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Composting of swine waste in the treatment of veterinary drug residues

Compostagem de efluente suíno no tratamento de resíduos de fármacos veterinários

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Highlights:
Composting is an inexpensive, effective and sustainable process;
The composting process has the capacity to remove antibiotics for veterinary use;
Environmental regulations do not foresee the contamination of environmental matrices by residues of veterinary drugs;
Contamination by veterinary drugs in environmental matrices such as soil and water have already been detected around the world.

Abstract

The increasing need for animal protein has exerted pressures on the current animal production system. One of the alternatives found by producers to improve animal performance has been the use of veterinary drugs, especially antibiotics. However, its indiscriminate use can be a risk to the environmental balance of the producing locations since Brazil has approximately 42 million pigs. With this herd, pig farming represents a great potential for generating environmental impacts. As an alternative use of the large volume of liquid pig manure generated, many producers have been using this slurry in the soil as a bio fertilizer. Residues of veterinary drugs are capable of accumulation with environmental matrices and leach into water resources. In this sense, it is mandatory to dedicate more efforts on the study of techniques and processes for the treatment of organic effluents contaminated by veterinary drugs. Low-cost and environmentally friendly alternative treatment systems are necessary, in order to minimize the entry of these contaminants into the environment. Therefore, the composting process, defined as aerobic microbial decomposition process of organic matter, can be an alternative for treating the effluents contaminated by veterinary drugs. This review to aims to create awareness in the academic community regarding the veterinary drug residues and their contamination potential in different environmental matrices, as well as evaluating the composting process as a technique to minimize the impacts of the swine activity waste on the environment.
Key words: Antibiotics. Contamination. Environment. Treatment. Accumulation.

Resumo

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A crescente necessidade por proteína animal tem exercido pressões no atual sistema produtivo animal. Uma das alternativas encontradas pelos produtores para melhorar o desempenho animal tem sido a utilização de medicamentos veterinários, principalmente os antibióticos. No entanto, seu uso indiscriminado, pode ser um risco ao equilíbrio ambiental dos locais produtores, pois o Brasil possui aproximadamente 42 milhões de cabeça de suínos. Com este rebanho, a atividade suinícola representa um grande potencial de geração de impactos ambientais. Como alternativa de uso para o grande volume dos dejetos líquidos de suínos gerados, muitos produtores vêm utilizando o chorume no solo como biofertilizante. Os resíduos de medicamentos veterinários possuem capacidade de acumulação junto às matrizes ambientais, de serem lixiviados para os recursos hídricos. Neste sentido fazem-se necessários maiores estudos sobre técnicas e processos de tratamento de efluentes orgânicos contaminados por fármacos veterinários. Sistemas alternativos de tratamento de baixo custo e ambientalmente viáveis, são necessidades para a minimização da entrada no ambiente destes contaminantes. Logo, o processo de compostagem que pode ser definido como um processo de decomposição microbiana aeróbia da matéria orgânica pode ser uma alternativa para o tratamento dos efluentes contaminados por fármacos veterinários. O presente trabalho revisional tem como objetivo esclarecer a comunidade acadêmica quanto aos resíduos de medicamentos veterinários e sua potencialidade de contaminação nas diversas matrizes ambientais e avaliar a compostagem como técnica para a minimização dos impactos dos resíduos da atividade suinícola junto ao meio ambiente.

Palavras-chave: Antibióticos. Contaminação. Meio Ambiente. Tratamento. Acumulação.

Introduction

The indiscriminate use of antibiotics in animal husbandry, especially in pig farms, has become a gateway for these pollutants into the environment (NGUYEN et al., 2017). Antibiotics may be used for different purposes, from the therapeutic and/or preventive use in the treatment of diseases, such as infections, diarrhea, or even as growth promoters (CHENG et al., 2019; BEN et al., 2017; TASHO; CHO, 2016; GUO et al., 2016; QIAN et al., 2016a).

Several authors (CHENG et al., 2019; TASHO; CHO, 2016; GUO et al., 2016; GELBAND et al., 2015; DAGHRIR; DROGUI, 2013; DU; LIU, 2012), indicate that, on average, 60% of the veterinary drug administered to the animals is excreted through urine and feces (PULICHARLA et al., 2017), and the most commonly used group of drugs is antibiotics (TASHO; CHO, 2016. Among them, tetracycline, sulfonamides, macrolides, and fluoroquinolones stand out (CHENG et al., 2019; SOLLIEC et al., 2016).

Veterinary drug residues can reach the soil and the water resources (QIAN et al., 2016b; GUO et al., 2016; SOLLIEC et al., 2016) as unchanged substances or metabolites (SOLLIEC et al., 2016). The occurrence of pharmaceutical products in water environments is causing increasing concern in the scientific community, since there is a lack of information on the risks and effects on the environment, and to public health (REIS et al., 2019). In this context, the use of swine waste as a bio fertilizer may be contributing to the dissemination of these residues into the environment (NGUYEN et al., 2017; PULICHARLA et al., 2017). Several studies have already confirmed the environmental contamination, in many countries, by antibiotics, one example being the tetracycline contamination in Brazil, Canada, and China, (PINHEIRO et al., 2013; PULICHARLA et al., 2017; WEI et al., 2016). Other cases are: contamination by sulfonamine in Bolivia, the Czech Republic, and the United States of America (ARCHUNDIA et al., 2017; HO et al., 2013; KOBA et al., 2016); contamination by macrolide in South Korea, United Kingdom, and Hong Kong (KIM et al., 2015; PETRIE et al., 2016; WU et al., 2016); by fluoroquinolones in Poland, Austria, and Thailand (GBYLIK-SIKORSKA et al., 2015; MARTÍNEZ-CARBALLO et al., 2007; RICO et al., 2014); and by quinolones in China and Malaysia (HO et al., 2013; LI et al., 2015).

Considering the problem of veterinary drug residues and their potential impacts on the environment, this article sought to contextualize the contamination potential of the environmental matrices by these residues in liquid swine manure, the used analytical detection techniques and finally to evaluate the potential of the composting process as an alternative for treating and reducing the concentrations of these pollutants.

Veterinary drugs and their uses

The use of veterinary drugs, and their benefits for animal production, comes from the 1950s (TASHO; CHO, 2016). With the increasing appeal for the production of animal protein, the need to use veterinary drugs to optimize the production of animals in confinement arose (TASHO; CHO, 2016). The purpose and uses of veterinary drugs are diverse, being used both for therapeutic use and for the prevention and control of diseases, or even as promoters of animals' growth (CHENG et al., 2019; TASHO; CHO, 2016; GUO et al., 2016; GONZALEZ RONQUILLO; HERNANDEZ, 2015; GELBAND et al., 2015).

Araujo et al. (2010), report the existence of approximately 4,000 types of veterinary drugs, utilized for over 10,000 purposes. The North American Food and Drug Agency (FDA) estimates that there are over 400 active ingredients, used in more than 2,000 veterinary products (FDA, 2017). Among the veterinary drugs, antibiotics represent the highest consumption demands, with tetracyclines, sulphonamide and macrolides being among the main classes, representing 90% of the total antibiotics used in the United Kingdom and 50% in South Korea (TASHO; CHO, 2016). Solliec et al. (2016) agree that tetracyclines are among the most widely consumed antibiotics in animal production. However, they disagree in relation to other compounds, pointing to β-lactams, sulfonamides, lincosamides, and macrolides as the most used.

Nevertheless, regarding consumption, it should be noted that in 2010 alone, approximately 63,151 tons of antibiotics were used for animal production (VAN BOECKEL et al., 2015). The main consuming countries were China (23%), the United States of America (13%), Brazil (9%), India (3%) and Germany (3%). Projections estimate that the consumption of these compounds could reach 105,596 tons until 2030 (VAN BOECKEL et al., 2015), distributed between China (30%), United States of America (10%), Brazil (8%), India (4%), and Mexico (2%). Zhang et al. (2019) states that China alone, in 2013, produced 163,000 tons of antibiotics, consuming around 52 % of these drugs in animals raising.

