Chapter

Nutrients Cycle within Swine Production: Generation, Characteristics, Treatment and Revaluation

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Abstract

The swine production generates slurries nutrients rich, which could be revaluated in cereal crops used for its food and energy generation (biogas) for use on the farm. However, the revaluation requires to know their physical–chemical and biological characteristics, which allow giving an adequate transformation (treatment). On the one hand, swine production and consumption market reveal the superiority of emergent countries on meat/cereal (feed) production and swine meat consumption (concentrated population). The food composition and growth phase will influence the swine slurries composition, which is rich in organic matter, macronutrients (N, P) and micronutrients (Cu and Zn). These characteristics will generate odors (organic matter, macronutrients) and ecotoxicology effects (macro/micronutrients) if they are not treated. Moreover, the swine slurries treatment allows revaluated them in agriculture and obtaining energy. Anaerobic technologies (anaerobic lagoon, mixed complete reactors, UASB, among others) are the most used/cost-effective to organic matter removal from swine slurries, obtaining from 0.28 to 0.83 m^3 biogas/kg organic matter. Meanwhile, passive technologies (constructed wetlands) are the most used technologies to nutrients and metals removal. Treated swine slurries from constructed wetlands have agronomic properties. Therefore, the nutrients cycle within swine production would favor concepts of revaluation in origin.

Keywords: biogas, soil fertilizer, nutrients, revaluation, swine slurries

1. Introduction

The economic and demographic growths are the factors that are activating the current world meat production [1]. Thus, developing countries where 75% of the population is located also concentrate 52% (41.5 million ton/year) of swine production. Moreover, in the last 40 years the growth of emergent economies are concentrating both meat and cereal production in one place. China is an emergent economy in where is 46% of the world's swine production, and 30% of cereal production.

On the other hand, demand is the main trigger factor of the current "livestock revolution" [2]. Thus, the meat consumption acquires connotation different depending on the consumer type. In developed countries, higher purchasing power and demanding lifestyles have promoted a higher swine meat demand (25 kg/per capita year). Meanwhile, developing countries consume only 8 kg/per capita year, condition related mainly with subsistence habits. However, developing countries (75% worldwide population) concentrates 64% (43.3 million ton/year) of the swine meat total consumption; while that, developed countries concentrate 36% (34.4 million ton/year) remaining. However, emergency economies (Brazil and China) are increasing about 21% the swine meat consumption per capita of their population, concentrating swine meat consumption in these countries [3].

2. Swine slurry: generation and characteristics

2.1 Origin of swine slurry

The swine slurry generation is related to the growth phase and its water/food requirements. Thus, lactation and reproduction phases have a great water supply (12.2–41.1 L water/animal d), mainly related to hydration improvement or fertility [4, 5]. Meanwhile, fattening and weaning have a greater food intake (1.9 kg food/animal d), exclusively given by increased weight or age [5, 6].

The swine diet is based on proteins, carbohydrates and starch concentrates, which exceed 50% of food total composition [7]. Indeed, fattening tends to prioritize the protein intake (>30%) [6]; while, reproduction and weaning consume mainly fiber (10%) to avoid overweight [8]. In both cases, the low food digestibility could generate nitrogen excretion (<30%) and phosphorus (<10%) [9]. This factor can be observed in the swine conversion index, which can vary from 2.0 to 4.3 and 0.9 to 2.3 kg feed/kg weight gained for fattening and previous phases, respectively [6, 10–12]. Indeed, digestibility can vary depending on the food and animal type, being slightly lowers in the final growth phases (fattening ~ 25%) than initial phases (weaning >50%).

Finally, the water/food ratios allow indirectly evaluating the swine slurry quantity and its composition. Thereby, initial phases (weaning) generate the water/feed ratios from 4.4 to 5.1 L water/kg food [8]; while, final phases (fattening) reaches values from 1.6 to 2.5 L water/kg food [11]. This indicator is indirectly related with nitrogen concentrations from urine/feces values. Indeed, greater urine/feces values are obtained by fattening (6.6–9.1) than weaning (5.5–6.3) [13]. At this point, it's important to note that within the swine excreta around 75% of the nitrogen is in urine, so a higher water intake will increase the nitrogen generation in the slurries [14] (**Table 1**).

2.2 Generation and physicochemical characteristics

The physicochemical composition from swine slurries will be influenced by the low digestibility of nitrogen (<33%), phosphorus (<32%) and micronutrients (<3%) [9, 17], as well as the animal growth phase [18]. Initial phases (maternity and lactation) produce more slurries (10.0–41.1 L/animal d) than weaning-fattening (3.5–9.10 L/animal d) [4–6]. This could be related with dilution by more water intake. **Table 2** summarizes the physicochemical characteristics from swine slurries according to the growth phase. The main differences are related to a higher content of organic matter (1.8–2.4 times), nitrogen (1.3–2.8 times) and phosphorus (2.1–4.6 times) from fattening with respect to maternity and weaning. This condition is related to a higher food intake (1.7 times), which is made up of carbohydrates and proteins [14]. Meanwhile, micronutrients, such as zinc are excreted (2.7–13.0 times) in the initial phases (weaning). In a different proportion, copper is excreted by swine slurries, increasing during fattening (1.5–7.2 times). Differences in the

Feed type	Conversion index kg feed/kg weight gained	Water/food ratio L water/kg feed	Reference
Pellet	2.13–3.33	—	[15]
With/out phytases	2.00–4.32	—	[6]
Wheat and soybeans (12–20%)	2.22–2.35	—	
Intensive/organic	2.70–3.20	—	[10]
Ad libitum	2.95–3.05	1.99–2.60	[11]
Wean/mat/fat food	0.98–2.14	2.00–20.00	[12, 16]

Table 1.
Productive indicators within swine production.

		Growth phase			
Parameter	Unit	Maternity	Weaning	Fattening	Reference
Slurry	L/animal d	10.0–16.0	23.5–41.1	3.5–9.1	[4–6]
pH		7.5	6.9	7.2–8.4	[6, 18, 20–22]
EC	mS/cm	12.8–15.5	14.2	15.3–25.3	[18, 21, 22, 24]
TS	%	1.7	2.7	3.2	[18, 19, 24]
BOD_5	g/L	9.0	25.0	16.6–21.6	[18, 22, 24, 25]
COD	g/L	24.0	65.2	45.3–57.7	[6, 18, 22, 24, 25]
TN	g/L	1.8–2.3	2.3	2.4–4.6	[6, 18–22, 24, 25]
$N\text{-}NH_4^+$	g/L	1.4–1.8	1.5	2.0–3.1	[6, 18–22, 24, 25]
TP	g/L	1.4	0.6	0.8–2.8	[18–22]
K	g/L	2.2	1.8	1.9–3.8	[18–22]
Cl^-	g/L	3.6	2.3	5.1	[18, 24]
Cu	mg/L	11.0	55.0	15.9–80.0	[18, 22, 24, 26]
Zn	mg/L	75.0	533.0	40.7–191.0	[18, 22, 24, 26]

Table 2.
Physicochemical characteristics from swine slurries.

presence of copper and zinc excreted is related to the use of both metals as growth promoters and specifically copper that is used additionally for therapeutic purposes (fighting diarrhea) in the most vulnerable swine population (weaning) [17]. Chloride, ammonium and potassium salts may also be present within swine slurries. The feeding has influenced a greater salts excretion (1.4–2.3 times) during weaning-fattening. These characteristics are related to the fact that the salts in the swine feeding, favor the liquids retention increasing weight during the growth [18].

On the other hand, raw swine slurries show agronomic properties (N:P: K between 1.1:0.6:1.0 and 1.3:0.4:1.0) [18–22]. Indeed, the nutritional requirements of cereal crops (e.g. corn, wheat) can reach values of N:P: K between 1.2:0.2:1.0 and 1.6:0.3:1.0 [23]. However, the presence of pathogenic organisms and micro-contaminating (metals, antibiotics) may limit their use prior to treatment.

