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Pig Husbandry and Solid Manures in a Commercial Pig Farm in Beijing, China

Roxana Mendoza Huaitalla[1], Eva Gallmann[1], Kun Zheng[2], Xuejun Liu[2], Eberhard Hartung[3]

***Abstract*—**Porcine production in China represents approximately the 50% of the worldwide pig production. Information about pig husbandry characteristics in China and manure properties from sows to fatteners in intensive pig farms are not broadly available for scientific studies as it is a time consuming, expensive task and highly inaccessible. This study provides a report about solid pig manures (28% dry matter) in a commercial pig farm located in the peri-urban area of Beijing as well as a general overview of the current pig husbandry techniques including pig breeds, feeds, diseases, housing as well as pig manure and wastewater disposal. The main results are intended to serve as a literature source for young scientists in order to understand the main composition of pig manures as well as to identify the husbandry techniques applied in an intensive pig farm in Beijing.

***Keywords*—**China, heavy metals, intensive pig farming, manure, nutrients, pig growing stages.

I. Introduction

MEAT production in China is dominated by pork that comprises approximately the 50% of the worldwide pig production [19]. The Chinese pork sector is expected to continue its growth as result of the increment of meat demands driven by the economical emergence of China and by the rapid expansion of industrial systems [41], [52], [63]. Pig production in China can be categorized into three operation scales: (i) backyard producers with less than 30 pigs a year, (ii) specialized households with less than 500 pigs a year and, (iii) large operations with more than 500 pigs a year. Nowadays, only about the 10% of the pork produced in China is originated from large pig operations. Therefore although there are few studies on household pig production in China there is a gap concerning studies focusing on the large commercial pig farms [50].

[1]Roxana Mendoza Huaitalla is with the Institute of Agricultural Engineering, University of Hohenheim, Stuttgart, 70599, Germany. (phone: +49 (0)711 459 24318; fax: +49 (0)711 459 24307; e-mail: roxana.mendoza@uni-hohenheim.de).

[1]Eva Gallmann is with the Institute of Agricultural Engineering, University of Hohenheim, Stuttgart, 70599, Germany. (e-mail: eva.gallmann@uni-hohenheim.de).

[2]Kun Zheng is with the College of Agricultural Resources and Environmental Sciences, China Agricultural University, Beijing, 100094, China. (e-mail: zhengkunwd@yahoo.com.cn).

[2]Xuejun Liu is with the College of Agricultural Resources and Environmental Sciences, China Agricultural University, Beijing, 100094, China. (e-mail: liu310@cau.edu.cn).

[3]Eberhard Hartung is with the Institute of Agricultural Engineering, Christian-Albrechts-University Kiel, Kiel, 24098, Germany. (e-mail: ehartung@ilv.uni-kiel.de).

To keep producing at large scale, pig producers have implemented the western model of livestock confinement that is specially spreading out in the peri-urban areas of big cities, for instance, Beijing.

Despite that China is the origin of about 70% of breed diversity in the world [28], high-value breeds found in capital farms are mainly introduced, i.e., *Large White*, *Yorkshire*, *Duroc* and *Pietrain* and hybrids like *Pietrain-Duroc* due to their improved traits for higher lean meat ratios (65%) that leads to the replacement of Chinese native pigs like the *Taihu Meishan* of short body length and high proportion of back fat putting the existence of indigenous breeds at risk [18], [56]. Indeed, improved breeds are characterized by good performance though they are susceptible to harsh tropical conditions and are dependant on high quality feeds [18].

At present, several confined pig farms produce fattening pigs or porkers as secondary activity being the production of breeding pigs of their main interest. Indeed, each breeding pig (100 Kg) can be sold for ca. 3000 Renminbi (RMB) while a porker of similar size, categorized by its poor body shape and fertility rate, can be merely sold for ca. 1000 RMB per live unit.

Confined animal production is considered the major source of manure by-products and surpluses in most countries [51]. Several sources have reported that pigs produce more manure per live weight than any other livestock. Besides, manure production also varies depending on the growing stage of pigs, with the rate of excretion less for young piglets and substantially more for lactating sows [47]. In fact, pork production can be subdivided into a number of physiological phases requiring different nutrient combinations. The practice of designing a feed for each growing stage is termed multi-phase feeding [30] and is practiced in the farm under study. Therefore, this investigation describes the manures in every pig growing stage, namely, gestation, farrowing, weaning and fattening.

Values reported in the literature vary due to differences in pig husbandry and manure management. Actual sample analyses should be performed for research purposes [50]. In fact, description of pig manures contents is not widely available due to cost and time limiting factors; the access to intensive pig farms is quite difficult due to the protection of information by the farm managers [41]. There is a need of information that describes the husbandry techniques and manure management under Chinese representative conditions. Therefore, this study presents the current husbandry techniques and reports the characterization of the different pig manures in a commercial pig farm of Beijing, China.

II. METHODS AND MATERIALS

A. Methods

Manure Sampling

A total of 20 pig manures samples were collected on a weekly basis during 5 months, from June to October, 2009. Samples were fresh (only feces contaminated with floor residues, urine and feed leftovers) and obtained from the floor surface of four barns of the pig farm. Sampling was performed following the natural pig growing stages, i.e., I. Gestation, II, Farrowing, III, Weaning and, IV Fattening as shown in Fig 1. Manure samples were stored in a freezer at -20°C and thawed prior to lab analysis.