Antibiotics can be characterized as drugs that destroy or inhibit the growth of bacteria, with small dosages (GONZALEZ RONQUILLO; HERNANDEZ, 2015), and can be classified as natural, semi-synthetic and synthetic, being administered orally, or added together with water and animal feed (GBYLIK-SIKORSKA et al., 2015). There are more than 6,500 products registered, for veterinary purposes, with the Ministry of Agriculture, Livestock and Supply (MAPA, 2015) in Brazil. Approximately 10% of these products are antimicrobial, antibiotic, and antiparasitic compounds, which are used in the productive processes of cattle, pigs, goats, poultry, and sheep, consisting of different groups such as avermectins, β-lactams, aminoglycosides, tetracyclines, and sulfonamides (PACHECO-SILVA et al., 2014).

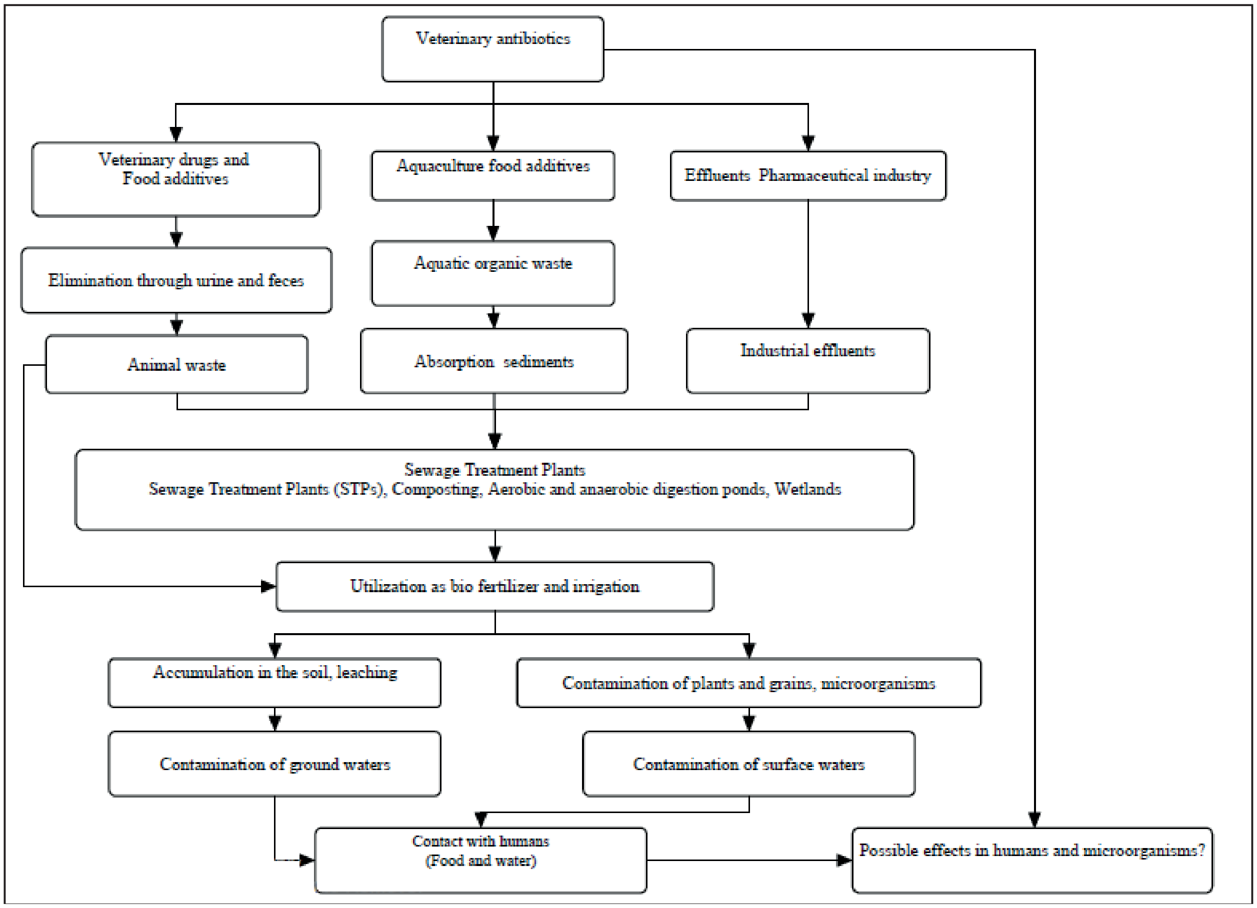
After being used, these compounds can reach the soil and water resources through the use of organic waste from animals, such as bio fertilizer (QIAN et al., 2016; GUO et al., 2016; SOLLIEC et al., 2016) or even as untreated waste (DU; LIU, 2012; GONZALEZ RONQUILLO; HERNANDEZ, 2015), occurring as unchanged substances or metabolites (SOLLIEC et al., 2016).

Contamination of the environment by veterinary drug residues

The possibilities of environment contamination by veterinary drug residues are varied, with different ways of introducing these products into the environment (Figure 1), which can start from the incomplete removal in the Sewage Treatment Plants (STP) (AMÉRICO et al., 2012), since most of STPs are not designed for antibiotic removal (HU et al., 2018). Other routes are the direct discharge into domestic sewage, hospital and pharmaceutical industries effluents disposed in water bodies and the inadequate disposal of drugs, directly into the environment, after the expiry of their expiration date (CARVALHO et al., 2009).

Due to the use of high doses of veterinary drugs (SOLLIEC et al., 2016), and the incomplete metabolism of these products by the organism, most of them come into contact with environmental matrices. Researches estimate that between 30 and 90% of veterinary drugs are not absorbed by the animal organism, going to treatment systems or being discarded in the environment (TASHO; CHO, 2016; GUO et al., 2016; GELBAND et al., 2015; DAGHRIR; DROGUI, 2013; DU; LIU, 2012).

Figure 1. Main entry routes of veterinary drugs into the environment.



Source: Adapted from Du and Liu (2012); Regitano and Leal (2010); Tasho and Cho (2016)a common practice worldwide. These bioactive organic compounds have short retention period and partial uptake into the animal system. The uptake effects of this pharmaceutics, with plants as the primary focus, has not been reviewed so far. This review addresses three main concerns 1.

Environmental effects of veterinary drugs from the pig sector

The utilization of animal waste, directly or indirectly applied on the soil as organic fertilizers (LI et al., 2015), has caused a number of environmental effects comprising modifications in the biotic community of the soil and in soil structure, soil contamination by heavy metals, and even the contamination of water resources (SUI et al., 2016; SEGURA et al., 2015)we decided to investigate the impact of income inequality between countries on the occurrence of anti-infectives in surface waters. In order to perform such study, we gathered concentration values reported in the peer-reviewed literature between 1998 and 2014 and built a database. To fill the gap of knowledge on occurrence of anti-infectives in African countries, we also collected 61 surface water samples from Ghana, Kenya, Mozambique and South Africa, and measured concentrations of 19 anti-infectives. A mixed one-way analysis of covariance (ANCOVA. They also potentialize the microorganism resistance to antibiotics (BONDARCZUK et al., 2016; CENTNER, 2016; LUCAS et al., 2016; RHOUMA et al., 2016; WANG et al., 2016a; HU et al., 2018) namely, tetracyclines (TCs, endangering the human health (LI et al., 2015; REGITANO; LEAL, 2010).

Currently, Brazil is the fourth largest pig producer in the world, behind China, the United States, and the European Union, with an estimated 42 million head herd (ABCS, 2014). In the three southern states of the country, Paraná, Santa Catarina and Rio Grande do Sul, swine farming accounts for 49.3% of the national production according Brazilian Institute of Geography and Statistics (IBGE, 2015), mainly conducted in these states by family farmers integrated with companies in the sector.

The state that pigs in the termination phase may produce up to 7.6 liters of waste/day. Considering the production of urine and manure of pigs between 25 and 100 kg, of gestating and lactating female pigs, males and weaned piglets, their production is respectively 4.9 kg/day, 11 kg/day, 18 kg/day, 6 kg/day, and 0.95 kg/day (OLIVEIRA; HIRAGASHI, 2006).

Some studies suggest that, based on the number of pigs currently produced in the three southern states of Brazil, 49.3% of the national production, (IBGE, 2015), it is possible to generate 300 million liters of waste daily, which in most cases is disposed in the surrounding crops, triggering several impacts to the environment (CADONÁ et al., 2016). Several researchers confirmed contamination in environmental matrices around the world, as shown in Table 1, which presents some examples of the main groups of antibiotics found in the literature, in different types of environmental matrices.

