for all situations and, clearly, there is not a process capable of removing manure. Only nitrogen (N) and carbon (C), besides of water, can be "removed" through the conversion of different N-forms to dinitrogen gas (N_2), and organic-C to methane (CH_4) or carbon dioxide (CO_2). Other components of manure can just be separated or concentrated. Nitrogen is the unique nutrient which can be removed or recovered and, therefore, technological strategies can be classified taking into account this fact (Table 2). There are also other factors in which focusing when planning treating manure, such as odors removal, hygienization, removal of xenobiotic compounds (emerging pollutants), or just energy recovery through anaerobic digestion.

Table 2. Technological strategies based on nitrogen management.

	Objective	**Comments**
Strategies based on nitrogen recovery		
Phases separation	Separating into liquid and solid flows to favor further treatments or managing each separately	Applicable to liquid manures and suspensions
Ammonia stripping and absorption	Nitrogen recovering as a salt or in a liquid solution	Applicable to liquid fractions. Previous anaerobic digestion favours the process
Thermal concentration (vacuum evaporation and drying)	Nutrients concentration to reduce transportation costs	Evaporation can be applied to liquid fractions and drying to concentrates and raw manures. Previous anaerobic digestion favours the process
Ammonium salts precipitation (struvite)	Nitrogen recovering as ammonium-phosphate salt	Applicable to liquid fractions Previous anaerobic digestion favours the process
Composting	Nitrogen recovering in organic form	Ammonia losses by volatilization should be prevented
Strategies based on nitrogen removal		
Nitrification-denitrification (NDN)	Nitrogen removal by ammonium oxidation to nitrite/nitrate and further reduction to N_2	Applicable to liquid fractions. Biodegradable organic matter is required for denitrification
Partial nitrification-anaerobic ammonium oxidation (PN-anammox)	Nitrogen removal by partial ammonium oxidation to nitrite and further reduction to N_2	Applicable to liquid fractions. No requirements of organic matter. Less energetic requirements than conventional NDN

Use of tools concerning Life Cycle Assessment (LCA) can provide new insights and help in objective discussion of the advantages and disadvantages of a given management model including treatments (Lopez-Ridaura *et al.*, 2009; Prapaspongsa *et al.*, 2010). In this kind of analysis it is necessary to consider all significant impacts to decide the best management option taking into account local issues and also climatic conditions (Sommer *et al.*, 2010). Clearly treatment cost, including capital investment and operation, is also a main factor that will be considered by livestock producers before making any decision.

Strategies dealing with nutrients balance

Phase separation can be used as a simple method to enhance manure management capability. It allows separating manure into a solid fraction, which can be composted on-farm, transported to farther distances or delivered to a centralized composting plant, and a liquid fraction, which can be used in the nearby lands by means of irrigation systems or further processed (Burton, 2007). Separation efficiency can be enhanced by using flocculant agents (Campos *et al*., 2008), or by shortening the storage time of the raw manure (Kunz *et al.*, 2009).

N-recovery by means of stripping-absorption (Bonmatí and Flotats, 2003a), by thermal concentration (Bonmatí and Flotats, 2003b) or by ammonium and phosphate salt precipitation -struvite-, takes benefit from a previous anaerobic digestion step. The higher the organic mineralization achieved during digestion, the higher the quality of outflows. A favorable market for the commercialization of recovered products (Rulkens *et al*., 1998) and energy prices encouraging anaerobic digestion are essential for successful practical application. At the moment there exist successful experiences of evaporation and concentration at farm scale (Melse and Verdoes, 2005) and large scale (Palatsi *et al*., 2005). Several unsuccessful centralized experiences in the past reported as limiting factors the high operational costs, the lack of an adequate financial and organizational framework and the need of a well established network for the distribution of the products obtained.

N-removal through nitrification-denitrification (NDN) is a well-known process which has already been implemented mainly at individual scale to successfully deal with N-surpluses (Béline *et al*., 2008; Vanotti *et al.*, 2009). Availability of biodegradable organic carbon is a key factor when combining this process with an anaerobic digestion step (Deng *et al.*, 2007; Bortone *et al.*, 2009). Optimization of the process can be achieved by avoiding formation of nitrate (Magrí and Flotats, 2008; Anceno *et al.*, 2009). Reductions in gaseous emissions of ammonia and GHG are also attainable in comparison to traditional management practices based on manure storage before land spreading (Loyon *et al*., 2007; Vanotti *et al.*, 2008). New totally autotrophic N-removal approaches based on the anaerobic ammonium oxidation (anammox) process represent a promising treatment alternative (Karakashev *et al.*, 2008; Magrí *et al*., 2010). This process implies significant reductions on oxygen needs during nitrification (60% less), no requirements of organic-C and the possibility of working with more compact reactors at higher loading rates.