2.3 Ecotoxicological characteristics

Swine slurries have ecotoxicological characteristics depending on the bioindicator used. **Tables 3** and **4** summarize the ecotoxicological characteristics (swine slurries and composition) on terrestrial and aquatic bio-indicators. The ecotoxicological

Organism	Test	Compound	Concentration (mg/L o %*)	Reference
Swine slurries				
Daphnia magna	48–24 h-LC_{50}	Raw swine slurry	1.8–5.0	[27, 28]
Nutrients				
Moina macrocopa	24 h-LC_{50}	NH_4^+	231–492	[31]
Penaeus semisulcatus	96 h-LC_{50}	NH_4^+	11.4–55.9	[36]
Ceriodaphnia dubia	48 h-LC_{50}	NH_4^+	20	[32]
Daphnia carinata	24–48 h-LC_{50}	NH_4^+	2.2–2.8	[33]
Monia australiensis	24–48 h-LC_{50}	NH_4^+	7.5–8.5	[33]
Daphnia magna	48 h-LC_{50}	NH_3	2.9–6.9	[34]
Metals				
Daphnia magna	48 h-LC_{50}	Zn	0.05	[41]
Daphnia magna	48 h-LC_{50}	Cu	0.56	[41]
Daphnia magna	LOEC 14d	Cu, Zn	0.12	[44]
Danio rerio	96 h-LC_{50}	Cu	0.12–0.13	[41]
Salts				
Oncorhynchus mykiss	6 h-LC_{40}	NaCl	20,000	[39]
Daphnia magna	24-48 h-LC_{50}	NaCl	1020–3240	[31]
Daphnia magna	48 h-LC_{50}	Cl_2	0.1–0.2	[34]
Daphnia pulex	48 h-LC_{50}	Cl^-	2042	[45]

% = percentage concentration.*

Table 3.
Ecotoxicological characteristics on aquatic organisms.

Organism	Test	Compound	Concentration (mg/L o %*)	Reference
Swine purines				
Lepidium sativum L.	Growth 24, 48, 72 h	raw swine slurry	3–10*	[29]
Eisenia foetida	Growth 28d	Untreated purine	25*	[30]
Nutrients				
Lactuca sativa	Growth 7d	NH_3	0.002	[38]
Hordeum vulgare	Growth 8d	NH_4^+	0.18	[37]
Metals				
Eisenia foetida	48 h-LC_{50}	Zn	268–439	[43]
Eisenia foetida	48 h-LC_{50}	Cu	153–249	[43]
Salts				
Different kind of plants	Growth	NaCl	0–1280	[40]

% = percentage concentration.*

Table 4.
Ecotoxicological characteristics terrestrial organisms.

studies have been carried out mainly in *Daphnia magna*, establishing higher acute toxicity at low concentrations (48 h-LC_{50}, 1.8–3.3%) [27, 28]. Meanwhile, chronic ecotoxicity has been observed on *Lepidium sativum* L. (growth inhibited at concentrations from 3 to 10%, v/v) [29]. However, *Eisenia foetida* growth (6000–20,000 worms/m^2) has also been reported at concentrations less than 25% [30]. Nutrients, salts, metals, antibiotics, among others separately can generate effect at different levels. On the one hand, NH_4^+ within swine slurries reaches values above 1 g/L [18]. Thus, ammonium on cladoceran aquatic organisms (*Ceriodaphnia dubia, Moina macrocopa, Daphnia carinata, Monia australiensis*) generate mortality at values above 7.5 mg NH_4^+/L [31–33]. Indeed, ammonium causes enzymatic inhibition and cell disruption [34]. Moreover, NH_4^+ is instable transforming to NH_3 under alkaline pH (>8) and/or temperature increasing [35]. Indeed, *Daphnia magna* shows acute toxicity at ammonia concentrations above 2.9 mg/L [34]. Meanwhile, organisms of higher trophic levels (*Penaeus semisulcatus*) reports acute toxicity at concentrations from 11 to 55 mgNH_4^+/L [36]. In the soil, toxic effects of NH_4^+/NH_3 have been observed mainly in vegetable species, generating necrosis, reduction/stimulation of growth and sensitivity to frost [38]. Indeed, *Lactuca sativa* and *Hordeum vulgare* report chronic effects (growth decreasing) at concentrations from 0.002 mg NH_3/L [37, 38].

Chlorides can exceed 1 g/L within swine slurries, being reported less acute toxicity of NaCl (1020–3240 mg/L) on *Daphnia magna* than Cl_2 (0.1–0.2 mg/L) [18, 31, 34]. However, toxic effect is decreased at high trophic levels (the chlorinated compounds toxicity decreases on higher trophic levels (*Oncorhynchus mykiss*)), reaching concentrations above 20 g/L [39]. In terrestrial environments, chlorides can cause chronic effects on the vegetal germination [40]. Swine slurries are compound also by micronutrients (copper and zinc), which not exceeds 0.5 g/L [26]. However, acute toxicity on aquatic organisms (*Danio rerio*) reaches concentrations about 0.1 mg/L and on terrestrial (*Eisenia foetida*) it is not exceeding at values of 249 mg/L [41–43].

2.4 Olfatometric characteristics

The odoriferous characteristics within swine slurries are evaluated using analytical methods (compounds) and sensory methods (odor) [46]. Olfactometric characteristics measured as odor concentration (OC/m^3) are influenced by the type/time of slurries storage. [47]. Indeed, fattening phase (2.1–5.6 times) has more odor than maternity/weaning. On the other hand, fresh swine slurries (1.5–5.4 times) generate more odor than stored slurries (2 months). These results have also shown the odor relationship with volatile compounds presence, which from by diet or slurries management. Thereby, sulfur, ammonia, phenolic and volatile fatty acid compounds from swine slurries influence the odor generation, which show different correlation degree (R^2 = 0.66–0.89) with the generated odor [46]. Particularly, odor precursor compounds from the swine production will be given by the protein's presence from food, generating sulfurous, indole, phenolic and long-chain fatty acids [47–49]. Meanwhile, carbohydrates generate short-chain or volatile fatty acids (less than 6 carbons) [40]. Thus, biological and chemical conditions determine the odor compounds formation. It has been possible to establish the presence of some autochthonous microorganisms (*Streptococcus, Peptostreptococcus, Eubacterium, Lactobacilli, Escherichia, Clostridium, Propionibacterium, Bacteroides, Megasphaera*, among others). Incomplete anaerobic digestion from these microorganisms produce and/or reduce macromolecules to odor compounds, so intermediates (e.g. volatile fatty acids) and finals (e.g. sulfides) [50, 51]. However, not only microorganisms can condition the odorant compounds formation, but also environmental conditions (pH and temperature), which active biological and chemical

Type of waste	Olfactometric technique	Odor threshold (D-T) *, Odor concentration (OC/m^3)^ or Odor index (OI°)	Reference
Bovine manure	Field (Nasal Ranger, box)	8.6–157.7*	[55]
	Dynamic	124.2–6561^	
Sheep, bovine and pig manure	Field (Nasal Ranger)	<2–60*	[56]
Swine purines	Dynamic	120–792^	[46, 47]
Swine manure	Triangular odor bags (dynamic mod.)	26.2–58.7°	[57]
Porcine, avian and bovine manure	Dynamic	<1–1000^	[58]

**=D-T units, ^ = OC/m^3 units,° = OI units.*

Table 5.
Olfactometric characteristics from swine slurries.

(e.g. ammonium/ammonia) processes [52, 53]. Temperature affects the microbial growth rate; while, pH influences the buffer capacity, favoring volatile fatty acids generation [54] (**Table 5**).

3. Reduction and Re-valorization of swine slurries

3.1 Slurries reduction

Swine has low digestibility (<30%) of nutrients and micronutrients, being necessary mechanisms of digestibility improvement, which could improve the physicochemical characteristics from slurries (feces + urine) [9]. Indeed, about 78% of N and P from swine food (proteins) is not assimilated, excreting concentrated urine and feces [14]. Therefore, farm managements are focused on the improvement of diet type and food quantity during each phase growth. On the one hand, raw protein is substituted by fiber, reducing until 8% (10 g RP/kg food) of nitrogen in the urine [7]. Other strategies are related to vary crude protein concentration (155, 145 and 135 g RP/kg) in the food, achieving the decrease of NH_4^+ (20.3–28.4%) in the excreta [13]. Studies have evaluated the replacement of crude protein by digestible or ileal amino acids (lysine, threonine, methionine, tryptophan, isoleucine and valine), finding that they can reduce the ammonium excretion in the urine from 40 to 50% [69]. Meanwhile, other techniques use feeding multi-phases, which improve the protein digestibility, reducing between 20 and 42% the nitrogen excretion [59, 60]. On the other hand, introducing phytases in the swine diet, it is possible to reduce 18% of phosphorus in the feces. Metals (Cu, Zn) used as growth promoters have been decreased (100–250 ppm Cu, 2000–3000 ppm Zn) by antibiotics (3–220 g/ton food) [61, 62]. Indeed, sulfonamides, tetracyclines and β-lactams increase the index conversion rate between 3 and 4%, improving the protein assimilation [62]. However, antibiotics also are excreted up to 10%, not being a good strategy because they are emerging contaminants [63]. The implementation of efficient water drinking reduces the slurry generation. The dozers incorporation and excreta handling techniques (e.g. hot beds) could reduce the floor washing, reusing waste organics (rice husk, straw) [64]. These strategies have reached reduce water requirements from 5 to 80% [4].