Table 1. Antibiotic groups and their environmental contamination in different environmental matrices.

Group	Location	Environmental Matrix (ces)	Reference
Tetracycline (TCs)	Austria	Soil; animal manure	Martínez-Carballo et al. (2007)
	USA	Soil	Ho et al. (2013)
	Malaysia	Soil; animal manure; Ground water	Cheng et al. (2016)
	China	Soil; animal manure	Ben et al. (2017)
	Canada	animal manure	Pulicharla et al. (2017)
	South Korea	Surface water	Kim et al. (2015)
	Ghana, Kenya, Mozambique, South Africa	Surface water	Segura et al. (2015)
	Hong-Kong	Surface water	Wu et al. (2016)
	China	Soil; Surface water	He et al. (2016)
	Thailand	Surface water; Sediment	Rico et al. (2014)
	Germany	Soil; animal manure; Ground water	Hamscher et al. (2005)
	Brazil	Surface water	Pinheiro et al. (2013)
	Poland	Surface water	Gbylik-Sikorska et al. (2015)
Sulfonamides (SAs)	China	Soil	Wei et al. (2016)
	China	Soil; animal manure	Li et al. (2015)
	Czech Republic	Soil	Koba et al. (2016)
	USA	Soil	Ho et al. (2013)
	Malaysia	Soil; animal manure; Ground water	Cheng et al. (2016)
	Bolivia	Soil; Surface water; Ground water	Archundia et al. (2017)
	China	Soil; animal manure	Ben et al. (2017)
	South Korea	Ground water	Kim et al. (2015)
	Hong-Kong	Ground water	Wu et al. (2016)
	China	Soil; Ground water	He et al. (2016)
	China	Surface water; Sediment	Li et al. (2012)
	United Kingdom	Surface water	Petrie et al. (2016)
	Taiwan	Animal manure	Yang et al. (2016)
Macrolides (MLs)	China	Soil; animal manure	Li et al. (2015)
	China	Soil	Zhang et al. (2016a)
	USA	Soil	Ho et al. (2013)
	Malaysia	Soil; animal manure; Ground water	Cheng et al. (2016)
	China	Soil; animal manure;	Sui et al. (2016)
	South Korea	Surface water	Kim et al. (2015)
	Hong-Kong	Surface water	Wu et al. (2016)
Fluoroquinolones (FQs)	China	Surface water; Ground water	Li et al. (2012)
	United Kingdom	Surface water	Petrie et al. (2016)
	Poland	Surface water	Gbylik-Sikorska et al. (2015)
	China	Soil	Wei et al. (2016)
	Austria	Soil; animal manure	Martínez-Carballo et al. (2007)
	South Korea	Surface water	Kim et al. (2015)
	Hong-Kong	Surface water	Wu et al. (2016)
	China	Surface water; Sediment	Li et al. (2012)
	Thailand	Surface water; Sediment	Rico et al. (2014)

The authors listed in Table 1 disclose contamination of several environmental matrices (Soil; Surface water; Groundwater and Sediment). As also shown in Table 1, the main studies on this aspect are in Asia, especially in China. Researches in South America and particularly in Brazil are incipient. In this context, stands out the work of Pinheiro et al. (2013), carried out in Brazil, evaluating the contamination of surface waters by veterinary drugs. There is also the study of Reis et al. (2019), investigating the occurrence of 28 prescribed drugs, of different therapeutic classes, in six Drinking Water Treatment Plants. However, there is a need for a more in-depth look by the scientific community on the issue of veterinary drugs and their environmental impacts, through further research, especially in countries where pig farming plays a prominent role, as in Brazil.

Legislation of veterinary drugs in Brazil and in the state of Rio Grande do Sul

Another important aspect that needs to be addressed is the issue related to the legislation concerning the quantification of potentially contaminant products. The current demand, consumption, and production of some compounds of diversified characteristics and composition, such as veterinary drugs, create the need for specific laws for the adequate disposal of these contaminants, especially for those not yet standardized (RODRIGUES-SILVA et al., 2014).

Brazil still does not have specific legislation to regulate maximum residue limits (MRLs) of veterinary drugs for environmental samples (soil and water), as well as for the final disposal of effluents. Current laws just standardize acceptable parameters for water meant for human consumption and for the disposal of effluents and their concentrations. These legislations are, respectively: the Consolidation Ordinance No. 05/2017 of the Ministry of Health (MH) addressing the water quality and its potability (BRASIL, 2017), and the CONAMA 357/2005 and 430/2011 resolutions (BRASIL, 2005, 2011), on effluents disposal. The CONSEMA 355/2017 resolution relates to the State of Rio Grande do Sul and establishes the standards for liquid effluent emission in surface waters. Regarding the concentrations of substances in soils and groundwater, Brazil has the CONAMA 420/2009 Resolution (BRASIL, 2009), which addresses the guiding quality criteria and values in relation to the presence of chemical substances, but no regulations or regulation offering any parameter for any class of antibiotics, as seen in Table 2.

Table 2. Environmental legislations and their maximum chemical substances concentrations in different legislations.

Substances	MH Ordinance MH 05/2017	CONAMA resolution 357/2006 ¹ 430/2011²	CONAMA resolution 420/2009		CONSEMA resolution 355/2017
			Dry soil	Water	
Total mercury	0.001 mg L^{-1}	0.0002 mg L^{-1}Hg¹ 0.01 mg L^{-1}Hg²	0.06 mg kg^{-1}	0.1	0.01 mg L^{-1}
Acrylamide	0.5 µg L^{-1}	0.5 µg L^{-1}	-	-	-
Benzene	5 µg L^{-1}	1.2 mg L^{-1}	0.06 mg kg^{-1}	5 µg L^{-1}	-
Aldrin¹ Dieldrin²	0.03 µg L^{-1}	0.005 µg L^{-1}	0.003¹ mg kg^{-1} 0.2² mg kg^{-1}	0.03 µg L^{-1}	(a)*
DDT	1 µg L^{-1}	0.002 µg L^{-1}	0.55 mg kg^{-1}	2 µg L^{-1}	(b)*
Glyphosate	500 µg L^{-1}	65 µg L^{-1}	-	-	-

(a)*Aldrin; (b)* DDT: disposal prohibited in water bodies.

The abovementioned ordinances and regulations established guidelines and concentrations for some emerging chemical compounds, such as substances arising from agrochemicals and fuel spillage. However, in cases with no pre-established parameters by the specific legislation, the environmental agency, through technical advice, may set standards for other substances not listed in CONSEMA 355/2017 ordinance, due to the constant development of new substances (RIO GRANDE DO SUL, 2017), becoming an alternative to the lack of standards for these compounds. However, considering that several authors in different countries have already registered the presence of drug residues, especially antibiotics, in different environmental matrices, as contaminants (Table 1), including in Brazil (PINHEIRO et al., 2013) the need for specific and appropriate legislation regulating MRLs for veterinary drugs in environmental samples in the country is essential and urgent.

Methods for the determination of veterinary drug residues in environmental samples

The increasing analytical demand, created by the higher number of studies and research on environmental monitoring, has raised the need for techniques capable of detecting drug compounds (LÓPEZ-SERNA et al., 2010). In this sense, the veterinary drug residues became the class of emerging pollutants that were analyzed in more detail in the last decades (BOLEDA et al., 2013). The technological advances in both equipment and detection systems are enabling the measurement and identification of these pollutants in very low concentrations (IDE et al., 2016), which allows the generation of knowledge and understanding of their behavior and their interactions with the different absorbent media, such as the organic matter (SILVA; COLLINS, 2011).

The major challenges in the determination and monitoring of veterinary drugs are related to their levels of detection, which are usually in the range of μg/L and ng/L (BARBOSA et al., 2016; DAGHRIR; DROGUI, 2013; PACHECO-SILVA et al., 2014; RIBEIRO et al., 2015). In addition, because of the difficulty in standardizing the analytical methods, it is imperative that the methods be efficient and effective in the identification and quantification of these substances. Another barrier to be considered is the variability of the various environmental samples (SOSA-FERRERA et al., 2013). This receptor of emerging compounds comprises the water resources (KIM et al., 2015; RICO et al., 2014; SEGURA et al., 2015; REIS et al., 2019), the soil (HAMSCHER et al., 2005; HO et al., 2013; MARTÍNEZ-CARBALLO et al., 2007; SUI et al., 2016), and settleable materials (LI et al., 2015), making the determination even more complex.