Analysis

Table I shows the methods used as reference for the execution of the chemical analysis. A total of 3 replications were made for the determination of nutrients and heavy metals for every kind of pig manure in order to assure the representativeness of analyzed the samples [15]. The chemical analyses were executed in the Colleague of Resources and Environmental Sciences of the China Agricultural University, Beijing and in the Research Station Quzhou, Hebei. International Standard methods were used in the samples analysis [37], [55]. Statistical descriptive analysis was carried out to find the mean, maximum, minimum and standard deviation values of the main elements contained in the pig manures. The values are shown in wet and dry basis. Tukey Statistical Test of significance ($p < 0.05$) was performed for the manures in each pig growing stage using the software OriginPro, Version 8. Additionally, international literature review was performed in order to compare the manure elements obtained in this study.

TABLE I
EVALUATED PARAMETERS AND METHODS USED

Parameter	Method
Dry matter	Dried at 105°C, 24 hours[a]
Phosphorus, Potassium, Calcium, Manganese, Cadmium, Copper, Zinc, Lead, Chromium	Inductively coupled plasma atomic emission spectroscopy (ICP)[a]
Total nitrogen	Kjeldahl[a]
Ammonium nitrogen	Quantofix. Direct reading[b]

[a] [37]; [b] [35], [55].

B. Materials

Pig Farm

A large-sized pig farm with a dimension of 10 ha with an annual stock of 12000 breeding swine and 20000 market pigs or porkers was selected. The farm is located in the Shunyi District at one and half hour from the center of Beijing. A total of 188 pig farms can be found in Shunyi representing the 34% of the total pig production in Beijing. Shunyi is charactercized by annual mean temperature of 11,5°C, mean relative humidity of 50% and annual mean precipitation of 625 mm [6]. Due to water shortages in China [41] and as a response to consider water conservation, solid manures in the pig farm under study are manually collected twice a day; this collection technique is termed in Chinese, "gan qing fen" or in English "cleaning the manure dryly" [62]. Pig manures are transported to the farm biogas plant that supplies about the 40% of the total local energy demand especially for cooking aims. The pig's industry in Shunyi is the main source of income for the villagers and focuses its production on breeding pigs and porkers. At production level, pig breeds have been introduced due to their genetic merit, for instance; Duroc has been imported from the USA, Pietrain was first imported from Taiwan, Large White and Landrace were imported from the UK and Belgium respectively [6].

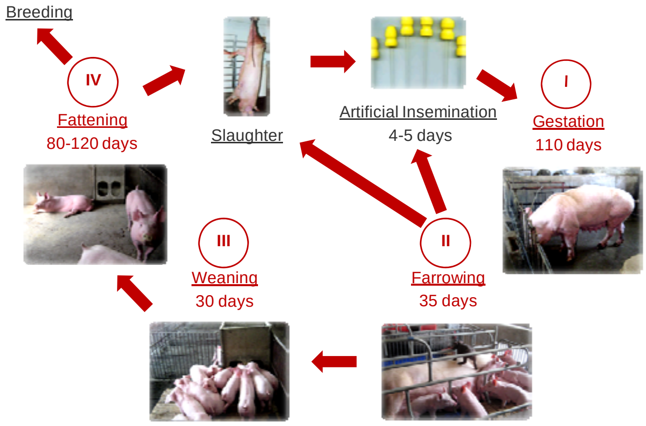

Fig. 1 Pig growing stages

III. RESULTS AND DISCUSSION

A. Pig Husbandry System

Pig breeds

There is no differentiation between breeding and fattening pigs during the growing phases. The main pig breeds are shown in Fig. 2 and described as follows,

-*Large White*. The origin of the Large White started when a small, fleshy type of pig from the Canton area in China was crossed with White pigs from Yorkshire and adjacent counties to produce the Small White, Middle White and Large White breeds. Specially, Large Whites came into prominence during the 19th century [22]. The size of the Large White is mainly for boars: 169-199 Kg and for sows: 159-169 Kg [1]. The Large White is a robust breed that can withstand a wide range of climatic conditions. Large White sows are recognized for its outstanding large litter size (11,4 compared to other breeds, refer to Table II), its good milk production and excellent maternal traits [22].

-*Landrace*. The origin of the American Landrace was in 1895 and it has decency from the Danish Landrace [58]. The size of the Landrace is mainly for boars: 169-179 Kg and for sows: 147-158 Kg [1]. Landrace is known for its good ability to cross well with other breeds. Specifically, it is found that Landrace has a rapid growth. Indeed, its weight at weaning is higher than other breeds [21]. Likewise, it has a high percentage of carcass weight in the ham and lean (66%, see Table II). Besides, Landrace sows are characterized as good milkers [58].

-*Duroc*. Its exact origin is unknown [20]. The size of Duroc is mainly for boars: 140-149 Kg and for sows: 131-140 Kg [1]. Duroc or Duroc cross do not have good maternal sire. Its litter size is lower than the Large White and Landrace. Male Durocs are found to be aggressive. Duroc performance depends on its genetic merit and the environment it develops [20]. Moreover, Durocs have good muscle quality and can grow fast resulting in high lean ratios (68%, see Table II) [58].

-*Pietrain*, originated from the Belgian village of the same name and is the result of the crossing between the English and French Pietrain races. The size of Pietrain is mainly for boars: 258-287 Kg and for sows: 229-258 Kg. This pig is neither strong nor robust and under stress it will possibly die [1]. Moreover, Pietrain represents the lowest litter sizes among the other pig breeds (see Table II).

