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Review

Mitigation and adaptation to climate change through the implementation of integrated models for the management and use of livestock residues. Review

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Abstract:

The need to optimize the management and the use of the excreta is due to the fact that animal species do not take advantage of 100 % of the nutrients consumed of the food, the excrement being a potential source of these. The amount and quality of excretion depends on factors such as food, animal species, production status, health status and type of facilities. Integrated models for waste management should consider the revaluation of these as raw material, in order to develop technologies that enable the recovery of nutrients. Pig waste silage, compost, vermicompost, and anaerobic digestion systems are part of these schemes. On the other hand, the importance of bioremediation lies in the use of the metabolic potential of microorganisms to transform organic pollutants, and can be used to clean contaminated spaces or water. The technological adoption strategy is designed and started by establishing the characteristics of the material to be treated, its conditioning and the conditions of operation of the process, to select the criteria and methods for its scaling in any production system.

Key words: Raw material, Manure, Exploitation, Environment, Integrated Systems, Bioremediation.

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Introduction

The human population has grown twice since 1960, demanding food and services; this growth is reflected in increases in animal population inventories. In terms of food, the production of meat, milk and eggs increases in proportion to the inventories of animal production; it is estimated that by the year 2020 approximately 200 billion liters of milk and 100 million kilograms of meat must be generated in order to satisfy the demand[1]. Like food production, the generation of organic waste is increasing, the agricultural sector being a major contributor to air pollution.

In 2013, at the global level, it was estimated that 14.5 % of the total greenhouse gases induced by the human being (7.1 gigatonnes of CO_2-equivalent for 2005, and 10 Gt for the year 2010) are represented by the livestock supply chain. Of these, 41 % correspond to the production of beef, 20 % to milk, 9 % to the production of pork, 8 % to the production of chicken meat and egg, 6 % to the production of milk and meat of small ruminants, and the rest, to that of other species of birds and ruminants[2].

In Mexico, according to the national inventory of greenhouse gas emissions, an emission of 748.25 megatonnes (Mt) of CO_2-equivalent were estimated in 2010, 12.3 % of which (Mt 92.18) corresponds to the emissions from agriculture, contributing from enteric fermentation and manure management with the emission of 3.74 Mt CO_2-equivalent[2,3]. Thus, organic livestock waste represents a growing and constant source of pollutants. The polluting potential of such waste (manure or excreta) lies in the presence of undigested nutrients, since no species takes advantage of the total nutrients consumed in the diet[4,5]. Therefore, excreta can be considered a potential source of nutrients, which can be exploited through various processes.

The production and quality of excreta is linked to factors such as: species, zootechnical end, production stage, quality of diets, digestibility, among others. Similarly, the infrastructure of the unit of production, the management and the equipment available for the collection, are factors that are linked to the physical and chemical characteristics of the waste[2,3].

The characterization of the organic livestock waste is the key for planning its management, use and disposal and, thus, to mitigate its emissions and its polluting effect.

Therefore, the objective of this work is to present the processes that can be adopted under an integrated model for the development of livestock waste while preserving and recycling nutrients derived from animal production systems.

Integrated models for the management and exploitation of waste

The integrated models for the management and utilization of waste consists in the integration of technologies that lead to this purpose. These models must be adaptable to different livestock production systems (family, medium-scale, large scale, intensive, extensive, and mixed) and interact with agriculture. Their main objective is the diversification of production and income, establishing environmentally-friendly processes to achieve sustainability. The most important and most promising challenge of these models is the articulation with the local and national production and commercial chains. In this sense, the efforts that have been made to address different problems are numerous, but isolated, and the solution is a holistic approach to the waste management needs in the agricultural sector.

For a long time, work has been done to identify, quantify, and treat the organic residues of livestock holdings, conceptualized as waste, with the aim of establishing strategies and policies to mitigate the impact that they have on the environment[6-12].

However, it is of vital importance to revalue the residues as raw materials in order to implement sustainable processes and consolidate integrated schemes for mitigating the negative impact on the environment and generating stability and profitability[2,13,14], and, therefore, it is necessary to determine their availability, composition, physical and chemical characteristics[15,16] and safety[17] —all of which are indispensable for determining the level of achievement in the various processes which they can be subjected.