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3.2 Treatment and re-evaluation of by-products

The swine slurry treatment is the most used tool management within intensive farms by environmental pressures (legislation), which regulates its discharge on water bodies or soil revaluation. The slurries management requires a balance between the environmental/social and economic requirements in the farms. Ideally, this management starts with the excreta fractionation (slurry = urine + feces/feces) by physical/chemical separation. Some techniques, such as: polymers, filter press, flotation, sedimentation, screw press, among others are used to remove sedimentable/suspended material, reducing mainly organic matter (62–84%) and phosphorus (70–89%) [65]. The solid fraction corresponding to non-mineralized organic matter is subjected to composting (aerobic/anaerobic), which stabilizes giving it agronomic properties (C/N < 20). The liquid fraction (slurries) with a C/N ratio about 10 is subjected to biological (aerobic/anaerobic) removal processes of organic matter, nutrients and other microcontaminants (metals, emergent) [66]. Several technologies are grouped within the aerobic biological processes (aerated lagoons, activated sludge, among others) and anaerobic (anaerobic lagoons, fixed bed reactors, SBR or Sequencing Batch Reactor, UASB or Upflow Anaerobic Sludge Blanket, among others) [67]. Thus, the removal of dissolved and colloidal organic matter is usually carried out by anaerobic lagoons (*Environmentally Superior Technologies*), which reduce 50% of organic matter. Meanwhile, anaerobic reactors (Manure-based biogas plants) remove more than 80% of organic matter. The by-products obtained from this stage are usually stabilized effluents (C/N < 10) used as soil stabilizer and biogas [65, 68]. In this last point, specific temperature conditions (psychrophilic, mesophilic and thermophilic) have allowed the biogas (60–70% CH_4, 40–30% CO_2) production between 0.03 (anaerobic lagoons) and 650 (anaerobic reactors) m^3/d. The main biogas uses are related with thermal energy (0.02–390 m^3 gas) and/or electrical (0.07–1560 kWh) within farms [65, 69]. Additionally, anaerobic treatment under optimum conditions (35°C) reduces odors (1.9 units depending on the hedonic tone) [52]. This anaerobically treated effluent can be subjected to biological treatment (nitrification/denitrification, SBR or constructed wetlands) [70–72] or physical–chemical (stripping, vacuum evaporation, precipitation) [71, 73, 74] to nutrients removal (nitrogen and phosphorus). The nitrogen removal efficiencies vary from 40% (constructed wetlands) to 97% (denitrification–denitrification) and 100% (stripping) [71, 73]. Meanwhile, phosphorus is removed between 44% (constructed wetlands) and 80% (chemical precipitation) [71, 75–77]. In very few cases, have been reported metals removal (Cu, Zn), mainly due to their low concentrations (<1 g/L) [26]. However, the metals removal has allowed to obtain removal efficiencies between 75% (precipitation) and 92% (constructed wetlands) [78, 79]. The by-products obtained in this stage can vary from crystallized ammonium salts for agronomic use [73] to treated effluents with a C/N ratio <5 usable in irrigation [71].

The irrigation (slurries) or soil stabilization (solid) are the most used re-valuation techniques. The treated swine slurries have nutritional value (N:P:K: 1:0.6:0.4–1:0.3:1) to be used in cereals irrigation for swine consumption (1.2:0.2:1 a 1.6:0.3:1) [23, 80]. Under optimal irrigation conditions (150–200 kg N/ha year) some soil characteristics with agronomic importance (organic matter content and moisture retention) could be improved [81, 82]. The slurries re-valorization in irrigation has decreased the chemical fertilizers use, being in some countries (New Zealand) valued economically (21 million USD/year) [82]. However, the livestock production intensification vs. land availability (Europe) has carried out to optimize the nutrients recovery. Thus, it is necessary to consider within slurries the balance of macro (N:P: K) and micronutrients (metals), as well as other contaminants (pathogens, emergent). Moreover, this balance must consider soil nutritional requirements and

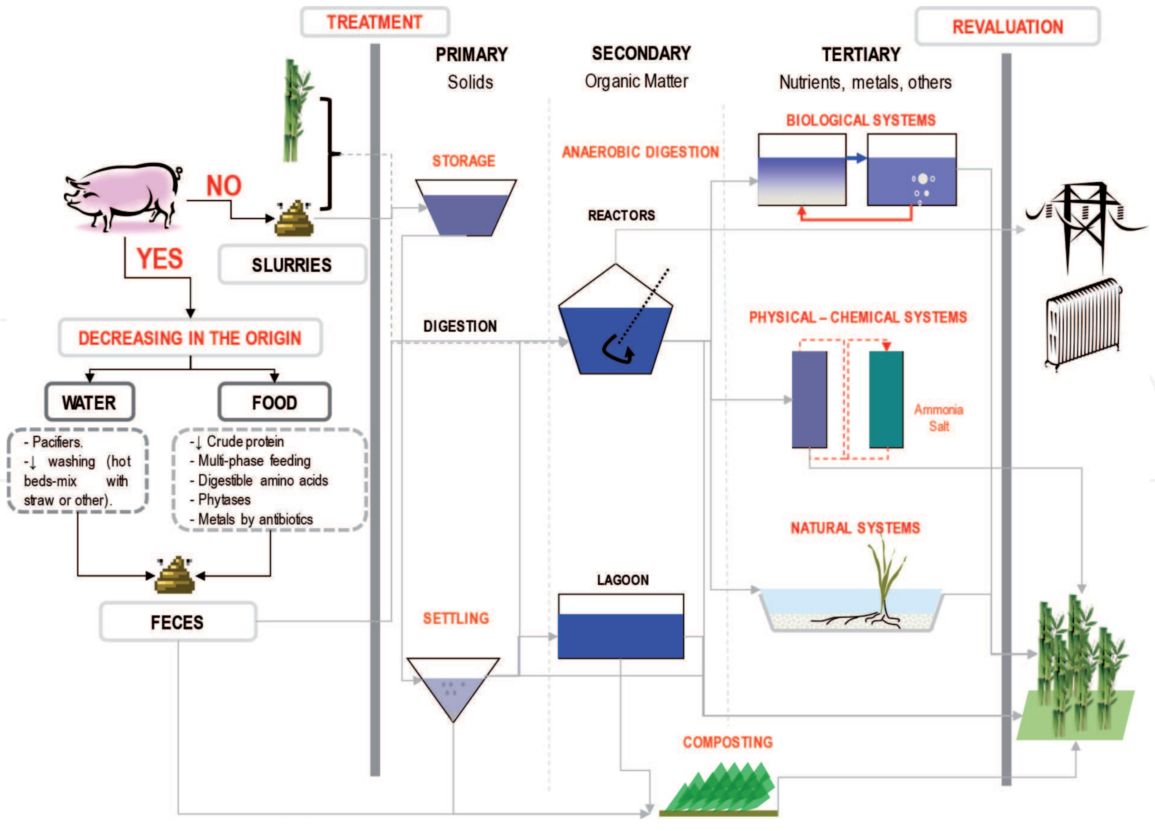

Figure 1.
Diagram of decision-making process within of the cycle of generation, treatment, and revaluation of swine slurry.

crop type, according to the international revaluation legislation [83, 84]. These tools would allow the cadasters establishment, which could facilitate the communication between nutritional requirements sites (agricultural soils) and nutrients-generating sites (animal farms) [85]. Preliminary Chilean studies have reported opportunities of livestock slurries revaluation in agriculture relating nutrients recovery sites with adequate agriculture sites [86].