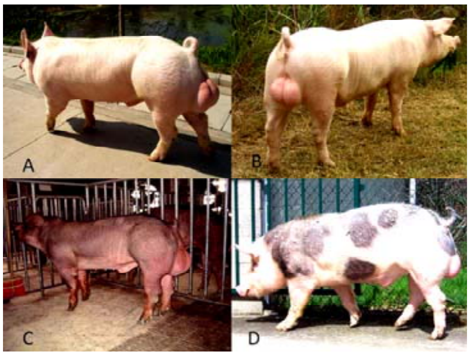

Fig. 2 Pig breeds in Beijing Farm A:Large White, B:Landrace, C:Duroc, D:Pietrain [33].

TABLE II
PIG BREEDS AND PERFORMANCE

Breed	35 days average weight (kg)	75 days average weight (kg)	Lean meat (%)	Litter size
Large White	8,42	30,3	65	11,4
Landrace	8,86	31,0	66	10,9
Duroc	8,60	30,0	68	10,1
Pietrain	-	-	67	9,7

-: no data available, [33].

Housing

The pig farm consists of a total of 56 barns. Pig barns are monitored by an indoor camera system. The main pig farm structure is described in Table III. Indoor mean temperature is 25°C during winter and summer seasons with an average relative humidity of 50% (results to be published). The pig barns are separated by a distance of 6 m that allows good cross ventilation especially in summer-windy days when temperatures in Beijing can reach the 40°C. For air conditioning, a system of false-ceiling is used to provide space for housing air ducts as shown in the Fig. 3 [14].

To minimize animal movements the natural cycle of pigs is reflected by the distribution of the pig barns [14]. Gestation and Farrowing barns are only found in the west side of the pig farm while Weaning and Fattening barns are mainly found in the east side of the pig farm. Pigs are housed on solid or slatted floors.

TABLE III
PIG FARM DESCRIPTION

Production cycle	N° barns	Capacity pig/barn	Feeding regime	Ventilation
Gestation	20	70	Wet meal	Forced
Farrowing	8	$200^p – 20^s$	Dry meal ^{s} Creep feed ^{p}	Forced
Weaning	3	200	Pellets	Natural
Fattening	25	300	Dry meal	Natural

^{p} piglet, ^{s} sow.

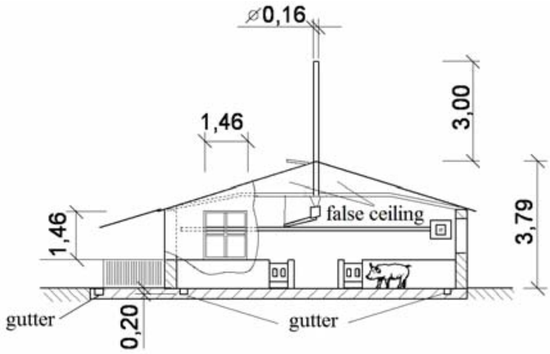

Fig. 3 Fattening pig barn layout

In the gestation barns, pregnant sows are confined in pig pens and not in crates as previously also found in the western systems (see Fig. 4). Pens or boxes are arranged in 2 rows along a central passageway. Each pen only houses from 1 to 2 sows. Individual housing can assure equal feed access and provide with good space for lying and exercising [14]. Although, individual housing can diminish the probability of attacks from other sows, nowadays in Europe, especially in the Netherlands and Germany group housing of pregnant sows in the waiting stables is a common practice and has became compulsory due to animal welfare aspects since indeed pigs enjoy being in groups [3]. For identification and recording the pigs are numbered after birth by ear notching.

Farrowing sows and their litter (piglets) are individually confined in farrowing crates with slatted floors (See Fig. 4). Rails found in the farrowing crate are used to prevent sows from lying over the piglets [14]. A nest cover is placed in one corner of the farrowing pen in order to provide a warm environment for piglets by means of an internal lamp.

Weaning pigs are separated from the sows at the age of 30 days (early weaning) [14], by this time piglets are used to eat creep feed (first solid feed) as the sow's milk yield has declined [10]. Weaners are raised indoors and grouped in pens from 8 to 12 pigs per pen. Weaning barns are characterized by two types of floors, i.e., slatted floor (plastic and cast iron) and concrete floor (see Fig. 5). Mortality at this stage is of 5% (information from pig farm bookings) mainly due to two reasons: (i) starvation due to the unequal feed access as result of the *adlib* feed system and, (ii) chilling due to drops of the indoor barn temperature reflected on the piglet grouping behavior as shown in the Fig. 5 on the left. General heating system based on charcoal furnace produces heat and can maintain indoor ambient temperatures over 20°C (with an optimum temperature of 25°C), however during the winter season in Beijing, the indoor heating produced might be not good enough to keep piglets warm.

Fattening pens are divided into two parts, an indoor living area with concrete floor and an outdoor area for use during summer season (this does not apply to all the pig barns) as shown in Fig. 6. Outdoor area is provided with a gutter in order to drain the urine that is produced by the pigs (see also Fig. 3). Pens are filled with equal numbers of pigs, evenly distributed in order to promote balanced feed access to all the pigs, although as explained in the weaning barns, the adlib system does not always assure a distribution of balanced feed rations. However, despite of the adlib feeding system most of the fattening pigs are able to reach the marketable weight at similar times (100 kg) [14]. Registered mortality rates are about 15% (information from pig farm bookings).