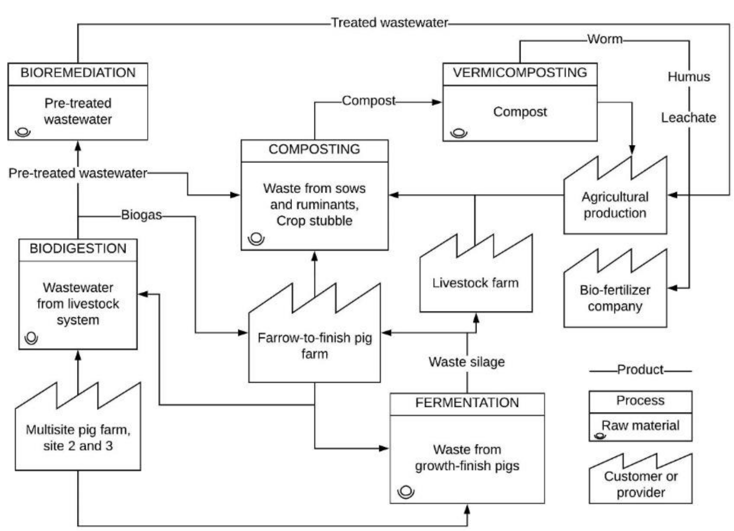
Currently, importance has been given to technologies that prioritize the recovery of nutrients contained in livestock waste (mainly nitrogen and phosphorus), especially in swine manure, with alternatives such as the generation of protein biomass for use in animal nutrition[18]. However, despite being a viable alternative to mitigate the environmental impact generated by waste, it is limited and does not consider aspects of food safety and toxicology.

On the other hand, there are viable alternatives to achieve the objective of mitigating the environmental impact and utilize the waste; however, the lack of training to design and operate them, coupled with inadequate management, suggests or leads one to believe that they are useless. An example of this are the anaerobic digestion systems (biodigesters); when these fail to treat adequate volumes, have not established a load regime or lack adequate levels of water retention for the characteristics of the residues, they generate effluents that may not be suitable for exploitation in agriculture, due to their high concentration of nutrients[19].

Therefore, it is essential to generate, validate and adapt technologies according not only to the needs of a wide range of schemes of agricultural production, but also to the characteristics of the raw material intended to be processed and to the production goal to be achieved, taking into account that, in this sense, savings in the environmental cost of production are implicit. In order to achieve this, it is necessary to generate integrated models that can include one or more processes (technologies for the management of sewage treatment) contributing to a common purpose.

At the National Institute for Research on Forestry, Agriculture and Livestock (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, INIFAP) various processes for packaging, handling, use, and revaluation of organic waste in the livestock sector have been designed and studied; these include: silage or fermentation of swine manure for animal feed[20-22], compost and vermicompost for the production of organic fertilizers[23], anaerobic digestion systems for the generation of renewable energy, and wastewater treatment[24]. These technologies have the capacity to generate byproducts with added value and condition the raw material to be subjected to another process that may also yield a byproduct, or prepare for a bioremediation scheme (Figure 1).

Figure 1: Model of integration of processes for the management and exploitation of livestock waste



The agricultural production systems are the providers of resources (organic matter) for processes (technological alternatives) that generate marketable products where a supplier can become a customer.

Conditioning of the waste and generation of byproducts through processes silage or fermentation of swine manure

For a long time, fresh or dried swine manure has been used for animal feed due, to a certain extent, to the lack of information about the risks and disadvantages that it entails, generating health problems and probably exacerbating diseases. And although there are studies that determine the feasibility of its use, they consider only productive aspects[25-29], but not conclusive aspects in relation to animal health, carcass quality, quality and organoleptic properties of milk, among others of importance to animal welfare and food safety; on the other hand, inadequate processing generates an environmental problem.Currently, the use of dried swine manure continues to rise with inclusions of up to 70 % in the diets, with losses of crude protein of up to 12 % of the total content of fresh excreta[30,31], which represents a limitation for the use of the nutrients contained in it.