The biogas production from anaerobic digestion of swine slurries is another revaluation alternative. In Europe, technologies based on biogas generation have been favored by state subsidies (10–30% investment cost) at farms level. These initiatives have allowed the building the more than 5000 anaerobic digestion projects [65, 87]. Swine slurries have potential capacity of methane generation between 0.25 and 0.30 m^3CH_4/kg VS [88]. Meanwhile, co-digestion with lignocellulosic materials (e.g. crop waste) could increase more than 16% produced methane [89]. Thus, centralized plants of anaerobic co-digestion are the current trend within European agricultural sector. Successful experiences have been reported in Germany and Denmark, where more than 32 plants have been built with a capacity between 16,000 and 200,000 tons/year of waste and with a production between 0.7 and 5.7 million m^3 biogas/year [90, 91]. Preliminary Chilean studies have allowed to establish the potential generation of bioenergy (biogas) from anaerobic co-digestion (livestock/crop wastes) at regional level [92]. **Figure 1** describes excretes management in the swine production.

4. Swine slurries treatment technologies

4.1 Organic matter removal

Anaerobic treatment technologies are widely used in this field, because they allow to remove organic matter, pathogens, odors, generating by-products (biogas, bio-fertilizer) [93]. There several anaerobic technologies, such as: biodigesters, anaerobic lagoon, complete mixing anaerobic reactors, anaerobic filters, UASB or Upflow Anaerobic Sludge Blanket, among other [94]. Worldwide, anaerobic technology based on conventional anaerobic mesophilic reactors (4935 plants) and thermophilic reactors (321 plants) treat around 49 million ton/year slurries, which have been built in Europe, mainly in Germany (more than 70%) [87]. State subsides, innovation technologic and centralization of biogas plants using agricultural wastes (livestock, crop) have favored their implementation [90, 91]. Meanwhile, more than 7000 technologies based on anaerobic lagoon have been built, but with only 60% operationally actives in the United States [63]. The conventional anaerobic reactors (complete mixture, piston flow) have been limited by its costs, remaining in disuse or only in building project around 77% [94]. However, currently these technologies are being replaced by more efficient technologies in terms of removal of nutrients, odors and pathogens [68, 71]. Technologies such as tubular biodigesters are the most used in countries where the livestock production in non-intensive.

The *anaerobic lagoons* are extensive and conventional typology, where organic matter is biodegraded without hydraulic or thermal control (environmental conditions) [95]. In the livestock sector, these systems offer some advantages related to their storage capacity and operation easy [96]. However, they can also cause odors, requiring spaces far spaces from neighboring population [94, 96]. Anaerobic lagoons obtain organic matter removal efficiencies between 26 and 79%, working under environmental conditions (5–32°C) and with residence times from 90 to 232 days [97, 98]. The lagoon design must consider thermal vertical stratification, suggesting depths between 0.8 and 4.0 m to maintain facultative conditions upper and anaerobic zone bottom [69, 99]. Its longer residence time also favors the macro (organic matter, nutrients) and micro (metals) nutrients precipitation. Thus, has been observed that anaerobic lagoon accumulates more than 50% COD, TN, P and Cu in the bottom, decreasing pH from 6.5–7.2 throughout its depth (>1.5 m) [99]. Another advantage is related with their disinfection capacity, due to its prolonged time exposure to solar radiation, causing cell lysis of pathogenic microorganisms [100]. However, this time exposure generates greenhouse gas emission (0.02–0.5 m^3 biogas/m^2 d) [69] and odors (168–262 OC/m^3, 101 μg NH_3/m^2 s, 5.7 μg H_2S/m^2 s) [101]. Operational improvements mainly related to the emission of gases from anaerobic lagoons have been made covering them.

The conventional full mix reactors or CSRT (Continuous Stirred Reactor Tank) are controlled systems, where the hydraulic retention time (residence time) is equal to the cell retention time [102]. The complete mixture is achieved through the recirculation from 25 to 40% of biogas generated [103]. It can operate under psychrophilic, mesophilic, and thermophilic conditions, which are carried out in two stages (acidogenic and methanogenic reactors) [93, 103]. This technology has been widely used mainly in Europe, obtaining organic matter removal efficiencies from 25 to 74%, but with organic loading between 5 and 40 times greater than anaerobic lagoon [87, 93]. CSRT reactor have been improved with the recirculation [93].

Other conventional technologies as anaerobic filters or AF generate biofilm around of the material support surface, while the flow goes up throughout the filter [102]. Inert (nylon meshes, polyurethane foams, polypropylene rings) and organic (blocks, wood chips) support material have been used [93]. The main advantage of this technology is that can operate at organic loading between 69 and 142 times greater than anaerobic lagoons; but have clogging problems [93].

The most advance technology has been developed to improve operational problems of conventional technologies. On the one hand, AFBR systems (Anaerobic Fluidized Bed Reactor) are technologies studied mainly at laboratory scale. They use support material (clay, wood and PVC), which is suspended due to the recirculation of the flow [102]. These characteristics partially avoid clogging [103]. On the other hand, UASB technology has been applied at the laboratory and pilot level. These treatment units generate biomass granulated, which sediments (4 m/h) improving the cellular retention time [102]. The flow goes up, favoring the washing of biomass non-granulated the granules are dense, harboring multi-species and diverse microbial communities. However, the granulation processes require longer periods of formation (2–8 months). Other innovative technologies from UASB systems are the EGSB (*Expanded Granular Sludge Bed*). This last technology is hydraulically improved respect to UASB, because it operates at greater flow velocity (>4 m/h) than UASB [104]. In general, UASB reactors are a viable alternative, since they are considered high load systems, operating at organic loadings between 2 and 162 times higher than conventional systems (anaerobic lagoons, CSRT). The organic matter removal efficiencies reach ranges between 19 and 86% [93, 94, 103, 105]. In addition, they offer other operational advantages related to their volume (0.006–0.5 times less volume than lagoons and CSRT) and sludge production (granular from UASB vs. suspended from lagoons/CSRT) [104]. Moreover, UASB generates higher biogas production (0.28–4.05 m^3/m^3 d) than conventional systems (0.02–1.69 m^3/m^3 d), thanks to the fact that they operate at higher organic loading (1–8.1 kg COD/m^3 d) [69, 93].

Table 6 and **Figure 2** describe the operational characteristics of anaerobic technologies applied on swine slurries.

4.2 Nutrients and metals removal

Constructed wetlands are used as a cost-effective alternative for the nutrients removal within the livestock sector [70]. In Europe, there are around 60 livestock farms, which treat 17,000 tons/year using constructed wetlands [87]. In the United States, about 33% (~ 70 farms) of constructed wetlands are used within livestock sector, being mainly (~ 83%) surface flow constructed wetlands (SF-CW) [70].

Operationally, there is experience in the use of different types of constructed wetlands within swine sector. However, SF-CW are the most used technology, mainly to avoid clogging [106]. Generally, SF-CW are used after the anaerobic lagoon, operating at nutrient loading between 5 and 36 kg N/ha and between 1 and 6 kg P/ha. The nitrogen and phosphorous removal efficiencies obtained reach values from 50 and 90 to and 25–66%, respectively [106–109]. Moreover, horizontal subsurface flow constructed wetlands HSS-CW have been studied at laboratory and pilot scales, operating at nutrient loading between 69 and 252 kg N/ha d and

Technology	Loading kg (BOD_5^*, COD^, VS°) /m^3 d	Temperature °C	Efficiency % (BOD_5^*, COD^, VS°)	Biogas m^3 biogas/ kg (BOD_5^*, COD^, VS°)	% Methane	Reference
Lagoon	0.05–0.08°	24–32	26–79*	0.43–0.80°	86–95	[69, 93, 97, 98]
CSRT	0.41–2.04°	20–60	25–74*	0.19–0.83°	60–79	[93, 94, 103]
AF	3.44–11.34°	31–55	35–61^	0.03–0.29°	61–87	[93]
AFBR	1.1–6.6^	—	66–91^	0.17–0.53^	75–84	[103]
UASB	1.0–8.1^	20.7–35	19–86*	0.28–0.50^	54–87	[93, 94, 103, 105]

CSRT, continuous stirred reactor tank, AF, anaerobic filter, AFBR, anaerobic fluidized bed reactor, UASB, upflow anaerobic sludge blanket.
** =BOD5 units, ^ = COD units,° = VS units.*

Table 6.
Operational characteristics of anaerobic reactors within swine sector.