Currently, the most used method for the identification of veterinary drugs is based on liquid chromatography (LC) (BOLEDA et al., 2013; GBYLIK-SIKORSKA et al., 2015; IDE et al., 2016; LÓPEZ-SERNA et al., 2010), followed by the solid phase extraction process (SPE). LC is able to separate elements in a single sample, facilitating the simultaneous identification of several chemical components. The LC technique, coupled to the mass spectrometry (MS) is being used (LÓPEZ-SERNA et al., 2010), owing to its great sensibility and accuracy, besides its speed and better cost/benefit ratio (LÓPEZ-SERNA et al., 2010; PRESTES et al., 2013).

With the advances in LC techniques for the analysis of these residues, several advantages have been demonstrated; from the decrease of sample volume, elimination of loss by the cartridge drought (column), resulting in the shorter analysis time, to the minimization of volume of organic solvents consumed during the analysis (SOSA-FERRERA et al., 2013). Table 3 presents some studies pursuing the monitoring of emerging pollutants and their extraction techniques.

Table 3. Studies conducted with different types of veterinary drugs in different environmental matrices and their detection techniques.

Compounds	Matrix	Cleaning	Column	Extraction Methods	Authors
45 Veterinary drugs	Water	SPE	C 18	LC-MS	(GBYLIK-SIKORSKA et al., 2015)
13 Veterinary drugs	Effluent and soil	SPE	C 18	HPLC-MS/MS	(WEI et al., 2016)
15 Veterinary antibiotics	Swine waste and soil	SPE	C 18	UPLC-MS/MS	(LI et al., 2015)
9 Antibiotics and 01 veterinary hormone	Broiler waste	SPE	C 18	LC-MS/MS	(HO et al., 2013)
Chlortetracycline	Domestic effluent	SPE	-	LDTD-MS/MS	(PULICHARLA et al., 2017)
12 Antibiotics	Surface water	SPE	C 18	HPLC-MS/MS	(WU et al., 2016)
18 Antibiotics	Surface water Swine waste Soil	SPE - HLB EU-SAX HLB	-	RRLC-MS LC-MS/MS	(HE et al., 2016)
3 Antibiotics	Soil	Ultrasonic	C 18	LC-MS/ MS	(KOBA et al., 2016)
Antibiotic groups	Surface water Ground water Soil	SPE	C18	LC-HRMS	(ARCHUNDIA et al., 2017)
90 Emerging compounds - antibiotics	Surface water	SPE - MAE	C 18	UPLC-MS/MS	(PETRIE et al., 2016)

LC: liquid chromatography; MS: mass spectrometry; SPE: solid phase extraction; UAE: ultrasound assisted extraction; MAE: microwave assisted extraction; DLLME-SFO: dispersive liquid-liquid micro extraction based on the solidification of floated decay organic mass; HSSE: high speed solvent extraction; UFLC: ultra efficiency liquid chromatography; UHPLC: ultra high pressure liquid chromatography; SPME: solid phase micro extraction; PLE: pressurized liquid extraction; LPME: liquid phase micro extraction.

The demand for reducing the volumes of solvents and other compounds used for the detection of veterinary drugs has been increasing, with efforts to adapt and prepare existing samples. Micro-extraction techniques has allowed the enrichment of samples and the minimization of solvent consumption, thus reducing environmental pollution. Examples are the Solid Phase Micro Extraction (SPME), Stir Bar Sorptive Extraction (SBSE) and Liquid Phase Micro Extraction (LPME) (SOSA-FERRERA et al., 2013). The SPME technique is an extraction method offering few advantages over the SPE, due to its high cost, fragility, and lack of selectivity for extracting compounds from complex matrices. The major disadvantage of this technique is the requirement of very clean samples, and hence, special instrumentation and experienced operators (SOSA-FERRERA et al., 2013).

With the development of several analytical techniques, there is a growing use of techniques based on the area of liquid chromatography applied to the detection of emerging pollutants. This technique is currently of great value for the standardization and quantification of new environmental standards of these compounds, thus helping in the analysis and monitoring thereof, for the purpose of follow-ups or even inspections, as well as contributing for the subsequent drafting of regulations and legislation.

Aerobic treatment system of veterinary drug residues

The proposal of methods and treatment processes for organic or industrial effluents contaminated by residues of veterinary drugs is a challenge for managers and technicians. The current treatment systems of effluents from chemical industries have used physicochemical processes due to the wide range of compounds produced in the effluent coming from the productive processes, making the treatment more complex, such as the advanced oxidative processes (RODRIGUES-SILVA et al., 2014). There are also other methodologies, already being tested, such as the use of biological and non-biological membranes (Reverse Osmosis, Ultrafiltration and Nano filtration) (YASSER et al., 2010).

The organic effluents generated in animal farms go to biological processes, which are used due to the potential to treat a large amount of effluent at the same time. Many emerging compounds, which are not biodegradable, can reach 50% removal rates in activated sludge processes and pond systems (MELO et al., 2009). Effluent treatment plants have their efficiency of veterinary drugs removal dependent on the treatment methods applied, as well as on the other related operation factors, ranging from the age of the sludge, hydraulic holding time, temperature, (LÓPEZ-SERNA et al., 2010).

Technologies that seek to reduce the residues of veterinary drugs, mainly antibiotics found in industrial and organic effluents, disposed as bio fertilizers in the soil, are a need in order to minimize the environmental impacts generated by these compounds (HO et al., 2013),

Among the several technologies and treatment systems for different origins and compositions of organic effluents, among them pig waste, composting stands out as a practical and low-cost proposal (HO et al., 2013; WEI et al., 2016) also considered a clean and feasible method (WU et al., 2017) for the proper management of these residues. This technique shall be an alternative for the treatment of effluents in small pig farms, located in regions with high concentration of pigs and little arable area available for final disposal of the effluents. It can also become a viable proposal for the treatment of veterinary antibiotics (LIU et al., 2015; WEI et al., 2016; HO et al., 2013; KIM et al., 2012).

The treatment of organic waste through composting reduces the volume of effluents, inactivates and immobilizes pathogens, nutrients and veterinary drugs (LIU et al., 2015; MITCHELL et al., 2015; QIAN et al., 2016a; ZHANG et al., 2016b), producing a by-product (substrate), with economic and agronomic value (OMAR et al., 2014). Veterinary drugs concentration decay through composting has been investigated by several authors (LIU et al., 2013; MITCHELL et al., 2015; MORTIER et al., 2016; OMAR et al., 2014; QIAN et al., 2016a; WANG et al., 2016b; ZHANG et al., 2016a; CHEN et al., 2018), for different type of effluents and organic wastes.

Bao et al. (2009) noticed a 27% decline in CTC (chlortetracycline) in swine waste and 92% in poultry manure in a composting system for 42 days. Mitchell et al. (2015) analyzed the decline of 4 antibiotics (florfenicol, sulfadimetoxin, sulfamethazine, and tylosin) during the composting process for domestic effluents, finding a decay between 95 and 99% of the antibiotics after 21 days of testing. Kim et al. (2012) assessed the decay of antibiotics during the composting process and recorded a 96% reduction in tetracycline levels, 99% for sulfonamides and 95% for macrolides. In a study by Liu et al. (2015), after

35 days of swine waste composting at bench scale, antibiotics Cheng et al. (2019) of the sulfonamide group - sulfametazine (SMZ) and sulfamethoxazole (SMX) - were not detected. Studies by) indicated that the efficiency of oxytetracycline (OTC), sulfamerazine (SM1), and ciprofloxacin (CIP) antibiotic removal, by composting, when in mixtures, was ≥85%. Zhang et al. (2019) showed that 64.7% of the veterinary antibiotics detected in animal manure were removed after composting for 171 days. According to the latter authors, the rates of removal for different classes of antibiotics ranged from complete removal, to macrolides, to no removal, for fluoroquinolones.