Depending on the disadvantages, risks and opportunities that the use of swine manure for animal feed entails, a process for conditioning, called swine manure or silage fermentation of swine manure has been developed and perfected, which consists in subjecting the excreta (from pigs in stages of weaning-completion) to a anaerobic fermentation process[20]; the swine manure silage is the final result and can be used for feeding ruminants[22,31-34], pigs[35-38] and even, in view of the characteristics of this ingredient, other species such as fish, birds and rabbits.

The main objective of this process, is to reduce the pH to levels below 5, in order to eliminate microorganisms indicating fecal contamination[39]), the process by which, organisms, viruses and parasites are also eliminated[17,40], provided that the process is carried out properly. The same principle of anaerobic fermentation is used for the treatment of human food residues and their use as food for pigs[41], as it provides advantages over their chemical, physical and microbiological characteristics, preventing spoilage.

In this sense, the silage of swine manure has also been used with the objective of conferring immunity to pigs and reducing the microbe count in hog farms[42]; this does not involve a risk, unlike the self-immunization strategies utilized in the presence of outbreaks of epidemic swine diarrhea[43] or other diseases in Mexico.

It is important to emphasize that the main benefit of swine manure silage lies in the reduction of production costs; recent work, suggest a reduction in the cost of production of up to 7 %, with the inclusion of 30 % at the stages of growth-development-completion of the hogs[21] and of up to 60 % in the feed for ruminants. It is essential to consider that swine manure silage is a highly available ingredient for the formulation of diets; therefore, it is indispensable to know its chemical composition (which tends to vary according to the quality of the raw materials used) in order to create formulations based on the nutritional needs of animals that are to be fed.

It is worth mentioning that, as specific research on the possible uses and applications of swine manure silage is carried out, an integral development will be achieved for the benefit of the various livestock production systems, the producers and the environment.

Compost and vermicompost

Unlike swine manure silage, which uses hog manure only at the wean-to-finish stage, composting is a versatile process which allows conditioning a large variety of agricultural waste products. Although composting is not a new practice, the adequacy of the technique and the acceleration of the process renders it innovative.

Although, in general, composting is considered a simple process, the practice suggests that it requires complex physical, chemical and microbiological conditions(23), and the lack of care or considerations has an impact on the quality of the final product (stabilized compost). Compost possesses an important content of organic matter and nutrients that can be utilized in a variety of ways in agriculture and in the preservation of the soil(44,45).

In order for the composting process to be carried out efficiently and for the compost to be rich in nutrients, it is important to consider the quality and composition of the raw materials. In this regard, the excreta of sows in reproduction and ruminants in general provide ideal characteristics for being mixed with an extensive range of hard to compost agricultural crops with a high carbon/nitrogen ratio, for their processing and utilization(13).

Another way to use and to give added value to compost is to utilize it as input for the generation of vermicompost through vermiculture(46). Vermiculture is considered a biotechnology, where the worm serves as a working tool for the transformation of residues in organic products such as the vermicompost; this contains active substances that act as plant growth regulators, has a high content of humic acids, and increases the capacity of moisture retention, facilitating aeration and soil drainage(23). In addition, vermicompost boasts a high content of potassium and phosphorus(46.47). Vermicompost also increases the microbial activity in the soil considerably, and there is evidence that plant growth regulators such as auxins, cytokinins, humic acids and micro-organisms promote plant growth regardless of supplementation with nutrients(48,49). Vermiculture yields not only vermicompost but also other subproducts with a high economic value, such as earthworm leachate and earthworm biomass(44,46).

Currently, importance is given to aspects of ecotoxicology and environmental safety[50], analyzing the risk associated with the use of compost in the generation of antimicrobial resistance[51], degradation of antibiotics[52,53], bioavailability of heavy metals[50], emission of gases[54], and persistence of pathogens[55], among others; however it is important to consider basic aspects related to the raw material, including the feeding of the animals, handling, health and biosafety, which are a guarantee of innocuous, high-quality food and waste.