Fig. 4 Gestation pen (left) and Farrowing crate (right)

Fig. 5 Pigs grouping (left) and slatted floor (right)

Fig. 6 Fattening barn outdoor (left) and indoor area (right)

Watering and Feeding

Water for drinking and servicing is pumped from ground water wells (30-40 m depth) [6]. Water tanks are distributed inside of the pig barns. Watering is adlib (unrestricted water access to satisfy durst) and supplied through a water-suckling system (easily learned by pigs however it produces lots of wastewater) [14]. In order to clean pig sites, cool pigs and dispose urine and manure rests over floors (see manure and wastewater below) approximately from 8 to 15 l of service water per pig a day is flushed [17].

The feeding regime is basically *adlib* (unrestricted feeding to satisfy appetite) [14]. Feeding follows a phase structure due to the change in nutrients requirements when pigs grow [13]. Feed consist of a mixture of commercial feedstuffs and formulation varies with the pig growing stage. Pig diets consist of corn, wheat, soybean meal, fish powder, compound premix and lysine. The pig farm buys complete diets as similar practiced in most of the farms in Netherlands [12]. Indeed, feed ingredients are obtained from local suppliers although fish powder or fishmeal is imported from Peru due to its high protein content (65%). Water is applied over sows' feed piles (known as wet meal) in order to avoid feed spills and easier the feed intake.

Diseases

Based on the bookings of the pig farm, the main diseases that affect the efficient pig production are, the classical swine fever, foot and mouth disease, blue ear disease, asthma, enteritis, diarrhea, atrophic rhinitis and, diseases caused by virus like the *Japanese encephalitis*, *parvovirus* and *pseudorabies* and the disease caused by the bacteria *haemophilus parasuis*. Main diseases are controlled by locally produced vaccines that are administered to the pigs via intramuscular with a frequency from 1 to 3 times a year.

Manure and wastewater

Pig manures (feces with some rests of urine) are collected by scraping the pigsites' floors twice a day. Later, the floors are flushed with water. This Chinese procedure is denominated gan qing fen or cleaning manure dryly [17]. The gan qing fen separation technique was introduced in China during the 1990s and is an efficient technique in order to separate the nutrients from manures instead of separating them by means of mechanical systems [38], [62]. Indeed, pig manures are characterized by high contents of dry matter and nutrients, i.e., ca. 28% dry matter, ca. 35 g/kg Total Nitrogen (TN), ca. 24 g/kg Phosphorus (P) and ca. 13 g/kg Potassium (K) between the most important (see Table VI).

In principle, the gan qing fen technique generates 2 separated fractions, i.e., solid and liquid fractions (see Fig. 7). Through the cleaning of manures dryly, solid manures area transferred to a store platform from where farmers utilize a part of this manure as crop and vegetable fertilizer in the adjacent small farmland [5]. Indeed, farmers do not spread liquid manures on the fields like is commonly practiced in western countries. Furthermore, a part of the manure is transported to the biogas plant in order to produce heat for cooking. Besides, some manure might be exported to the composting plant for organic compost production. Indeed, it is not possible to effectuate a simple export of manure nutrients [31].

Piggery wastewater (urine, flushing water, manure rests, feed spills) drains through the slatted floor (only found in farrowing and weaning barns) to a urine gutter, whereas in the gestation and fattening barns with solid concrete floors, wastewater flows through a lengthwise gutter as appreciated in Figs. 3 and 6. Piggery wastewaters are characterized by low TN (4 g/Kg), P, (0,43 g/Kg) and K (1,8 g/Kg) contents (results to be published) that indicates the dilution of pig urines with spilt drinking water and cleaning water as also found in an experiment in the Netherlands in which pig manures were collected under the slatted floor avoiding the contamination with urine and wastewaters [23].

Piggery wastewater and manures (only during winter) follow a biological process, anaerobic and aerobic generating two main byproducts, i.e., methane and irrigation water. Effectively, the gan qing fen technique based on the separation manure solids and liquid can offer advantages in terms of improved handling and management characteristics of the two fractions or sub-products [23]. The general procedure is shown as follows,

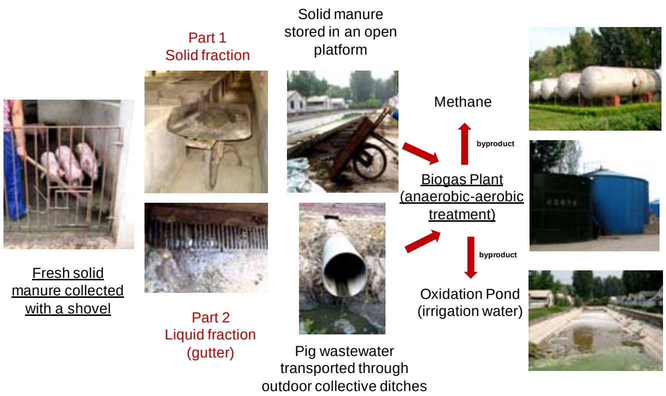

Fig. 7 Gan qing fen manure management system

B. *Manurial Composition*

Results based on the analysis of each pig growing stage

The summary of the descriptive statistics of nutrients and heavy metals obtained from the different types of manures in each pig growing stage, i.e. gestation, farrowing, weaning and fattening are presented in Table IV and V. The mean values of TN, AN, P and K were mainly not significantly different ($p < 0.05$) for gestation and farrowing manures suggesting that, samples were obtained from pregnant and lactating sows with very similar feed ratios and thus similar excretion parameters. It is also observed that there is no statistically significant difference ($p < 0.05$) between weaning and fattening TN, AN, P and K values. This can be explained by the fact that manure weaning samples were taken from weaners passing to next stage: fattening, thus manure components were very similar between the weaners in last stage (ca. 30 kg) and the fatteners (30 kg-100 kg) of this study. In effect, Tukey's test revealed the existence of two significantly different groups of manures, pig manures from sows in gestation and farrowing stage and manures from the weaning and fattening stages.