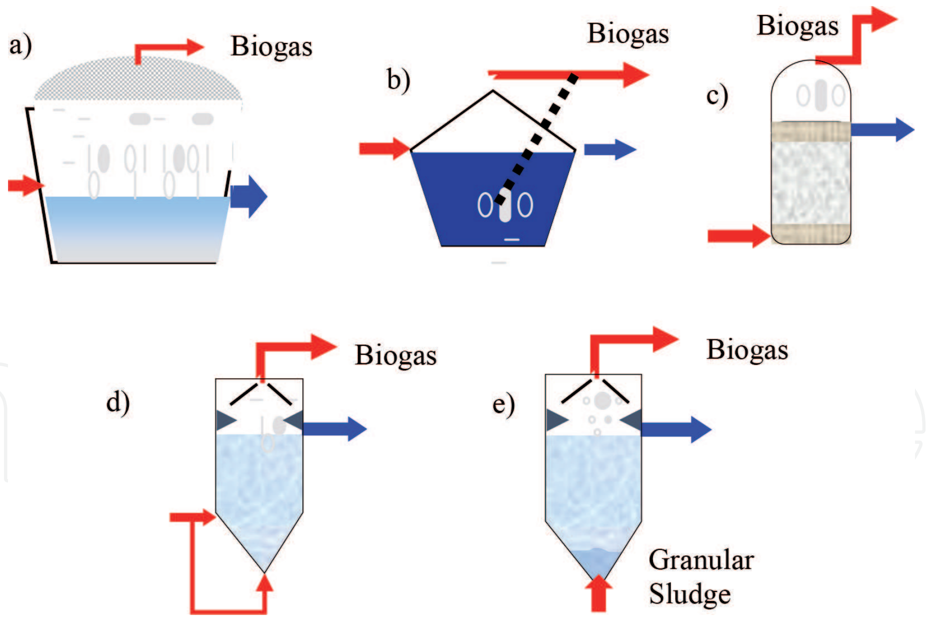

Figure 2.
Schemes of different types of anaerobic reactors used in the swine slurry treatment. (a) Lagoon, (b) CSRT, (c) AF, (d) AFBR, (e) UASB.

Species	Type	Prior Treatment	HRT (days)	Loading rate		Efficiency (%)		Reference
				kg N/ ha d	kg P/ ha d	N	P	
Tl, Sa	6 (HSS-lagoon-HS)	Anaerobic Lagoon	18	7–40	3.0–22.0	37–51^	13–31^	[109]
Sa, Sc, Sv, Je, Spa, Ta, Tl	4HSS	Anaerobic Lagoon Nitrifying unit	11–13	4.8–27.2 44–51	0.9–6.0 7–9	50–84^ 78–88^	25–38^ <10^	[107, 108, 106]
Ec	1HSS	Activated Sludge	27.5	69.0–262.0	15.0–47.0	10.0-24.0^	47.0-59.0^	[110]
Pc, Pa, Tl	Hybrid (2VS + 1HSS)	Anaerobic lagoon + Sand filter Recirculated treated purine (25–100%)	— —	214 —	30 —	50^ 54–67^	42^ 47–49^	[112]
Pa, Tl, Cp, Ca, Sl, Sm, Fu, Is, Ma, Ac, Se, Apa, Ls, Rl, S, P, Lm, Sta, Msp, Eca	Hybrid 8(HS+ HSS + VS)	Activated sludge	—	1.2–10	0.4–1	99.3^	99.6^	[113]
Gm, Ga, Gs, Mm, Poa	16HSS	Anaerobic digester	—	11.2–36.0	1.1–1.8	78–90*	56–66^	[106]
Cdp, Ap, Tl	2HSS	Filtration Tank	4.8	93.3	22.1	—	—	[111]
Ci, So, Pa	Híbrido (3 VS + 1 HSS)	Aeration lagoon	4–5	76.3	2.6	64^	61^	[114]

Acorus calamus: Ac; Alisma plantago-aquatica: Apa; Althernanthera philoxeroides: Ap; Canna indica: Ci; Carex pseudocyperus: Cp; Carex acutiformis: Ca; Cynodon dactylon Pers: Cdp; Elodea canadensis: Eca; Eichhornia crassipes: Ec; Filipendula ulmaria: Fu; Glyceria aquatica: Ga; Glyceria maxima: Gm; Iris pseudacorus: Ip; Juncus effusus: Je; Lemna minor: Lm; Lythrum salicaria: Ls; Mentha aquatica: Ma; Myriophyllum spicatum: Msp; Molinia maxima: Mm; Phragmites australis: Pa; Phragmites communis: Pc; Poa aquatic: Poa; Populus spp.: P; Ranunculus lingua: Rl; Salix spp.: S; Scirpus lacustris: Sl; Scirpus maritimus: Sm; Scirpus validus: Sv; Scirpus cyperinus: Sc; Schoenoplectus americanus: Sa; Sparganium erectum: Se; Sparganium americanum: Spa; Stratiotes aloides: Sta; Symphytum officinale: So; Typha angustifolia: Ta; Typha latifolia: Tl.
^ = *NH4+*

Table 7.
Operational characteristics of constructed wetlands within swine sector.

between 15 and 47 kg P/ha d. The nitrogen and phosphorus removal efficiencies vary from 10 to 24 and 47 to 59%, respectively [110, 111]. There are also experiences hybrid systems (SF/HSS/VSS) operating with plant species emergent and floating, which have achieved nitrogen and phosphorus removal efficiencies higher than 50 and 42%, respectively [112–114]. In general, constructed wetland systems will be operationally work with any previous technology. Thus, activated sludge has been used prior to constructed wetland increasing from 2 to 20 times the nutrients removal than anaerobic lagoons [109, 113]. The metals removal efficiencies have been reported in SF-CW, which have operated at rates from 0.09 to 0.25 kg Cu/ha and 0.58 to 1.58 kg Zn/ha d, obtaining removal efficiencies of up to 83 and 92%, respectively [78, 79, 111].

Currently, there are some innovations related to the constructed wetland treatment [106]. Likewise, the partial recirculation of pre-nitrified slurry has allowed to increase the nitrogen removal via denitrification up to 4 times, decreasing the ammonium volatilization [112, 115]. Other design concepts are based on the use of "*marsh-pond-marsh*" [109]. Constructed wetland technologies, could be improved operationally using intermittent hydraulic rate, which favors the oxygenation improving the nitrification [116].

Table 7 details the constructed wetlands operational characteristics of constructed wetlands used in the pig sector.

5. Future perspective and conclusions

Currently, the swine production should be looking to set the "new zoo technical order" with improvements in the life quality of the animals. Some reasons are given by environmental and health concerns given by the presence of emerging pollutants in meat and animal excreta. Indeed, swine meat has been reported as one of the sources of staphylococcus microbial resistance in humans [117]. Moreover, studies evidence the consumption of about 63,000 ton/year antibiotics in the livestock production (veterinary/promoters), being the main source of emerging pollutants in swine excreta/slurry [118]. Both water bodies and soil can be affected when these wastes are discharged or revaluated, since current treatment technologies are not designed to remove them. These two factors are further enhanced by the greenhouse gasses emissions responsibility from livestock production. Thus, swine production generates about 24 kg CO_2 eq/kg protein, which is mainly attributed to the mismanagement of their excreta/slurries [119]. In this last aspect, it is that the closing of the cycle the generation, treatment and revaluation of swine excreta fulfills a fundamental role. Studies report that reductions of up to 30% in greenhouse emissions could be achieved by a comprehensive management of resources (slurry, excreta, crops remains) between livestock and crop production [120]. Thus, livestock production through appropriate technology and management practices can be a source of nutrients for crops that provide food to animals. Agricultural production would support the energy generation inside farms by anaerobic. In the future, the livestock production could be supported from integral improvement from animal production to treatment and revaluation of wastes.