Anaerobic digestion systems

The systems of anaerobic digestion are a viable alternative for the pre-treatment of agricultural waste[56]. Its main function is to degrade organic matter and transform it into methane; effluents have also been used as fertilizers for crop lands[57,58]. The above will depend on the efficiency of the reactor (biodigester).

There are different types of biodigesters: among those considered to be high-load are the anaerobic sequential batch reactor (ASBR), and the upflow anaerobic sludge blanket (UASB). This type of biodigesters offers the advantage of reducing the loads of solids of the wastewater in a relatively short time; however, the required investment is high[59].

In Mexico, the most commonly used biodigesters for the treatment of effluents from livestock production units are the covered lagoon digesters[60], several versions of which have been developed to facilitate their management and useful life, through the implementation of systems of sludge extraction and agitation[61].

The common, widespread management of this type of biodigesters consists in channeling 100 % of the solid waste generated in the production unit by means of high volumes of water, in the form of "haulage". This type of practice occurs even in areas where there is a marked shortage of water, which is inconsistent with the aim of mitigating the environmental impact[62]. As a result, there is a need for large digesters that require a large space and a high investment. In some cases, this type of biodigesters have been proven to have efficiencies of 78 % to 90 % in the removal of the chemical oxygen demand[63] and in the total reduction of helminth eggs[60].

Another very popular type of biodigesters in Mexico is the tubular polyethylene (Taiwan) type; these biodigesters have been efficient in backyard systems for the generation and self-supply of the generated biogas; however, this type of biodigesters under livestock production schemes tend to be surpassed by the production of waste, so that their use fails to bring a benefit. In addition, recent studies have shown that this type of biodigesters under continuous flow in pig farms are unable to eliminate certain pathogens such as: *L. intracellularis*, *S.*

aureus, *E. coli*, *Salmonella* spp, mesophiles, Clostridium sulphite reducers, total coliforms and coccidia[64,65], and therefore the use of their effluents as *biol* or fertilizer entails a health risk.

On the other hand, various sectors (including livestock), have used the biodigesters as generators of renewable energies, and some research institutions have bet on the development and industrialization of this technology. The use of various raw materials[66,67], the conservation of raw materials for use in the production of biogas[68], and the development of systems of purification, compression and use in spark ignition engines[69], are some of the topics of research.

However, in the livestock sector the main purpose of the biodigesters is the production of electrical energy to self-supply their productive processes; in this sense, pig farming is the most promising for this purpose, given the characteristics of the waste and its peculiarities in the production system. This provides the industry with an opportunity to be competitive — in economic, social and environmental terms— in the generation of electric power[70,71].

In recent years, the adoption of biodigestion systems has become popular among small and medium-sized producers; the main reasons for this are: the novel idea to generate biogas or energy, pressure from the authorities to establish a process for the treatment of waste, the introduction into the market of low-priced designs, and financing facilities.

However, before implementing a biodigester (regardless of the scale of the production unit), it is necessary to know the quantity and characteristics of the waste generated in order to develop a strategy of technology integration and to direct the waste to each one of the processes as appropriate. If the biodigester carries out one or more of the processes under consideration, it is useful to determine its level of achievement and its purpose, i.e., the pretreatment of wastewater, the generation of (heat or electric energy), or both. This makes it possible to establish its design-operation and to measure and maximize its performance.

Bioremediation

Bioremediation is a branch of the biotechnology that uses the metabolic potential of microorganisms to transform organic contaminants in compounds with minimal or no side effects, and, therefore, it can be used to clean polluted spaces or water, with very ample perspectives[72,73].

However, it is important to mention certain considerations in relation to bioremediation: compared to the chemical methods that are based on the transfer of contamination between the three physical states in which it occurs (gaseous, liquid, and solid), bioremediation transfers little pollution from one medium to another because this technology is not very intrusive and generally does not require significant structural or mechanical components; moreover, it is economically profitable, because it is a natural process which is accepted in a context that goes beyond the technical implications[(74)].

Bioremediation has some disadvantages and limitations. For example, incomplete biodegradation can generate unacceptable metabolic intermediaries with a polluting power that is similar or even superior to that of the original product. On the other hand, some compounds, are resistant to or inhibit bioremediation. The time required for proper treatment can be difficult to predict; in addition, following up and controlling the speed and the extent of the process are laborious tasks.