Pigs excrete most of the nutrients they consume [47]. In effect, sources cite that the N digestibility in sows, weaners and growing pigs is assumed to be 80%, 85% and 83% respectively [12]. In our study, on a dry matter basis, the mean value of TN was 35 g/kg, varying in a range from 27 g/kg for gestation manures to 42 g/kg for fattening manures. Similar results were reported for TN in manures originated from a large pig farm in China [64]. In effect, pigs less than 40 kg or fattening pigs in first stage showed pig manures with TN contents of 32 g/kg while pigs from 40 to 80 kg reported TN values of ca. 23 g/kg and pigs with more than 80 Kg reported manures with TN concentrations of ca. 19 g/kg.

The AN content over the TN content in every pig cycle represented the 14,5%, 14%, 17% and 18% for gestation, farrowing, weaning and fattening cycles respectively. Weaning and fattening manures showed the higher values which reflected the degree of mineralization of manures and consequently revealed the potential risk of ammonium losses to the atmosphere as stated by R. Moral *et al.*, 2005 [54] in a study of pig slurries from pits in Spain. Similar results were also found by Martinez-Suller *et al.*, 2008 during a study in livestock slurries from farms across Italy [44], and by Longjian *et al.*, 2009 during the evaluation of physicochemical models and equations for rapidly estimating pig manure nutrient contents [45].

On the other side, P mean values were notable higher for the group of gestation and farrowing sows, 30 g/kg and 31 g/kg respectively; than finisher and weaner pig manures, 15 g/kg and 20 g/kg respectively. A study performed in Denmark found that the utilization of P by fattening pigs, piglets (i.e., weaners), and sows was 36% and 14% respectively, leaving 65%, 61%, and 86% of the P intake excreted in the feces and urine [24]. Thus, it is shown that sows had the lowest P intake and hence the highest P excretion patterns. This finding is also observed in our results where the manures from farrowing sows presented the highest contents of P among the rest of the samples. Additionally, scientific studies report that feeding strategies by growing stage (phase feeding in this study) and the improvement of P digestibility by phytase supplemented feeds can reduce P excretion in manures [4]. Furthermore, ca. 90% of the K supplemented in the pig ratios was excreted in the feces and urine [11]. Indeed, the highest K content was found in fattening manures (13 g/kg). The K values were similar to those reported by Jiang Lian *et al.*, 2004 [42]. For instance, for pigs with a weight less than 40 kg or fattening pigs in first stage, he reported pig manures with P contents of 19 g/kg, while for pigs with a average weight from 40 to 80 kg he reported K values of ca. 14 g/kg and, for pigs with a body mass over 80 Kg he reported manures with K concentrations of ca. 19 g/kg.

Ca was found to be highest in farrowing manures (54 g/kg), fact that is related to the needs of lactating sows to produce milk and thus to the high supplementation of Ca in their feed ratios. Likewise, manipulation of the sow's diet during breeding, gestation, and lactation is effected in order to increase available lactose in the milk for piglets [48].

For aims of improving feed efficiency, animal health (minimize disease outbreaks) and grow promoting properties feed additives are added at low concentrations within the pig diets [2], [25]. Heavy metals found in manures depend basically on their concentrations in feed rations that vary with the pig growing stage (multiphase feeding) [29]. On a dry matter basis, Mn, Zn, Cu, Cd, Pb and Cr contents were clearly higher for weaning pigs. Menzi *et al.*, 1998 noted in a study that there was a close dependence between the heavy metals contents in feeds and in excreted manures [25]. As expected, heavy metals in the weaner diets (results to be published) were found to be closely linked to the high contents of heavy metals in the pig manure. Further, high values of Cu were observed in the group of weaning and fattening manures, 171 g/kg and

149 g/kg respectively. Zn values were higher for farrowing and weaning manures, 313 g/kg and 595 g/kg respectively. Cu and Zn supplementation in pig feeds is practiced in order to achieve an antimicrobial effect, i.e., against diarrhea as well as to influence on pig growth [48], [61]. Zn and Cu amounts added to pig feeds can usually be found until 20 times more over the normal feed requirement, usual procedure effected in order to improve the performance of weaning pigs [13]. In fact, highest concentrations of Zn and Cu are rather found in pig manures than in other animal manures [49]. A study that compared the Cu concentrations in pig manures of Beijing and Fuxin during the years 1999 and 2005 revealed that Cu concentrations in pig rations have been increased due to the abusive addition of Cu supplements into the pig ratios due to the financial capacity of large pig farms that may let the farmers to easily afford feed additives [64]. For instance, Cu concentrations in pig manures during 2005 in Beijing were of 1112 g/kg for weaners, 888 g/kg for grower-finisher pigs and of 255 g/kg for sows. The values were more than 10 times higher than the results found in this study that might indicate that the pig farm under study does not overuse Cu as feed additives in the pig farm or it can be implied that the mentioned farms in Beijing during 2005 overused additives making our results to seem too low.