However, this process, as a proposal to treat residues of different classes of veterinary drugs, has not yet been developed in Brazil, evidencing the need for research aimed at the treatment of these residues. This is necessary in order to minimize the potential environmental risks caused by these contaminants, since in contact with the environmental matrices, they can accumulate in the soil and be leached to the water resources with potential contamination of humans (ZHANG et al., 2016a). Additionally, although effective antibiotic removal may occur after composting, this removal is controlled by activities that vary considerably with environmental factors, such as C/N ratio, humidity and pH, which also present variations in the different stages of composting (CHENG et al., 2019). According to Ezzariai et al. (2018), some changes in the composting management process would have the potential to influence the degradation process of the antibiotics. In this sense, the authors point out that increasing the composting period could allow more time for the degradation of antibiotics, especially during the maturation stage, but this could lead to the proliferation of antibiotic resistance genes.

According to Zhang et al. (2019), the destiny of veterinary antibiotics during the composting process is linked to different monitored environmental variables, which need further investigation. Thus, although composting is considered a promising solution to eliminate or reduce the discharge of antibiotics, further research is needed to better understand the mechanisms of antibiotic transformation and their interactions, as a requirement for the development of process management practices that aim at reducing their load on the environment (EZZARIAI et al., 2018).

Therefore, there is great potential for significant reduction of veterinary drug residues found in the swine waste, through the use of the composting process, thus ensuring a decrease in environmental effects associated with the use of these products; however, studies on this topic are required.

Conclusion

The contamination potential of environmental matrices by residues of veterinary drugs brings to the fore a problem that has not been properly addressed in Brazil, which has a large animal production system, especially associated with the pig production chain. Several studies point to the existence of contamination in environmental matrices around the world, especially in the major animal protein-producing countries, both in Asia and in Europe. This reinforces the need for further studies on this problem, and its impact on the environment, but also on the optimization of treatment processes capable of minimizing or degrading these contaminants. In this regard, the advance and the advent of technologies for detection is mandatory, especially the liquid chromatography coupled with mass spectrometry, which is making possible the measurement of these compounds, even in the order of micro and nano-grams. Regarding the possibility of reducing the veterinary drugs found in swine waste, one of the main alternatives to be studied is composting, as an alternative to treat effluent contaminated with veterinary drug residues, since it is less expensive and does not demand specialized labor near the property. In addition, it is easily implementable, besides treating large amounts of effluents, allowing the use of the compound as organic fertilizer. However, studies on the use of this practice for monitoring and reduction of drug residues in swine manure in Brazil need to be performed.

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References

AMÉRICO, J. H. P.; ISIQUE, W. D.; MINILLO, A.; CARVALHO, S. L.; TORRES, N. H. Fármacos em uma estação de tratamento de esgoto na região Centro-oeste do Brasil e os riscos aos recursos hídricos. *Revista Brasileira de Recursos Hídricos*, Porto Alegre, v. 17, n. 3, p. 61-67, 2012. DOI: 10.21168/rbrh.v17n3.p61-67

ARAUJO, K.; NEVES, M.; SÁ, M.; SILVA, L.; BRITO, N. Fármacos residuais: um problema de caráter ambiental. In: CONGRESSO DE PESQUISA E INOVAÇÃO DA REDE NORTE NORDESTE DE EDUCAÇÃO TECNOLÓGICA, Maceió, 2010. *Anais...* Maceió: Instituto Federal de Alagoas, 2010. p. 1-8.

ARCHUNDIA, D.; DUWIG, C.; LEHEMBRE, F.; CHIRON, S.; MOREL, M. C.; PRADO, B.; BOURDAT-DESCHAMPS, M.; VINCE, E.; AVILES, G. F.; MARTINS, J. M. F. Antibiotic pollution in the Katari subcatchment of the Titicaca Lake: major transformation products and occurrence of resistance genes. *Science of The Total Environment*, Sonora, México, v. 576, n. 3, p. 671-682, 2017. DOI: 10.1016/j.scitotenv.2016.10.129

ASSOCIAÇÃO BRASILEIRA DE CRIADORES DE SUÍNOS - ABCS. ABCS e representantes de agroindústrias se reúnem para discutir Projeto de Lei sobre produção integrada. Brasília: SIG, 2014. Disponível em: http://www.abcs.org.br/informativo-abcs.Janeiro de 2014. Acesso em: 22 jan. 2014.

BAO, Y.; ZHOU, Q.; GUAN, L.; WANG, Y. Depletion of chlortetracycline during composting of aged and spiked manures. *Waste Management*, Tianjin, v. 29, n. 4, p. 1416-1423, 2009. DOI: 10.1016/j.wasman.2008.08.022

BARBOSA, M. O.; MOREIRA, N. F.; RIBEIRO, A. R.; PEREIRA, M. F.; SILVA, A. M. Occurrence and removal of organic micropollutants: an overview of the watch list of EU Decision 2015/495. *Water Research*, Porto, v. 94, n. 7, p. 257-279, 2016. DOI: 10.1016/j.watres.2016.02.047

BEN, W.; WANG, J.; PAN, X.; QIANG, Z. Dissemination of antibiotic resistance genes and their potential removal by on-farm treatment processes in nine swine feedlots in Shandong Province, China. *Chemosphere*, Beijing, v. 167, n. 2, p. 262-268, 2017. DOI: 10.1016/j.chemosphere.2016.10.013

BOLEDA, M. R.; GALCERAN, M. T.; VENTURA, F. Validation and uncertainty estimation of a multiresidue method for pharmaceuticals in surface and treated waters by liquid chromatography-tandem mass spectrometry. *Journal of Chromatography A*, Barcelona, v. 1286, n. 15, p. 146-158, 2013. DOI: 10.1016/j.chroma.2013.02.077

BONDARCZUK, K.; MARKOWICZ, A.; PIOTROWSKA-SEGET, Z. The urgent need for risk assessment on the antibiotic resistance spread via sewage sludge land application. *Environment International*, Katowice, v. 87, n. 2, p. 49-55, 2016. DOI: 10.1016/j.envint.2015.11.011

BRASIL. Portaria de consolidação de nº 4 de 28 de setembro de 2017 do Ministério da Saúde. *Dispõe sobre os procedimentos de controle e de vigilância da qualidade da água para consumo humano e seu padrão de potabilidade*. Brasília: Ministério da Saúde, 2017. 350 p. Disponível em: http://bvsms.saude.gov.br/bvs/saudelegis/gm/2017/prc0005_03_10_2017.html. Acesso em: 14 jun. 2019

BRASIL. Resolução do CONAMA n° 357, de 18 de março de 2005. *Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes, e dá outras providências.* Brasília: Congresso Nacional, 2005. 27 p. Disponível em: http://www.mma.gov.br/port/conama/res/res05/res35705.pdf. Acesso em: 10 fev. 2017.

BRASIL. Resolução do CONAMA n° 420, de 28 de dezembro de 2009. *Dispõe sobre critérios e valores orientadores de qualidade do solo quanto à presença de substâncias químicas e estabelece diretrizes para o gerenciamento ambiental de áreas contaminadas por essas substâncias em decorrência de atividades antrópicas.* Brasília: Congresso Nacional, 2009. 20 p. Disponível em: http://www.mma.gov.br/port/conama/legiabre.cfm?codlegi=620. Acesso em: 20 fev. 2017.

BRASIL. Resolução do CONAMA nº. 430. *Dispõe sobre as condições e padrões de lançamento de efluentes, complementa e altera a Resolução nº 357, de 17 de* *março de 2005, do Conselho Nacional do Meio Ambiente, CONAMA*. Brasília: Congresso Nacional, 2011. 9 p. Disponível em: http://www.mma.gov. br/port/conama/legiabre.cfm?codlegi=646. Acesso em: 15 nov. 2016.

CADONÁ, E. A.; SOUZA, E. L.; GUERRA, D.; BOHRER, R. E. G. Utilização de adubação orgânica com dejetos de suínos e contaminação de água e de solo por coliformes. *Ciência e Natura*, Santa Maria, v. 38, n. 3, p. 1601-1609, 2016. DOI: 10.5902/2179460X22410

CARVALHO, E. V.; FERREIRA, E.; MUCINI, L.; SANTOS, C. L. Aspectos legais e toxicológicos do descarte de medicamentos. *Revista Brasileira de Toxicologia*, São Paulo, v. 22, n. 1-2, p. 1-8, 2009.