The efficiency of this technique depends on several factors such as:
a) The properties of the polluting agent or agents (biodegradability).
b) The presence of microbial communities with the ability to metabolize the enzymatic or compounds. Microorganisms can be indigenous (intrinsic bioremediation or attenuation)[(75)], added to the system in order to improve the degradation (bioaugmentation) or by providing optimal conditions that stimulate microbial activity (biostimulation) by supplying oxygen, nutrients or modifications of pH, among others.
c) Availability of the pollutant. It is a more important critical factor than the presence of microbial communities itself. In order for the degradation of a contaminant to occur, the microbial cells must interact directly with the pollutant, preferably in an aqueous medium[(76)].

Bioremediation for decontamination in livestock waste

The selection of processes and the design of the strategy for the bioremediation of water and soils contaminated with organic compounds such as livestock waste begin by clearly establishing the characteristics of the material to be bioremedied (effluent from livestock production units or contaminated soils), the microorganisms to be used, the types of reactor (e.g. anaerobic digesters or lagoon systems), the pretreatment of the contaminating material (mainly excreta, which can be pretreat or conditioned with the alternatives mentioned above), and the conditions of operation of the process (given by the production system and the adopted integrated model). It is necessary to consider also the laboratory evaluations in order to explore operation alternatives and quantify the degradation speeds in terms of critical operation parameters such as pH, oxygen and oxidation-reduction potential, with the purpose of determining the effectiveness and efficiency of the bioremediation process. At a small scale, the physicochemical phenomena must be observed, and specific conditions for improving the process must be determined. These aspects provide an important basis for criteria and methods of scaling the processes (from pilot to semi-commercial to commercial), as well as the requirements for their implementation and control[77,78].

Characteristics of distribution of pollutants

Before selecting any alternative bioremediation process, the site or material to be cleaned must be very well characterized, a technical and economic pre-feasibility study must be performed, and the physical, chemical and microbiological hazards must be clearly established, in order to accurately determine the details of cleaning speed, as well as the factors that influence it, and subsequently proceed to obtain data on the kinetics and balance in physical, chemical and biological processes reaction mechanisms that are important for the design of the process. Also, the type of contaminant, its concentration, the extent of the problem must be known, as well as the bioavailability of the substance, especially in leaching processes[79].

Determination of the microorganisms to be utilized

Degradation tests with different microorganisms are essential to determine which must be used; this requires information mainly about the medium (water, soil) on which the process will take place, the organic matter content, and the particle size distribution profile[77]. Microbiological analyses include parameters such as the biochemical oxygen demand, the determination of viable count, in vitro degradation studies prior to the escalation of the process[73]; and, from the biochemical point of view, the metabolic pathways involved during the biodegradation of the contaminants and potential beneficial or harmful effects toward the same process of degradation[80]. It is important to consider the conditions of temperature, oxygen, nutrient supply and availability of the contaminant, as they can limit the speeds of degradation, mainly at the beginning of the processes where even the limiting factors are not well defined.

The experience says that the best microorganisms for a process of bioremediation are, precisely, at the site to be bioremedied, that is to say, it is preferable to use a native microorganism[81]. However, it is important to determine the efficiency and speed of biodegradation because the cell concentration or biomass of native microorganisms is generally low, or because there are no microorganisms capable of biodegrading the contaminating material[76], allowing for the use of a collection microorganism[82,83].

Bioremediation of wastewater and agricultural soils, with microbiological, biochemical and engineering support, is one of the most promising strategies for decontaminating these resources and is currently an additional alternative for the integrated systems of management and utilization of waste and the business incubation through proper use of positive results that are generated from research projects, with technological application at reduced costs, and with tangible benefits for the population and the environment.

Conclusion

The integration of technologies for the management and use of organic livestock waste and bioremediation of soil and water is feasible. This type of model must be articulated with local, national and international markets and with environmental policies in order to meet the demand for food in both quantity and quality, with the premise to exploit and conserve the natural resources. Its adoption provides an opportunity to obtain economic, environmental, social and technological benefits.

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