Although the practice of high supplementation (high safety ranges) of Zn and Cu is done in order to improve pig productivity, it is found in the literature that dietary excesses of Zn (2000 mg/Kg) and Cu (300-500 mg/Kg) could on the contrary generate growth depression [61].

On the other side, the lowest Mn, Zn, Cu, Cd, Pb and Cr mean values were found in the gestation manures. The concentrations of heavy metals in the pig solid manures can be ranked in the following order: Zn> Cu> Mn> Cr> Pb> Cd.

For all the heavy metals studied, the range between the highest and the lowest value was considerable and this is due that exceptionally high values were responsible for the wide range that is related to the high inputs in the pig feeds. Especially, for weaners, the Zn, Cu and Mn mean content in weaner feeds surpassed the allowed amounts of feed compounds given by the GB 8471-87 “Feeding Standard for lean-type pigs” [46] (results to be published) that suggests, maximum Zn, Cu, Mn contents of 110; 4,36 and 2,18 mg/kg respectively. Nevertheless, a fraction of heavy metals found in manures might be the result of the possible contamination of manures with foreign bodies such as soil rests found in the pigsites’ floors as observed in this study during the manure collection and handling.

Results based on the analysis of aggregated data and literature review

The data compiled in the Tables VI, VII and VIII was assured to proceed from pig solid manures and not from liquid manures. Indeed, it clear indicated that, for instance, the TN value (35 g/kg) of our aggregated pig manures was distributed within the literature data range from 4 g/kg to 109 g/kg. However, compared to the values cited from the different authors the results of this study were generally higher than those reported in the European countries (Table VI) and this may be due to the high nutrients supplementation in the pig feed rations of the farm under study, that is reflected in the manure basically due to two reasons, (i) extremely high safety margins practiced by the Chinese farmers and (ii) avoidable unequal feeding access to pigs (see section feeding and watering) in comparison with European countries with improving housing systems where pigs feed ratios can be automatically adjusted-controlled in order to achieve efficient pig performance reducing feed wastage and likewise improving the accurately supply of the nutritional needs of pigs at different stages of growth (thus the excretion of nutrients can be reduced) [29] by means of mechanical feeders as usually practiced in pig farms of the Netherlands, which use a multi-phase feeding system similar to the farm of the present study [12].

Further, K and P concentrations were found to be closer to the data found in the Asian literature (Table VII), which may be due to the similarity in the manure and husbandry management systems practiced in Asian countries than in other continents. However, in contrast to the literature review from the rest of the world (Table VIII), the mean values of the pig manure elements obtained in this study were quite similar to the values found in 1978 in an extensive study performed in 24 piggeries in Victoria, Australia [15] which may be related to the fact that those results reported were strictly originated from pig feces samples as also were analyzed in this investigation.

In general, the heavy metal contents of the aggregated pig manures agreed with those reported in the literature. Considering that feeding formulations vary within the countries, both Zn and Cu contents were found to be the highest among the rest of the manure components.

The great variability between the data obtained from the literature might be result of the clear differences between husbandry management systems among the countries that is observed in the diverse values of nutrients and heavy contents found in the pig manures, as also noted by Zhu *et al.*, 2003 when trying to define a coefficient of determination, R^2, between TN and P values in order to measure gestation slurry nutrient contents by means of a soil hydrometer and regression equations [34]. In effect, the values showed in the Tables VI and VII vary considerably specially when comparing the Chinese and European compositions. This is due to the production technique in the Chinese pig husbandry system, specifically, the gan qing fen manure management technique, the use of Chinese local feedstuffs including some vegetables such as carrots (as observed during some pig farm’s visits), pig rations, animal breeds and hot climate. This variability is indeed not only observed within China but also has been observed across European farms [26]. Last but not least, some authors term solid manure (including urine) instead of liquid manure making difficult the reliable comparison of data [26]. However, in this study, the data of the Tables VI, VII and VIII proceeds from pig solid manures samples and not from liquid manures or slurries that is out of comparison with our results. Thus, this quotation should be taken into consideration for similar further research.

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TABLE IV
DESCRIPTION OF NUTRIENTS AND HEAVY METALS (WET BASIS OR AS SAMPLED) FOUND IN THE DIFFERENT PIG MANURES