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References

[1] Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C. La larga sombra del ganado: problemas ambientales y opciones. Italia, Roma: División de Comunicación de la FAO; 2009. pp. 465

[2] Delgado C, Rosegrant H, Steinfeld H, Ehui S, Courbois C. Livestock to 2020. The Next Food Revolution. Food, Agriculture, and the Environment Discussion Paper 28. Washington D.C., United States: International Food Policy Research Institute; 1999. pp. 83

[3] FAOSTAT. Organización de las Naciones Unidas para la Alimentación y la Agricultura, Datos, Ganadería [Internet]. 2019. Available from: http://www.fao.org/faostat/es/#data/QA

[4] Froese C. Water usage and manure production rates in today's pig industry. Advances in Pork Production. 2003;**14**:218-223

[5] Solé F, Flotats X. Guía de técnicas de gestión ambiental de residuos agrarios. Catalunya, España: Centre UdL-IRTA; 2004

[6] Portejoie S, Dourmad J, Martinez J, Lebreton Y. Effect of lowering dietary crude protein on nitrogen excretion, manure composition and ammonia emission from fattening pigs. Livestock Production Science. 2004;**91**(1-2):45-55

[7] Galassi G, Colombini S, Malagutti L, Crovetto GM, Rapetti L. Effects of high fibre and low protein diets on performance, digestibility, nitrogen excretion and ammonia emission in the heavy pig. Animal Feed Science and Technology. 2010;**161**(3-4):140-148

[8] Kruse S, Traulsen I, Krieter J. Analysis of water, feed intake and performance of lactating sows. Livestock Science. 2011a;**135**(2-3):177-183

[9] Dourmad JY, Jondreville C. Impact of nutrition on nitrogen, phosphorus, Cu and Zn in pig manure and on emissions of ammonia and odours. Livestock Science. 2007;**112**(3):192-198

[10] Basset-Mens C, Van der Werf HMG. Scenario-based environmental assessment of farming systems: The case of pig production in France. Agriculture, Ecosystems and Environment. 2005;**105**(1-2):127-144

[11] Santomá G, Pontes M. Influencia del alojamiento sobre la nutrición de aves y cerdos. Barcelona, 16-17 octubre. XXII Curso de especialización FEDNA; 2006

[12] Dong GZ, Pluske JR. The low feed intake in newly weaned pigs: Problems and possible solutions. Asian-Australasian Journal of Animal Sciences. 2007;**20**(3):440-452

[13] Hernández F, Martínez S, López C, Megías MD, López M, Madrid J. Effect of dietary crude protein levels in a commercial range, on the nitrogen balance, ammonia emission and pollutant characteristics of slurry in fattening pigs. Animal: An International Journal of Animal Bioscience. 2011;**5**(8):1290-1298

[14] Dourmad JY, Guingand N, Latimier P, Séve B. Nitrogen and phosphorus consumption, utilisation and losses in pig production: France. Livestock Production Science. 1999;**58**:199-211

[15] Gonyou HW, Stricklin WR. Effects of floor area allowance and group size on the productivity of growing/finishing pigs. Journal of Animal Science. 1998;**76**:1326-1330

[16] Ward D, McKague K. Water Requirements of Livestock. Food and Rural Affairs, Ontario: Fact-sheet Ministry of Agriculture; 2007

[17] Jondreville C, Revy PS, Dourmad JY. Dietary menas to better control the environmental impact of copper and zinc by pigs from weaning to slaugter. Livestock Production Science. 2003;**84**(2):147-156

[18] Moral R, Perez-Murcia MD, Perez-Espinosa A, Moreno-Caselles J, Paredes C. Estimation of nutrient values of pig slurries in Southeast Spain using easily determined properties. Waste Management. 2005;**25**(7):719-725

[19] Scotford IM, Cumby TR, White RP, Carton OT, Lorenz F, Hatterman U, et al. Estimation of the nutrient value of agricultural slurries by measurement of physical and chemical properties. Journal of Agricultural Engineering Research. 1998;**71**:291-305

[20] Martínez-Suller L, Azzellino A, Provolo G. Analysis of livestock slurries from farms across northern Italy: Relationship between indicators and nutrient content. Biosystems Engineering. 2008;**99**(4):540-552

[21] Provolo G, Martínez-Suller L. In situ determination of slurry nutrient content by electrical conductivity. Bioresource Technology. 2007;**98**(17):3235-3242

[22] Suresh A, Choi HL. Estimation of nutrients and organic matter in Korean swine slurry using multiple regression analysis of physical and chemical properties. Bioresource Technology. 2011;**102**(19):8848-8859

[23] Ciampitti IA, García FO. Requerimientos nutricionales Absorción y extracción de macronutrientes y micronutrientes. Cereales, oleaginosos e industriales. Buenos Aires, Argentina; INPOFOS Archivos agronómico. 2007. pp. 13-15

[24] Moral R, Perez-Murcia MD, Perez-Espinosa A, Moreno-Caselles J, Paredes C, Rufete B. Salinity, organic content, micronutrients and heavy metals in pig slurries from South-Eastern Spain. Waste Management. 2008;**28**(2):367-371

[25] Boursier H, Béline F, Paul E. Piggery wastewater characterization for biological nitrogen removal process design. Bioresource Technology. 2005;**96**(3):351-358

[26] Marcato CE, Pinelli E, Pouech P, Winterton P, Guiresse M. Particle size and metal distributions in anaerobically digested pig slurry. Bioresource Technology. 2008;**99**(7):2340-2348

[27] De la Torre AI, Jimenéz JA, Carballo M, Fernandez C, Roset J, Muñoz MJ. Ecotoxicological evaluation of pig slurry. Chemosphere. 2000;**41**(10):1629-1635

[28] Villamar CA, Cañuta T, Belmonte M, Vidal G. Characterization of swine wastewater by toxicity identification evaluation methodology (TIE). Water, Air, and Soil Pollution. 2011;**223**:363-369

[29] Hoekstra NJ, Bosker T, Lantinga EA. Effects of cattle dung farms with different feeding strategies on germination and initial root growth of cress (*Lepidium sativum* L.). Agriculture, Ecosystems and Environment. 2002;**93**(1-3):189-196

[30] Li YS, Robin P, Cluzeau D, Bouché M, Qiu JP, Laplanche A, et al. Vermifiltration as a stage in reuse of swine wastewater: Monitoring methodology on an experimental farm. Ecological Engineering. 2008;**32**(4):301-309

[31] Mangas-Ramírez E, Sarma SSS, Nandini S. Combined effects of algal (*Chorella vulgaris*) density and ammonia concentration on the population dynamics of *Ceriodaphnia dubia* and *Monia macrocopa* (Cladocera). Ecotoxicology and Environmental Safety. 2002;**51**(3):216-222

[32] Dave G, Nilsson E. Increased reproductive toxicity of landfill leachate after degradation was caused by nitrate. Aquatic Toxicology. 2005;**73**(1):11-30

[33] Leung J, Kumar M, Glatz P, Kind K. Impacts of un-ionized ammonia in digested piggery effluent on reproductive performance and longevity of *Daphnia carinata* and *Monia australiensis*. Aquaculture. 2011;**310**(3-4):401-406

[34] Pretti C, Chiappe C, Baldetti I, Brunini S, Monni G, Intorre L. Acute toxicity of ionic liquids for three freshwater organisms: *Pseudokirchneriella subcapitata*, *Daphnia magna* and *Danio rerio*. Ecotoxicology and Environmental Safety. 2009;**72**(4):1170-1176

[35] Ip YK, Chew DJ, Randall DJ. Ammonia toxicity, tolerance, and excretion. Fish Physiology. 2001;**20**:109-148

[36] Kir M, Kumlu M, Eroldogan OT. Effects of temperature on acute toxicity of ammonia to *Penaeus semisulcatus* juveniles. Aquaculture. 2004;**241**(1):479-489

[37] Britto DT, Kronzucker HJ. NH_4^+ toxicity in higher plants: A critical review. Journal of Plant Physiology. 2002;**159**(6):567-584

[38] Van Der Eerden LJM. Toxicity of ammonia to plants. Agriculture and Environment. 1982;**7**(3-4):223-235

[39] Waller DL, Fisher SW, Dabrowska H. Prevention of zebra mussel infestation and dispersal during aquaculture activities. The Progressive Fish-Culturist. 1996;**58**(2):77-84

[40] Bernstein L. Effects of salinity and sodicity on plant growth. Annual Review of Phytopathology. 1975;**13**:295-312

[41] Martins J, Oliva Teles L, Vasconcelos V. Assays with *Daphnia magna* and *Danio rerio* as alert systems in. Aquatic Toxicology. 2007;**33**(3):414-425