CENTNER, T. J. Recent government regulations in the United States seek to ensure the effectiveness of antibiotics by limiting their agricultural use. *Environment International*, Athens, v. 94, n.7, p. 1-7, 2016. DOI: 10.1016/j.envint.2016.04.018

CHEN, C.; RAY, P.; KNOWLTON, K. F.; PRUDEN, A.; XIA, K. Effect of composting and soil type on dissipation of veterinary antibiotics in land-applied manures. *Chemosphere*, Blacksburg, v. 196, n. 6, p. 270-279, 2018. DOI: 10.1016/j.chemosphere.2017.12.161

CHENG, D.; FENG, Y.; LIU, Y.; XUE, J.; LI, Z. Dynamics of oxytetracycline, sulfamerazine, and ciprofloxacin and related antibiotic resistance genes during swine manure composting. *Journal of Environmental Management*, Beijing, v. 230, n. 2, p. 102-109, 2019. DOI: 10.1016/j.jenvman.2018.09.074

CHENG, W.; LI, J.; WU, Y.; XU, L.; SU, C.; QIAN, Y.; ZHU, Y.-G.; CHEN, H. Behavior of antibiotics and antibiotic resistance genes in eco-agricultural system: A case study. *Journal of Hazardous Materials*, Hangzhou, v. 304, n. 4, p. 18-25, 2016. DOI: 10.1016/j.jhazmat.2015.10.037

DAGHRIR, R.; DROGUI, P. Tetracycline antibiotics in the environment: a review. *Environmental Chemistry Letters*, Quebec, v. 11, n. 3, p. 209-227, 2013. DOI: 10.1007/s10311-013-0404-8

DU, L.; LIU, W. Occurrence, fate, and ecotoxicity of antibiotics in agro-ecosystems. A review. *Agronomy for Sustainable Development,* Beijing, v. 32, n. 2, p. 309-327, 2012. DOI: 10.1007/s13593-011-0062-9

EZZARIAI, A.; HAFIDI, M.; KHADRA, A.; AEMIG, Q.; EL FELS, L.; BARRET, M.; MERLINA, G.; PATUREAU, D.; PINELLI, E. Human and veterinary antibiotics during composting of sludge or manure: Global perspectives on persistence, degradation, and resistance genes. *Journal of Hazardous Materials*, Marrakech, v. 359, n. 18, p. 465-481, 2018. DOI: 10.1016/j.jhazmat.2018.07.092

FOOD AND DRUG ADMINISTRATION - FDA. The Green Book - FDA, approved products. food and drug administration. Rockville: FDA, 2017. Disponível em: http://www.accessdata.fda.gov/scripts/animaldrugsatfda.2012. Acesso em: 20 fev. 2017.

GBYLIK-SIKORSKA, M.; POSYNIAK, A.; SNIEGOCKI, T.; ZMUDZKI, J. Chemosphere liquid chromatography - tandem mass spectrometry multiclass method for the determination of antibiotics residues in water samples from water supply systems in food-producing animal farms. *Chemosphere*, Pulawy, v. 119, n. 2, p. 8-15, 2015. DOI: 10.1016/j.chemosphere.2014.04.105

GELBAND, H.; MILLER-PETRIE, M.; PANT, S.; GANDRA, S.; LEVINSON, J.; BARTER, D.; WHITE, A.; LAXMINARAYAN, R. *State of the world's antibiotics.* Washington: Center for Disease Dynamics, Economics & Policy, CDDEP, 2015. 84 p.

GONZALEZ RONQUILLO, M.; HERNANDEZ, J. C. A. Antibiotic and synthetic growth promoters in animal diets: review of impact and analytical methods. *Food Control*, Toluca, v. 72, Part. b, p. 255-267, 2017. DOI: 10.1016/j.foodcont.2016.03.001

GUO, C.; WANG, M.; XIAO, H.; WANG, F.; PAN, W.; LIAO, X.; LIU, Y. Development of a modified QuEChERS method for the determination of veterinary antibiotics in swine manure by liquid chromatography tandem mass spectrometry. *Journal of Chromatography B: Analytical Technologies in the Biomedical and Life Sciences*, Guangzhou, v. 1027, n. 19, p. 110-118, 2016. DOI: 10.1016/j.jchromb.2016.05.034

HAMSCHER, G.; PAWELZICK, T. G.; HOPER, H. N. Different behavior of tetracyclines and sulfonamides in sandy soils after repeated fertilization with liquid manure. *Environmental Toxicology and Chemistry*, Hannover, v. 24, n. 4, p. 861-868, 2005. DOI: 10.1897/04-182R.1

HE, L. Y.; YING, G.-G.; LIU, Y.-S.; SU, H.-C.; CHEN, J.; LIU, S.-S.; ZHAO, J.-L. Discharge of swine wastes risks water quality and food safety: antibiotics and antibiotic resistance genes from swine sources to the receiving environments. *Environment International*, Guangzhou, v. 92-93, n. 6, p. 210-219, 2016. DOI: 10.1016/j.envint.2016.03.023

HO, Y. B.; ZAKARIA, M. P.; LATIF, P. A.; SAARI, N. Degradation of veterinary antibiotics and hormone during broiler manure composting. *Bioresource Technology*, Selangor, v. 131, n. 4, p. 476-484, 2013. DOI: 10.1016/j.biortech.2012.12.194

HU, J.; ZHOU, J.; ZHOU, S.; WU, P.; TSANG, Y. F. Occurrence and fate of antibiotics in a wastewater treatment plant and their biological effects on receiving waters in Guizhou. *Process Safety and Environmental Protection*, Guiyang, v. 113, n. 1, p. 483-490, 2018. DOI: 10.1016/j.psep.2017.12.003

IDE, A. H.; AHMAD, S. M.; NENG, N. R.; NOGUEIRA, J. M. F. Enhancement for trace analysis of sulfonamide antibiotics in water matrices using bar adsorptive microextraction (BAμE). *Journal of Pharmaceutical and Biomedical Analysis*, Lisboa, v. 129, n.12, p. 593-599, 2016. DOI: 10.1016/j.jpba.2016.07.022

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. Produção da Pecuária Municipal. Rio de Janeiro: IBGE, 2015. v. 43, 49 p. Disponível em: http://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?view=detalhes&id=784. Acesso em: 14 jan. 2016.

KIM, K.; OWENS, G.; OK, Y. S.; PARK, W. K.; LEE, D. B.;. KNON, S. I. Decline in extractable antibiotics in manure-based composts during composting. *Waste Management*, Kyounggi-do, v. 32, n. 1, p. 110-116, 2012. DOI: 10.1016/j.wasman.2011.07.026

KIM, Y.; LEE, K. B.; CHOI, K. Effect of runoff discharge on the environmental levels of 13 veterinary antibiotics: a case study of Han River and Kyungahn Stream, South Korea. *Marine Pollution Bulletin*, Seoul, v. 107, n. 1, p. 1-8, 2015. DOI: 10.1016/j.marpolbul.2016.03.011

KOBA, O.; GOLOVKO, O.; KODESOVÁ, R.; FÉR, M.; GRABIC, R. Antibiotics degradation in soil: a case of clindamycin, trimethoprim, sulfamethoxazole and their transformation products. *Environmental Pollution*, Vodňany, v. 220, part B, p. 1251-1263, 2016. DOI: 10.1016/j.envpol.2016.11.007

LI, C.; CHEN, J.; WANG, J.; MA, Z.; HAN, P.; LUAN.; LU, A. Occurrence of antibiotics in soils and manures from greenhouse vegetable production bases of Beijing, China and an associated risk assessment. *Science of the Total Environment*, Beijing, v. 521-522, n. 19, p. 101-107, 2015. DOI: 10.1016/j.scitotenv.2015.03.070

LI, W.; SHI, Y.; GAO, L.; LIU, J.; CAI, Y. Occurrence of antibiotics in water, sediments , aquatic plants, and animals from Baiyangdian Lake in North China. *Chemosphere*, Beijing, v. 89, n. 11, p. 1307-1315, 2012. DOI: 10.1016/j.chemosphere.2012.05.079

LIU, B.; LI, Y.; ZHANG, X.; FENG, C.; GAO, M.; SHEN, Q. Effects of composting process on the dissipation of extractable sulfonamides in swine manure. *Bioresource Technology*, Beijing, v. 175, n. 1, p. 284-290, 2015. DOI: 10.1016/j.cjche.2017.06.020