Element	Gestation	Farrowing	Weaning	Fattening
Total nitrogen (TN), g/kg	6,26-8,91 (7,93 ± 0,70) [a]	7,48-16,07 (9,98 ± 2,62) [a]	6,08-16,48 (12,33 ± 3,18) [b]	9,46-12,37 (10,71 ± 0,92) [b]
Ammomium nitrogen (AN), g/kg	1,08-2,53 (1,46 ± 0,41) [a]	0,84-2,76 (1,59 ± 0,71) [a]	1,44-3,15 (1,99 ± 0,56) [b]	0,89-3,15 (1,93 ± 0,63) [b]
Potassium (K), g/kg	2,75-4,06 (3,22 ± 0,36) [ab]	2,42-4,75 (3,42 ± 0,80) [ab]	2,85-6,76 (4,76 ± 1,19) [c]	2,77-3,76 (3,16 ± 0,33) [b]
Phosphorus (P), g/kg	6,58-10,48 (8,59 ± 1,10) [a]	4,64-12,60 (9,27 ± 2,74) [a]	3,84-6,08 (5,36 ± 0,73) [b]	3,44-4,42 (3,89 ± 0,30) [b]
Calcium (Ca), g/kg	12,45-17,33 (14,70 ± 1,61) [a]	9,93-21,04 (16,43 ± 4,09) [a]	7,31-11,61 (9,20 ± 1,20) [b]	5,38-8,46 (6,82 ± 1,20) [b]
Manganese (Mn), mg/kg	14,59-19,45 (16,46 ± 1,56) [a]	12,88-28,68 (19,48 ± 5,17) [ab]	18,28-32,95 (24,43 ± 5,17) [c]	15,58-21,31 (18,07 ± 1,80) [b]
Zinc (Zn), mg/kg	20,18-30,01 (25,22 ± 3,02) [ac]	23,17-350,12 (93,50 ± 130,68) [abc]	20,89-352,47 (169,33 ± 127,01) [b]	22,68-29,42 (24,91 ± 2,23) [c]
Copper (Cu), mg/kg	3,83-5,88 (4,91 ± 0,66) [a]	4,42-55,80 (15,72 ± 20,66) [a]	33,84-62,74 (47,06 ± 10,18) [b]	30,55-48,74 (37,77 ± 5,65) [b]
Cadmium (Cd), mg/kg	0,04-0,12 (0,08 ± 0,03) [ab]	0,10-0,39 (0,19 ± 0,10) [ac]	0,07-0,76 (0,34 ± 0,24) [d]	0,05-0,25 (0,08 ± 0,05) [bc]
Lead (Pb), mg/kg	0,00-0,24 (0,08 ± 0,08) [ab]	0,00-3,47 (0,71 ± 1,37) [ac]	0,49-3,67 (2,04 ± 1,17) [d]	0,54-0,87 (0,68 ± 0,10) [bc]
Chromium (Cr), mg/kg	1,39-4,90 (2,44 ± 1,07) [ab]	1,21-6,72 (2,54 ± 1,67) [ac]	1,59-10,35 (4,29 ± 2,17) [d]	1,24-10,84 (2,27 ± 2,39) [bcd]

n=20, values in parentheses are mean ± SD. Means followed by different lower case letters (a,b,c,d) are significantly different from each other by the Tukey Test ($p < 0,05$).

TABLE V
DESCRIPTION OF NUTRIENTS AND HEAVY METALS (DRY BASIS, CA. 28%) FOUND IN THE DIFFERENT PIG MANURES

Element	Gestation	Farrowing	Weaning	Fattening
Total nitrogen (TN), g/kg	22,20-29,87 (27,08 ± 2,61) [a]	21,21-45,56 (29,87 ± 8,47) [a]	18,94-52,91 (41,33 ± 10,89) [b]	35,80-46,80 (41,48 ± 3,60) [b]
Ammomium nitrogen (AN), g/kg	3,63-10,05 (5,38 ± 1,84) [a]	2,38-9,29 (4,68 ± 2,44) [a]	5,97-11,49 (7,95 ± 1,97) [b]	3,73-12,04 (7,88 ± 2,57) [b]
Potassium (K), g/kg	9,09-12,94 (11,05 ± 1,19) [ab]	6,87-16,24 (11,40 ± 2,76) [ab]	11,87-23,80 (17,33 ± 4,14) [c]	10,62-15,69 (12,45 ± 1,50) [b]
Phosphorus (P), g/kg	21,72-39,24 (29,60 ± 4,78) [a]	14,98-41,13 (30,53 ± 7,92) [a]	15,99-22,30 (19,51 ± 1,89) [b]	12,89-17,60 (15,32 ± 1,59) [b]
Calcium (Ca), g/kg	38,96-63,79 (50,72 ± 7,71) [a]	33,25-68,68 (54,26 ± 12,07) [a]	30,31-38,19 (33,45 ± 2,51) [b]	20,56-33,44 (26,88 ± 4,49) [b]
Manganese (Mn), mg/kg	49,28-63,43 (56,48 ± 4,80) [a]	49,16-69,41 (64,54 ± 16,91) [ab]	72,55-109,11 (88,37 ± 13,23) [c]	59,22-84,25 (71,13 ± 8,66) [b]
Zinc (Zn), mg/kg	75,71-96,67 (86,18 ± 6,08) [ac]	88,41-1174,65 (313,03 ± 441,57) [abc]	79,60-1097,27 (595,24 ± 422,79) [b]	84,99-117,22 (98,03 ± 10,91) [c]
Copper (Cu), mg/kg	14,44-19,77 (16,76 ± 1,51) [a]	15,44-189,80 (52,70 ± 69,81) [a]	123,50-209,46 (170,57 ± 28,23) [b]	114,69-192,71 (148,78 ± 25,02) [b]
Cadmium (Cd), mg/kg	0,14-0,42 (0,28 ± 0,08) [ab]	0,38-1,32 (0,62 ± 0,34) [ac]	0,28-2,38 (1,18 ± 0,77) [d]	0,18-0,98 (0,31 ± 0,19) [bc]
Lead (Pb), mg/kg	0,00-0,93 (0,29 ± 0,31) [ab]	0,00-11,50 (2,42 ± 4,60) [ac]	2,00-11,75 (7,20 ± 3,75) [d]	1,99-3,33 (2,66 ± 0,41) [bc]
Chromium (Cr), mg/kg	4,43-16,22 (8,39 ± 3,68) [ab]	4,63-22,25 (8,43 ± 5,61) [ac]	6,42-36,01 (15,42 ± 7,26) [d]	4,73-42,76 (8,94 ± 9,43) [bcd]

n=20, values in parentheses are mean ± SD. Means followed by different lowercase letters (a,b,c,d) are significantly different from each other by the Tukey Test ($p < 0,05$).

