Patterns of dairy manure management in China

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Abstract: The dairy industry in China is rapidly developing, particularly in terms of the upscaling of dairy farms. However, nutrient-rich manure brings challenges to the sustainability of the dairy industry. This study investigated and reviewed the patterns of dairy manure management in China, and the results indicate that dairy manure could be used as an organic fertilizer because of its high organic nutrient content and low metal content. However, legislation prohibits the application of untreated (raw) dairy manure. An existing technology for handling animal slurry is the separation into a liquid and a solid manure fraction. The solid fraction can be used as compost and bedding materials, and it has limited environmental risk. However, the emissions from the storage of liquid manure need further attention. The cycle of manure production, collection, transportation, separation and storage can only be closed if the nutrients are eventually applied to grass and arable land according to crop needs. Therefore, distribution of knowledge on nutrient levels, crop needs and nutrient management plans, supported by legislation on maximum application standards, is needed. In this way, an environmentally friendly development of dairy manure management might be possible.

Keywords: dairy manure, manure handling pattern, legislation, nutrient recycling, emissions

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1 Introduction

Livestock production in China is rapidly developing, and as a consequence, livestock manure as a product has been significantly increasing. The total amount of livestock manure was 3.1×10^9 t in 2003 and this is predicted to increase to 4.2×10^9 t by 2020[1]. The sustainable development of the livestock sector therefore needs an environmentally friendly management of manure that will recycle nutrients and reclaim bio-energy. The dairy farming industry in China is experiencing a boom, with an estimated 15 million cows in 2012 compared with only 6.88 million cows in 2002[2]. In recent years, technological improvements have encouraged the upscaling and intensified development of dairy farms. Large-scale farms of more than 100 cows accounted for 45% of the total number of dairy farms[2], and figures from the China Dairy Yearbook 2013 indicated that there were approximately 60 individual farms each with over 10 000 cows. However, pollutant discharge and emissions from this livestock sector

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contribute to the deterioration of groundwater and air quality. To reduce the negative environmental effects, dairy manure should be recycled into the soil as nutrients. In recent years, China has experienced severe air pollution, and it is the world's largest ammonia emitter[3]. Ammonia emissions significantly contribute to the formation of $PM_{2.5}$, and the emission from livestock manure is the largest source of ammonia, accounting for 40% of total emissions[4].

Pollution and emissions on dairy farms are the bottleneck for the rapid and sustainable development of the dairy industry. Optimization of manure management is needed to reduce the negative effects on the environment. Furthermore, recycling manure into soil reduces the 20% share of the total ammonia emissions from chemical nitrogen fertilizers. With the rapid growth of the dairy industry, poor manure management is a setback to the industry's development. The government, technicians and scholars have focused their attention on how to promote the sustainable development of the dairy industry. Currently, dairy manure is managed as a source of pollutant instead of its alternative use as a recyclable organic fertilizer. The utilization of manure fertilizer remains uncertain under current manure legislation, and previous research on manure management has focused on the introduction of methods used internationally, or is limited to a certain administered region[5-7].

This research aims to describe and discuss the current patterns of dairy manure management in China, as well as to identify potential improvements in the recycling of manure nutrients with regards to agricultural land, and the environmentally friendly manure handling process.

2 Materials and methods

2.1 Manure management legislation review

Since 2001, a multitude of legislation has been implemented to reduce the negative environmental effects of the livestock industry in China[8]. The national legislation is entitled 'Discharge standard of pollutants for livestock and poultry breeding'. The code for the legislation begins with 'GB' and the code for local documents starts with 'DB'. In 2014, a new national legislation on pollution control for large-scale livestock farms was issued for the development of an environmental effect assessment plan and the construction of facilities for pollution prevention and control.

2.2 Field investigations

Field investigations were conducted to study the current patterns of the manure handling process in China. Four farms were selected for analysis and information collection on different manure treatment processes. The nutrient content, metals and solid/liquid separation of the four dairy manure farms were analyzed. In this research, the four farms discussed are marked Farms A, B, C and D, and detailed information about them is provided in Table 1.