LIU, L.; LIU, C.; ZHENG, J.; JUANG, X.; WANG, Z.; LIU, W.; ZHU, G. Elimination of veterinary antibiotics and antibiotic resistance genes from swine wastewater in the vertical flow constructed wetlands. *Chemosphere,* Xiamen, v. 91, n. 8, p. 1088-1093, 2013. DOI: 10.1016/j.chemosphere.2013.01.007

LÓPEZ-SERNA, R.; PÉREZ, S.; GINEBREDA, A.; PETROVIC, M.; BARCELÓ, D. Fully automated determination of 74 pharmaceuticals in environmental and waste by online solid phase extradition-liquid chromatography-electrospray tandem mass spectrometry. *Talanta*, London, v. 83, n. 2, p. 410-424, 2010. DOI: 10.1016/j.chroma.2012.06.078

LUCAS, D.; BADIA-FABREGAT, M.; CAMINAL, G.; RODRIGUEZ-MOZAZ, S.; BALCAZAR, J. L.; BARCELO, D. Fungal treatment for the removal of antibiotics and antibiotic resistance genes in veterinary hospital wastewater. *Chemosphere*, Girona, v. 152, n. 10, p. 301-308, 2016. DOI: 10.1016/j.chemosphere.2016.02.113

MARTÍNEZ-CARBALLO, E.; GONZÁLEZ-BARREIRO, C.; SCHARF, S.; GANS, O. Environmental monitoring study of selected veterinary antibiotics in animal manure and soils in Austria. *Environmental Pollution*, Spittelauer Lande, v. 148, n. 2, p. 570-579, 2007. DOI: 10.1016/j.envpol.2006.11.035

MELO, F. V.; BROWN, G. G.; CONSTANTINO, R.; LOUZADA, J. N. C.; LUIZÃO, F. J.; MORAIS, J. W.; ZANETTI, R. *A importância da meso e macrofauna do solo na fertilidade e como biondicadores*. Colombo: Boletim Informativo da SBCS, jan./abr. 2009. 3 p. Disponível em: http://sbcs.solos.ufv.br/solos/ boletins/biologia%20macrofauna.pdf. Acesso em: 10 fev. 2017.

MINISTÉRIO DA AGRICULTURA, PECUÁRIA E ABASTECIMENTO - MAPA. Brasil. Brasília: MAPA, 2015. Disponível em: http://www.agricultura.gov.br/animal/especies/suinos. Acesso em: 18 out. 2015.

MITCHELL, S. M.; ULLMAN, J. L.; BARY, A.; COGGER, C. G.; TEEL, A. L.; WATTS, R. J. Antibiotic degradation during thermophilic composting. *Water Air Soil Pollut*, Pullman, v. 13, n. 226, p. 1-12, 2015. DOI: 10.2134/jeq2015.05.0256

MORTIER, N.; VELGHE, F.; VERSTICHEL, S. Organic recycling of agricultural digestion. In: POLTRONIERI, P.; D'URSO, O. F. (Ed.). *Biotransformation of agricultural waste and by-products*. Amsterdam. The Food, Feed, Fibre, Fuel (4F) Economy, Elsevier Radarweg 29, PO Box 211, 1000 AE Amsterdam, Netherlands, 2016. p. 69-124.

NGUYEN, T. K. X.; THAYANUKUL, P.; PINYANKONG, O.; SUTTINUN, O. Tiamulin removal by wood-rot fungi isolated from swine farms and role of ligninolytic enzymes. *International Biodeterioration & Biodegradation*, Bangkok, v. 116, n. 1, p. 147-155, 2017. DOI: 10.1016/j.ibiod.2016.10.010

OLIVEIRA, P. A. V.; HIRAGASHI, M. M. *Unidade de compostagem para o tratamento dos dejetos de suínos*. Concórdia: EMBRAPA, 2006. n. 1, 39 p. (Documento, 114).

OMAR, F. N.; XIANG, L. Y.; LIE, L. Y.; DZULKRNAIN, C. A.; MOHAMMED, M. A. P.; BAHARUDDIN, A. S. Investigation of physico-chemical properties and microbial community during poultry manure co-composting process. *JES*, Selangor, v. 28, n. 1, p. 81-94, 2014. DOI: 10.1016/j.jes.2014.07.023

PACHECO-SILVA, É.; SOUZA, J. R.; CALDAS, E. D. Resíduos de medicamentos veterinários em leite e ovos. *Quimica Nova*, Brasília, v. 37, n. 1, p. 111-122, 2014. DOI: 10.1590/S0100-40422014000100020

PETRIE, B.; YOUDAN, J.; BARDEN, R.; KASPRZYK-HORDEN, B. Multi-residue analysis of 90 emerging contaminants in liquid and solid environmental matrices by ultra-high-performance liquid chromatography tandem mass spectrometry. *Journal of Chromatography A*, Bath, v. 1431, n. 4, p. 64-78, 2016. DOI: 10.1016/j.chroma.2015.12.036

PINHEIRO, A.; ALBANO, R. M. R.; ALVES, T. C.; KAUFAMANN, V.; SILVA, M. R. Veterinary antibiotics and hormones in water from application of pig slurry to soil. *Agricultural Water Management*, Blumenau, v. 129, n. 375, p. 1-8, 2013. DOI: 10.1016/j.agwat.2013.06.019

PRESTES, O. D.; MARTINS, M. L.; FRIGGI, C. A.; MUNARETTO, J. S.; ADAIME, M. B.; ZANELLA, R. O estado da arte na determinação de resíduos de medicamentos veterinários em alimentos de origem animal empregando técnicas cromatográficas acopladas à espectrometria de massas. *Quimica Nova*, Santa Maria, v. 36, n. 5, p. 697-710, 2013. DOI: 10.1590/S0100-40422013000500015

PULICHARLA, R.; BRAR, S. K.; ROUISSI, T.; AUGER, S.; DROGUI, P.; VERMA, M.; SURAMPALLI, R. Y. Degradation of chlortetracycline in wastewater sludge by ultrasonication, Fenton oxidation, and ferro-sonication. *Ultrasonics Sonochemistry*, Québec, v. 34, n. 1, p. 332-342, 2017. DOI: 10.1016/j.ultsonch.2016.05.042

QIAN, M.; WU, H.; WANG, J.; ZHANG, H.; ZHANG, Z.; ZHANG, Y.; LIN, H.; MA, J. Occurrence of trace elements and antibiotics in manure-based fertilizers from the Zhejiang Province of China. *Science of the Total Environment*, Hangzhou, v. 559, n. 20, p. 174-181, 2016a. DOI: 10.1016/j.scitotenv.2016.03.123

QIAN, X.; SUN, W.; GU, J.; WANG, X.-J.; SUN, J.-J.; YIN, Y.-N.; DUAN, M.-L. Variable effects of oxytetracycline on antibiotic resistance gene abundance and the bacterial community during aerobic composting of cow manure. *Journal of Hazardous Materials*, Yangling, v. 315, n. 15, p. 61-69, 2016b. DOI:10.1016/j.jhazmat.2016.05.002

REGITANO, J. B.; LEAL, R. M. P. Comportamento e impacto ambiental de antibióticos usados na produção animal Brasileira. *Revista Brasileira de Ciencia do Solo*, Piracicaba, v. 34, n. 3, p. 601-616, 2010. DOI: 10.1590/S0100-06832010000300002

REIS, E. O.; FOUREAUX, A. F. S.; RODRIGUES, J. S.; MOREIRA, V. R.; LEBRON, Y. A.; SANTOS, L. V.; AMARAL, M. C. S.; LANGE, L. C. Occurrence, removal and seasonal variation of pharmaceuticals in Brasilian drinking water treatment plants. *Environmental Pollution*, Belo Horizonte, v. 250, n. 6, p. 773-781, 2019. DOI: 10.1016/j.envpol.2019.04.102

RHOUMA, M.; BEAUDRY, F.; LETELLIER, A. Resistance to colistin: what is the fate for this antibiotic in pig production? *International Journal of Antimicrobial Agents*, Saint-Hyacinthe, v. 48, n. 2, p. 119-126, 2016. DOI: 10.1016/j.ijantimicag.2016.04.008

RIBEIRO, A. R.; NUNES, O. C.; PEREIRA, M. F. R.; SILVA, A. M. T. An overview on the advanced oxidation processes applied for the treatment of water pollutants de fi ned in the recently launched Directive 2013 / 39 / EU. *Environment International*, Porto, v. 75, n. 2, p. 33-51, 2015. DOI: 10.1016/j.envint.2014.10.027

RICO, A.; OLIVEIRA, R.; McDONOUGH, S.; MATSER, A.; KHATIKARN, J.; SATAPORNAVANIT, K.; NOGUEIRA, A. J. A.; SOARES, A. M. V. M.; DOMINGUES, I.; BRINK, P. J. Use, fate and ecological risks of antibiotics applied in tilapia cage farming in Thailand. *Environmental Pollution*, Wageningen, v. 191, n. 7, p. 8-16, 2014. DOI: 10.1016/j.envpol.2014.04.002

RIO GRANDE DO SUL. Secretaria do Ambiente e Desenvolvimento Sustentável - Conselho Estadual do Meio Ambiente - Resolução CONSEMA N º 355, de 13 de junho de 2017. Dispõe sobre os critérios e padrões de emissão de efluentes líquidos para as fontes geradoras que lancem seus efluentes em águas superficiais no Estado do Rio Grande do Sul. Porto Alegre: SEMA, 2017. Disponível em: http://www.sema.rs.gov.br/resolucoes. Acesso em: 1 set. 2017.