TABLE VI
PIG MANURE COMPOSITION (DRY BASIS) IN THE EUROPEAN LITERATURE. PART I

Component	Mean value This study	Germany [a] (2007)	Belgium [b] (2005)	Germany [c] (2004)	Austria [d] (2004)	Germany [e] (2002)	Denmark [f] (2002)	UK [g] (1999)
TN, g/kg	35,06	-	7,35	-	-	-	4,20	-
AN, g/kg	16,71	-	5,01	-	-	-	3,60	-
K, g/kg	13,06	-	4,96	-	-	-	3,20	-
P, g/kg	23,74	-	3,53	-	-	-	1,26	-
Ca, g/kg	41,33	-	3,36	-	-	-	-	-
Mn, mg/kg	70,13	-	-	-	-	-	-	-
Zn, mg/kg	273,12	491,00	-	1220,00	733,00	1196,67	-	431,00
Cu, mg/kg	97,20	213,00	-	740,00	276,00	663,17	-	374,00
Cd, mg/kg	0,60	0,36	-	0,43	0,49	0,42	-	0,37
Pb, mg/kg	3,14	1,90	-	-	8,70	2,80	-	2,94
Cr, mg/kg	10,29	12,30	-	11,00	10,50	-	-	1,98

-: no data available, [a] [59]; [b] [60]; [c,d] [16]; [e] [7]; [f] [27]; [g] [8].

TABLE VII
PIG MANURE COMPOSITION (DRY BASIS) IN THE ASIAN LITERATURE. PART II

Element	Mean value This study	Japan [a] (2006)	China[b] (2004)	China [c] (2004)	China [d] (2003)	China [e] (2001)	Japan [f] (2001)	China [g] (1990)
TN, g/kg	35,06	46,00	24,60	-	-	24,20	-	-
AN, g/kg	16,71	-	-	-	-	-	-	-
K, g/kg	13,06	-	17,24	-	-	16,50	-	-
P, g/kg	23,74	-	11,25	-	-	39,00	-	-
Ca, g/kg	41,33	-	-	-	-	38,60	-	-
Mn, mg/kg	70,13	-	-	133,64	-	560,00	2100,00	-
Zn, mg/kg	273,12	1225,00	-	144,17	843,30	819,00	2900,00	137,20
Cu, mg/kg	97,20	528,00	-	105,36	472,60	97,00	1000,00	37,60
Cd, mg/kg	0,60	-	-	0,57	4,80	-	-	0,86
Pb, mg/kg	3,14	-	-	10,68	10,10	-	-	13,20
Cr, mg/kg	10,29	-	-	25,71	46,60	-	-	10,60

-: no data available, [a] [57]; [b] [42]; [c] [40]; [d,g] [43]; [e] [53]; [f] [51].

TABLE VIII
PIG MANURE COMPOSITION (DRY BASIS) IN THE REST OF THE WORLD LITERATURE. PART III

Element	Mean value This study	Canada [a] (2008)	USA [b] (2008)	USA [c] (2004)	Brazil [d] (1996)	USA [e] (1993)	USA [g] (1982)	Australia [g] (1978)
TN, g/kg	35,06	5,62	38,23	108,80	-	-	-	30,40
AN, g/kg	16,71	-	-	62,60	-	-	-	-
K, g/kg	13,06	1,52	-	-	-	-	-	9,70
P, g/kg	23,74	1,28	11,05	33,60	-	-	-	25,90
Ca, g/kg	41,33	-	-	-	869,00	171,00	197,00	-
Mn, mg/kg	70,13	-	-	-	1440,00	278,00	-	600,00
Zn, mg/kg	273,12	-	-	-	1338,00	45,00	1279,00	280,00
Cu, mg/kg	97,20	-	22,17	-	-	36,10	-	35,10
Cd, mg/kg	0,60	-	-	-	0,25	-	-	0,77
Pb, mg/kg	3,14	-	-	-	14,00	-	-	9,89
Cr, mg/kg	10,29	-	-	-	33,00	-	-	-

-: no data available, [a] [32]; [b] [39]; [c] [9]; [d,f] [51]; [e] [49]; [g] [15].

IV. CONCLUSION

Intensive pig production in the Chinese pig farm is characterized by foreign pig breeds due to their high lean meat ratios. Pigs are either individually confined or grouped depending on their growing stage. Pig diseases are identified and controlled. Manure and wastewater disposal are basically done under the gan qing fen technique, meaning the manual separation of feces and urine.

The study of nutrients and heavy metals in the pig manures show a significant variation when fractioning the analysis in each production cycle. Nutrients such as N, P and K are important indicators of the pig performance, of external conditions and local management practices affecting the feed intake and nutrients assimilation of pigs. Likewise, heavy metals concentrations in pig manures might be result of possible imbalanced feed ratios supplemented in the pig diets. The results obtained from the analysis of nutrients and heavy metals in the pig manures agree with those results found in the international literature review. Further studies in aggregated and disaggregated data of pig manures should be performed in order to offer more scientific platform for comparisons. Likewise, additional research is required on the potential effects of the gan qing fen manures on air pollution, on their application as organic fertilizer and thus their impact on crops, water and groundwater sources.

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