[42] Shah FUR, Ahmad N, Masood KR, Peralta-Videla JR, Ahmad FuD. Heavy metal toxicity in plants. In: Plant Adaptation and Phytoremediation. New York, USA. Springer Publisher; 2010. pp. 71-97

[43] Lukkari T, Aatsinki M, Väisänen A, Haimi J. Toxicity of copper and zinc assessed with three different earthworm tests. Applied Soil Ecology. 2005;**30**(2):133-146

[44] Muyssen BTA, Janssen CR. Age and exposure duration as a factor influencing Cu and Zn toxicity toward *Daphnia magna*. Ecotoxicology and Environmental Safety. 2007;**68**(3):436-442

[45] Kristin MG, Todd VR. Effect of road salt application on seasonal chloride concentrations and toxicity in south-Central Indiana streams. Journal of Environmental Quality. 2010;**39**:1036-1042

[46] Blanes-Vidal V, Hansen MN, Adamsen APS, Feilberg A, Petersen SO, Jensen BB. Characterization of odor released during handling of swine slurry: Part I. relationship between odorants and perceived odor concentrations. Atmospheric Environment. 2009a;**43**(18):2997-3005

[47] Blanes-Vidal V, Hansen MN, Adamsen APS, Feilberg A, Petersen SO, Jensen BB. Characterization of odor released during handling of swine slurry: Part II. Effect of production type, storage and physicochemical characteristics of the slurry. Atmospheric Environment. 2009b;**43**(18):3006-3014

[48] Mackie RI, Stroot PG, Varel VH. Biochemical identification and biological origin of key odor components in livestock waste. Journal of Animal Science. 1998;**76**(5):1331-1342

[49] Schiffman SS, Bennett JL, Raymer JH. Quantification of odors and odorants from swine operations in North Carolina. Agricultural and Forest Meteorology. 2001;**108**(3):213-240

[50] Zhu J. A review of microbiology in swine manure odor control. Agriculture, Ecosystems and Environment. 2000;**78**(2):93-106

[51] Welsh FW, Schulte DD, Kroeker EJ, Lapp HM. The effect of anaerobic digestion upon swine manure odors. Canadian Agricultural Engineering. 1977;**19**(2):122-126

[52] Chae KJ, Jang A, Yim SK, Kim IS. The effects of digestion temperature and temperature shock on the biogas yields from the mesophilic anaerobic digestion of swine manure. Bioresource Technology. 2008;**99**(1):1-6

[53] Espinoza-Escalante FM, Pelayo-Ortíz C, Navarro-Corona J, González-García Y, Bories A, Gutiérrez-Pulido H. Anaerobic digestion of the vinasses from the fermentation of Agave tequilana weber to tequila: The effect of pH, temperature and hydraulic time on the production of hydrogen and methane. Biomass and Bioenergy. 2009;**33**(1):14-20

[54] Sheffield R, Thompson M, Dye B, Parker D. Evaluation of field-based odor assessment methods. Proceedings of the water environment federation. WEF/A&WMA Odors and Air emissions. 2004;**10**:870-879

[55] Pan L, Yang SX, DeBruyn J. Factor analysis of downwind odours from livestock farms. Biosystems Engineering. 2007;**96**(3):387-397

[56] Hanajima D, Kuroda K, Morishita K, Fujita J, Maeda K, Morioka K. Key odor components responsible for the impact on olfactory sense during swine feces composting. Bioresource Technology. 2010;**101**(7):2306-2310

[57] Nimmermark S. Influence of odour concentration and individual odour thresholds on the hedonic tone of odour from animal production. Biosystems Engineering. 2011;**108**(3):211-219

[58] Pomar C. Alimentar mejor a los cerdos para reducir el impacto medio ambiental. Jornadas técnicas: Factores que afectan la eficiencia productiva y la calidad en porcino. Vic, 1 de junio de 1999; 1999

[59] Jacela JY, DeRounchey JM, Tokach MD. Feed additives fro swine: Fact sheets – High dietary levels of copper and zinc for young pigs, and phytase. Journal Swine Health Production. 2010;**18**(2):87-91

[60] McEwen SA. Antibiotic use in animal agriculture: What have we learned and where are we going? Animal Biotechnology. 2006;**17**:239-250

[61] Choi F. Piggery Waste Management. Towards a Sustainable Future. London, United Kingdom: IWA Publishing; 2007. pp. 167

[62] Babot D, Martinez L, Teira MR. Gestión de subproductos y residuos porcinos. Mundo ganadero. 2001;**133**:34-36

[63] Martínez-Almela J, Barrera JM. SELCO-Ecopurin pig slurry treatment system. Bioresource Technology. 2005;**96**(2):223-228

[64] Aust M-O, Thiele-Bruhn S, Eckhardt K-U, Leinweber P. Composition

of organic matter in particle size fractionated pig slurry. Bioresource Technology. 2009;**100**(23):5736-5743

[65] Bernet N, Béline F. Challenger and innovations on biological treatment of livestock effluents. Bioresource Technology. 2009;**100**(22):5431-5436

[66] Vanotti MB, Szogi AA, Millner PD, Loughrin JH. Development of a second-generation environmentally superior technology for treatment of swine manure in the USA. Bioresource Technology. 2009;**100**(22): 5406-5416

[67] Safley LM Jr, Wasterman PW. Biogas production from anaerobic lagoons. Biological Wastes. 1988;**23**:181-193

[68] Knight RL, Payne VWE Jr, Borer RE, Clarke RA Jr, Pries JH. Constructed wetlands for livestock wastewater management. Ecological Engineering. 2000;**15**:41-55

[69] Vanotti MB, Szogi AA, Hunt PG, Millner PD, Humenik FJ. Development of environmentally superior treatment system to replace anaerobic swine lagoons in the USA. Bioresource Technology. 2007;**98**(17):3184-3194

[70] Belmonte M, Vázquez-Padín JR, Figueroa M, Campos JL, Méndez R, Vidal G. Denitrifying activity via nitrite and N_2O production using acetate and swine wastewater. Process Biochemistry. 2012;**47**(7):1202-1206

[71] Bonmatí A, Flotats X. Air stripping of ammonia from pig slurry: Characterization and feasibility as a pre- or post-treatment to mesophilic anaerobic digestion. Waste Management. 2002;**23**(3):261-272

[72] Bonmatí A, Flotats X. Pig slurry concentration by vacuum evaporation: Influence of previous mesophilic anaerobic digestion process. Air and Waste Management. 2003;**53**(1):21-31

[73] Neubauer ME, Plaza de los Reyes C, Pozo G, Villamar CA, Vidal G. Growth and nutrient uptake by *Schoenoplectus californicus* (C.A. Méyer) Sójak in a constructed wetland fed with swine slurry. Journal of Soil Science and Plant Nutrition. 2012;**12**(3):421-430

[74] Plaza de los Reyes C, Villamar CA, Neubauer M, Pozo G, Vidal G. Behavior of *Typha angustifolia* L. in a free water surface constructed wetland for the treatment of swine wastewater. Journal of Environment Science and Health, Part A. 2013;**48**(10):1216-1224

[75] Villamar CA, Rivera D, Neubauer ME, Vidal G. Nitrogen and phosphorus dynamics in a constructed wetland fed with treated swine slurry from an anaerobic lagoon. Journal of Environmental Science and Health: Part: A. 2015;**50**(1):60-71

[76] Yeh TY, Chou CC, Pan CT. Heavy metal removal within pilot-scale constructed wetlands receiving river water contaminated by confined swine operations. Desalination. 2009;**249**(1):368-373

[77] Villamar CA, Neubauer ME, Vidal G. Distribution and availability of copper and zinc in a constructed wetland fed with treated swine slurry from an anaerobic lagoon. Wetlands. 2014;**34**(3):583-591

[78] Sánchez M, González JL. The fertilizer value of pig slurry. I. Values depending on the type of operation. Bioresource Technology. 2005;**96**(10):1117-1123

[79] Ndayegamiye A, Coté D. Effect of long-term pig slurry and solid cattle manure application on soil chemical and biological properties. Canadian Journal of Soil Science. 1989;**69**:39-47

[80] Wang H, Magesan G, Bolan N. An overview of the environmental effects of land application of farm effluents. New Zealand Journal of Agricultural Research. 2004;**47**(4):389-403