RODRIGUES-SILVA, C.; MANIERO, M. G.; GUIMARÃES, J. R. Avaliação da atividade antimicrobiana de soluções de flumequina submetidas aos processos eletroquímico e foto-eletroquímico. *Quimica Nova*, Campinas, v. 37, n. 5, p. 789-795, 2014. DOI: 10.5935/0100-4042.20140127

SEGURA, P. A.; TAKADA, H.; CORREA, J. A.; SAADI, K.; KOIKE, T.; ONWONA-AGYENAN, S.; OFOSU-ANIM, J.; SABI, E. B.; WASONGA, O. V.; MAGHALU, J. M.; SANTOS, A. M.; NEWMAN, B.; WEERTS, S.; YARGEAU, V. Global occurrence of anti-infectives in contaminated surface waters: impact of income inequality between countries. *Environment International*, Sherbrooke, v. 80, n. 6, p. 89-97, 2015. DOI: 10.1016/j.envint.2015.04.001

SILVA, C. G. A.; COLLINS, C. H. Aplicações de cromatografia líquida de alta eficiência para o estudo de poluentes orgânicos emergentes. *Química Nova*, Campinas, v. 34, n. 4, p. 665-676, 2011. DOI:org/10.1590/S0100-40422011000400020

SOLLIEC, M.; ROY-LACHAPELLE, A.; GASSE, M.-O.; COTÉ, C.; GÉNÉREUX, M.; SAUVÉ, S. Fractionation and analysis of veterinary antibiotics and their related degradation products in agricultural soils and drainage waters following swine manure amendment. *Science of the Total Environment*, Montréal, v. 543, n. 4, p. 524-535, 2016. DOI: 10.1016/j.scitotenv.2015.11.061

SOSA-FERRERA, Z.; MAHUGO-SANTANA, C.; SANTANA-RODRÍGUEZ, J. J. Analytical methodologies for the determination of endocrine disrupting compounds in biological and environmental samples. *BioMed Research International*, Las Palmas de Gran Canaria, v. 2013, n. 3, p. 674-838, 2013. DOI: 10.1155/2013/674838

SUI, Q.; ZHANG, J.; CHEN, M.; TONG, J.; WANG, R.; WEI, Y. Distribution of antibiotic resistance genes (ARGs) in anaerobic digestion and land application of swine wastewater. *Environmental Pollution*, Beijing, v. 213, n. 5, p. 751-759, 2016. DOI: 10.1016/j.envpol.2016.03.038

TASHO, R. P.; CHO, J. Y. Veterinary antibiotics in animal waste, its distribution in soil and uptake by plants: a review. *Science of the Total Environment*, Jeollabuk-do, v. 563-564, n. 3, p. 366-376, 2016. DOI: 10.1016/j.scitotenv.2016.04.140

VAN BOECKEL, T. P.; BROWER, C.; GILBERT, M.; GRENFELL, B. T.; LEVIN, S. A.; ROBINSON, T. P.; TEILLANT, A.; LAXMINARAYAN, R. Global trends in antimicrobial use in food animals. *Proceedings of the National Academy of Sciences of the United States of America*, Princeton, v. 112, n. 18, p. 5649-5645, 2015. DOI: 10.1073/pnas.1503141112

YANG, C. W.; HSIAO, W. C.; CHANG, B. V. Biodegradation of sulfonamide antibiotics in sludge. *Chemosphere*, Taipei, v. 150, n. 8, p. 559-565, 2016. DOI: 10.1016/j.chemosphere.2016.02.064

YASSER, M. A.; SANG, S. L.; SUNG-CHUL, K.; JAE, E. Y.; YONG, S. O. Novel approaches to monitoringand remediation of veterinary antibiotics in soil and water: a review. *Korean Journal of Environmental Agriculture*, Chuncheon, v. 29, n. 4, p. 315-327, 2010. DOI: 10.5338/KJEA.2010.29.4.315

WANG, J.; BEN, W.; YANG, M.; ZHANG, Y.; QIANG, Z. Dissemination of veterinary antibiotics and corresponding resistance genes from a concentrated swine feedlot along the waste treatment paths. *Environment International*, Beijing, v. 92-93, n. 6, p. 317-323, 2016a. DOI: 10.1016/j.envint.2016.04.020

WANG, R.; CHEN, M.; FENG, F.; ZHANG, J.; SUI, Q.; TONG, J.; WEI, Y.; WEI, D. Effect of red mud addition on tetracycline and copper resistance genes and microbial community during the full scale swine manure composting. *Bioresource Technology,* Beijing, v. 216, n. 17, p. 1049-1057, 2016b. DOI: 10.1016/j.biortech.2016.06.012

WEI, R.; GE, F.; ZHANG, L.; HOU, X.; CAO, Y.; GONG, L.; CHEN, M.; WANG, R.; BAO, E. Occurrence of 13 veterinary drugs in animal manure-amended soils in Eastern China. *Chemosphere*, Nanjing, v. 144, n. 2, p. 2377-2383, 2016. DOI: 10.1016/j.chemosphere.2015.10.126

WU, J.; ZHAO, Y.; YANG, T.; ZHANG, X.; XIE, X.; CUI, H.; WEI, Z. Effect of precursors combined with bacteria communities on the formation of humic substances during different materials composting. *Bioresource Technology*, Harbin, v. 226, n. 4, p. 191-199, 2017. DOI: 10.1016/j.biortech.2016.12.031

WU, M.-H.; QUE, C.-J.; XU, G.; SUN, Y.-F.; MA, J.; XU, H.; SUN, R.; TANG, L. Occurrence, fate and interrelation of selected antibiotics in sewage treatment plants and their receiving surface water. *Ecotoxicology and Environmental Safety,* Shanghai, v. 132, n. 10, p. 132-139, 2016. DOI: 10.1016/j.ecoenv.2016.06.006

ZHANG, M.; HE, L. Y.; LIU, Y. S.; ZHAO, J. L.; LIU, W. R.; ZHANG, J. N.; CHEN, J.; HE, L. K.; ZHANG, Q. Q.; YING, G. G. Fate of veterinary antibiotics during animal manure composting. *Science of the Total Environment*, Beijing, v. 650, n. 2, p. 1363-1370, 2019. DOI: 10.1016/j.scitotenv.2018.09.147

ZHANG, Y.; LI, H.; GU, J.; QIAN, X.; YIN, Y.; LI, Y.; ZHANG, R.; WANG, X. Residues and risks of veterinary antibiotics in protected vegetable soils following application of different manures. *Chemosphere,* Beijing, v. 152, n. 10, p. 229-237, 2016a. DOI: 10.1016/j.chemosphere.2016.02.111

ZHANG, Y.; SALLACH, J. B.; HODGES, L.; SNOW, D. D.; BARTELT-HUNT, S. L.; ESKRIDGE, K. M.; LI, X. Effects of soil texture and drought stress on the uptake of antibiotics and the internalization of Salmonella in lettuce following wastewater irrigation. *Environmental Pollution*, Lincoln, v. 208, n. 1, p. 523-531, 2016b. DOI: 10.1016/j.envpol.2015.10.025