Ammonium and phosphate from liquid manures can be precipitated together forming struvite (Uludag-Demirer *et al*., 2005; Çelen *et al.*, 2007). Also, phosphorus can be precipitated as calcium phosphate (Szogi and Vanotti, 2009). Once precipitated, both minerals can be converted into a valuable product. In order to reduce consumption of reagents to increase the pH, strategies such as CO_2 stripping (Fattah *et al.*, 2010) or nitrification (Szogi and Vanotti, 2009) can be applied.

Treatments dealing with hygienization

There is an epidemiologic risk when managing manure linked to the possible transmission of zoonotic agents to other animals or the contamination of the human food chain (Venglovsky *et al.*, 2009). Manure contains enteric microorganisms, a small percentage of which are pathogens, some of them being obligate parasites so that they can no more multiply outside of their hosts. Generally speaking, the higher the temperature and storage/treatment time, the lower the survival of bacterial pathogens. However, besides pathogen bacteria there are also parasitic protozoa and spore-forming bacteria much less sensitive to the temperature. Viruses seem to be more resistant to inactivation than bacteria (Turner and Burton, 1997).

A temperature-time criterion of 70ºC for 1h has been stated as a minimum for specific thermal treatments prompting reductions equivalent to 4-$\log_{10}$ units, although it could be excessive for certain pathogens and low for others (Heinonen-Tanski *et al.*, 2006). The composting process requires of thermophilic temperatures during the decomposition phase, favoring manure hygienization, although high variability of operational conditions and the lack of monitoring (especially in rural facilities) can make discussable the effectiveness of the process (Martens and Böhm, 2009). Although pathogens reduction exists in both mesophilic and thermophilic anaerobic reactors, in the first case it is quite lower. Aerobic digestion of liquid manures in self-heated thermophilic bioreactors (ATAD) has been proposed as effective for hygienization (Juteau *et al.*, 2004), although with high electrical power requirements for transferring oxygen. NDN processes are relatively efficient for the reduction of pathogens. In this sense, Vanotti *et al.* (2009) obtained 2.6-$\log_{10}$ reduction through such treatment, increasing to 4-$\log_{10}$ units in a subsequent stage running at pH of 9.5 for the recovery of phosphorus as calcium phosphate.

Treatments dealing with emerging pollutants and xenobiotic compounds

Xenobiotics are human-made chemicals that are unnaturally present in the environment and that could cause environmental and sanitary problems. In the case of livestock industry, there are special concern compounds such as antibiotics and hormones due to the routinely use in farms. Such substances are not completely absorbed by animal bodies and thus excreted as parent compounds or metabolites (Kemper, 2008). Release of antibiotics to the environment is of considerable concern because it may lead to the development of antibiotic-resistant bacteria (Chee-Sanford *et al.*, 2009). Numerous xenobiotics are susceptible of photodegradation, which can occur at the surface of manure in storage facilities, and at the soil-atmosphere interface once manure is applied to soil. Nevertheless, sorption phenomena protect xenobiotics against photolysis and other potential degraders (Jjemba, 2002). Hydrolysis can be another degradation pathway (Chee-Sandford *et al.*, 2009) being highly influenced by temperature, pH and the molecular composition of chemical compounds. Generally, the degradation of most xenobiotics is faster and more complete under aerobic as compared to anaerobic conditions (Thiele-Bruhn, 2003). Antibiotics also can negatively affect bioprocesses performance when processing manure (Álvarez *et al.*, 2010). More research is needed in this field.

Finals remarks

The adoption of a manure treatment technology must be the result of a strategy defined to solve a problem posed by a nutrient management planning or other restrictions, such as hygienization requirements. Although energy production by anaerobic digestion can be an objective by itself, it must be taken into account that this process offers other technical advantages, such as odors abatement (Wilkie, 1998), greenhouse gasses emission mitigation, decrease of manure viscosity and particle size, decrease of weed seeds contents in digested manure and mineralization, which also favors the efficiency of many other processes dealing with nutrients recovery, or with the N-removal when combined with the autotrophic anaerobic ammonium oxidation process.

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