[81] Teira-Esmatges MR, Flotats X. A method for livestock waste management planning in NE Spain. Waste Management. 2003;**23**(10):917-932

[82] Bastian R, Murray D. Guidelines for Water Reuse, EPA/600/R-12/618. Washington, DC, USA: US EPA Office of Research and Development; 2012. p. 643

[83] Provolo G. Manure management practices in Lombardy (Italy). Bioresource Technology. 2005;**96**(2):145-152

[84] Villamar CA, Vera I, Rivera D, de la Hoz F. Reuse and recycling of livestock and municipal wastewater in Chilean agriculture: A preliminary assessment. Water. 2018;**10**(6):817-833

[85] Henning F, Flotats X, Bonmati A, Palatsi J, Magri A, Schelde KM. Inventory of manure processing activities in Europe. Technical Report No. I concerning “Manure Processing Activities in Europe” to the European Commission, Directorate-General Environment; 2011. pp. 138

[86] Angelidaki I, Ellegaard L. Codigestion of manure and organic wastes in centralized biogas plants. Applied Biochemistry and Biotechnology. 2003;**109**:95-105

[87] Lehtomäki A, Huttunen S, Rintala JA. Laboratory investigations on co-digestion of energy crops and crop residues with cow manure for methane production: Effect of crop to manure ratio. Resources, Conservation and Recycling. 2007;**51**:591-609

[88] Al Seadi T. Danish Centralised Biogas Plants-Plants Descriptions. Esbjerg, Demarck: Bioenergy Department, University of Southern Denmark; 2000. pp. 27

[89] Weiland P. Anaerobic waste digestion in Germany –status and recent developments. Biodegradation. 2000;**11**(6):415-421

[90] Villamar CA, Rivera D, Aguayo M. Anaerobic co-digestion plants for the revaluation of agricultural waste: Sustainable location sites from a GIS analysis. Waste Management & Research. 2016;**34**(4):316-326

[91] Chynoweth DP, Wilkie AC, Owens JM. Anaerobic processing of piggery wastes: a review. ASAE Annual International Meeting. Orlando, Florida, July 11-16; 1998

[92] Lusk P. Methane Recovery from Animal Manures the Current Opportunities Casebook. 3rd ed. Washington D.C., United States: NREL/SR-25145.Golden, CO: National Renewable Energy Laboratory. Work performed by Resource Development Associates; 1998. pp. 174

[93] Wu B, Chen Z. An integrated physical and biological model for anaerobic lagoons. Bioresource Technology. 2010;**102**(9):5032-5038

[94] Barker JC. Lagoon design and management for livestock waste treatment and storage. North Carolina Cooperative Extension Service, Pub. No. EBAE, 103-83; 1996

[95] Hart SA, Turner ME. Lagoons for livestock manure. Water Environment Federation. 1965;**37**(11):1578-1596

[96] McLaughlin MR, Brooks JP, Adeli A. Temporal flux and spatial dynamics of nutrients, fecal indicators, and zoonotic pathogens in anaerobic swine manure lagoon water. Water Research. 2012;**46**(16):4949-4960

[97] Lovanh N, Loughrin JH, Cook K, Rothrock M, Sistani K. The effect of stratification and seasonal variability on the profile of an anaerobic swine waste treatment lagoon. Bioresource Technology. 2009;**100**(15):3706-3712

[98] Hill VR. Prospects for pathogen reductions in livestock wastewater: A review. Critical Reviews in Environmental Science and Technology. 2003;**33**(2):187-235

[99] Lim T-T, Heber AJ, Ni J-Q, Shao P. Atmospheric pollutans and trace gases: Odor and gas release from anaerobic treatment lagoons for swine manure. Journal of Environmental Quality 2003;**32**:406-416

[100] Liu X, Yan Z, Yue Z-B. Biofuels and bioenergy/biogas. In: Moo-Young M, editor. Comprehensive Biotechnology. Second ed. Vol. V3. 2011. pp. 99-144

[101] Montalvo S, Gerrero L. Tratamiento anaerobio de residuos. Producción de biogás. Valparaíso, Chile: Universidad Técnica Santa María; 2003. pp. 413

[102] Seghezzo L, Zeeman G, van Lier JB, Hamelers HVM, Lettinga G. A review: The anaerobic treatment of sewage in UASB and EGSB reactors. Bioresource Technology. 1998;**65**(3):175-190

[103] Rodríguez DC, Belmonte M, Peñuela G, Campos JL, Vidal G. Behaviour of molecular weight distribution for the liquid fraction of pig slurry treated by anaerobic digestion. Environmental Technology. 2011;**32**(4):419-425

[104] Harrington C, Scholz M. Assessment of pre-digested piggery wastewater treatment operations with surface flow integrated constructed wetland systems. Bioresource Technology. 2010;**101**(20):7713-7723

[105] Stone KC, Hunt PG, Szögi AA, Humenik FJ, Rice JM. Constructed wetlsn design and performance for swine lagoon wasteeater treatment. American Society of Agricultural Engineers. 2002;**45**(3):723-730

[106] Hunt PG, Szögi AA, Humenick FJ, Rice JM, Matheny TA, Stone KC. Constructed wetlands for treatment of swine wastewater from an anaerobic lagoon. Soil science Society of America Journal. American Society of Agricultural Engineers. 2002;**45**(3):639-647

[107] Poach ME, Hunt PG, Reddy GB, Stone KC, Johnson MH, Grubbs A. Swine wastewater treatment by marsch-pond-marsh constructed wetlands under varyring nitrogen loads. Ecological Engineering. 2004;**23**(3):165-175

[108] Lee C-Y, Lee C-C, Lee F-Y, Tseng S-K, Liao C-J. Performance of subsurface flow constructed wetland taking pretreated swine effluent under heavy loads. Bioresource Technology. 2004;**92**:173-179

[109] Matos AT, Freitas S, Martinez MA, tótola MR, Azevedo AA. Tifton grass yield on constructed wetland used for swine wastewater treatment. Revista Brasileira de Engenharia Agrícola e Ambiental. 2010;**14**(5):510-516

[110] Lian-sheng H, Hong-liang L, Bei-dou X, Ying-bo Z. Enhancing treatment effiency of swine wastewater by effluent recirculation in vertical-flow constructed wetland. Journal of Environemtnal Sciences. 2006;**18**(2):221-226

[111] Meers E, Tack FMG, Tolpe I, Michels E. Application of a full-scale constructed wetlsn for tertiary treatment of piggery manure: mo itoring results. Water, Air, and Soil Pollution. 2008;**193**(1):15-24

[112] Borin M, Politeo M, De Stefani G. Performance of a hybrid constructed wetland treating piggery wastewater. Ecological Engineering. 2013;**51**:229-236

[113] Hunt PG, Stone KC, Matheny TA, Poach ME, Vanotti MB, Ducey TF. Denitrification of nitrified and non-nitrified swine lagoon wastewater in the suspended sludge layer of treatment wetlands. Ecological Engineering. 2009;**35**(10):1514-1522

[114] Poach ME, Hunt PG, Reddy GB, Stone KC, Johnson MH, Grubbs A. Effect of intermittent drainage on swine wastewater treatment by marsch-pond-marsh constructed wetlands. Ecological Engineering. 2007;**30**(1):43-50

[115] Simeoni D, Rizzotti L, Cocconcelli P, Gazzola S, Dellaglio F, Torriani S. Antibiotic resistance genes and identification of staphylococci collected from the production chain of swine meat commodities. Food Microbiology. 2008;**25**(1):196-201

[116] Tasho RP, Cho JY. Veterinary antibiotics in animal waste, its distribution in soil and uptake by plants: A review. Science of the Total Environment. 2016;**563**:366-376

[117] Herrero M, Havlík P, Valin H, Notenbaert A, Rufino MC, Thornton PK, et al. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. Proceedings of the National Academy of Sciences. 2013;**110**(52):20888-20893

[118] Adegbeye MJ, Reddy PRK, Obaisi Ai, Elghandour MMMY, Oyebamiji KJ, Salem AZM, et al. Sustainable agriculture options or production, nutritional mitigation o greenhouse gasses and prollution, and nutrient recycling in emergingn and transitional nations – An review. Journal of Cleaner Production. 2019 (In press)