Total solid (TS), volatile solid (VS), suspended solid (SS), volatile suspended solid (VSS), chemical oxygen demand (COD), nitrogen, and total phosphorus (TP) were measured following the standard methods of the American Public Health Association[9]. Metals were analyzed by an inductively coupled plasma mass spectrometer (ICP-MS, Agilent Technologies HP4500) with a detection limit of parts per trillion.

Table 1 Basic information of the four dairy farms

Farm	Location	Total cows	Milking cows
Farm A	Hebei Province	12 000	8500
Farm B	Shanxi Province	4300	2500
Farm C	Beijing	3600	2300
Farm D	Beijing	2300	1700

2.3 Manure management questionnaire survey

In 2015, a questionnaire survey on manure management was conducted and supported by the Sino-Dutch Dairy Development Centre (SDDDC). A total of 205 questionnaires were recovered and 189 complete questionnaires were statistically analyzed. The recovery rate is 92.20%. The questionnaire included the collection of manure from the cowshed, the separation facilities, and the solid fraction treatment and disposal. The 'Parameter of Basic Management' was related to manure management. In terms of the manure collection pattern, the respondents could choose between 'automatically', 'manually' and 'manually + automatically'. Automatic refers to automatic collection with water cleaning, whereas manual refers to cleaning by workers.

3 Results and discussion

3.1 Manure management legislations

In China, manure is managed mainly to address environmental pollution and not as a source of nutrients. As defined by the national standard 'Organic Fertilizer' NY525-2012, without controlled composting treatment, manure is not considered organic fertilizer, or if it fails to meet the specific standard. Thus, the legislation on manure treatment and handling is normally issued by the Ministry of Environment. According to the National Standard for Manure Treatment, parameters, such as biological oxygen demand (BOD), COD, SS, ammonium, TP, faecal coliforms, ova of roundworm, and odour, need to be regulated. The values of these parameters are listed in Table 2. Clearly, the national legislation aims to prevent manure pollution in water systems. In China, the targets of pollution discharge include BOD_5, COD, SS, NH_3-N and TP[10]. The current study reviewed the serials of regulations (2001-2016), and the land application of dairy manure was not specifically issued. Thus, manure cannot be used as 'fertilizer' in China although farms do use it to improve soil quality and add nutrients.

Table 2 Discharge standards of pollutants for livestock and poultry breeding

	National Standard	Local standard					
	GB18596-2001	DB37534-2005 Shandong Province			DB33/593-2005 Zhejiang Province	DB44613-2009 Guangdong Province	
	2001-	2005.5-2007.4	2007.5-2010.4	2010.5.1-	2005-	2009-	
BOD_5/mg·L^{-1}	150	140	100	60	140	140*	150
COD/mg·L^{-1}	400	380	250	120	380	380*	400
SS/mg·L^{-1}	200	160	120	70	160	160*	200
NH_4^+-N/mg·L^{-1}	80	70	50	25	70	70*	80
TP/mg·L^{-1}	8	8	7	5	7	7*	8
fecal coliforms/unit·L^{-1}	1000	10000	10000	10000	10000	10000*	10000
ova of roundworm/mg·L^{-1}	2	2	2	2	2	2*	2
Odor	70	70	70	70	60	0	60

Note: *: standards for pearl river delta in Guangdong province.

The national standard shows that some provinces have legislations on manure discharge, and the local standard is typically stricter than the national standard. Liquid manure after long-term storage or the digestate from anaerobic digestion of manure is not easily degraded to meet the discharge standard. In the Netherlands, untreated manure is used as organic fertilizer and the standards on the amount of manure nutrients in land application are strict. Liquid manure does not need high-cost biological treatment, but outside the growing season for crops, long-term and closed storage is required and transportation and the amount of manure fertilizer is strictly monitored. The prevention of manure emissions and the respect of nutrient application standards for nitrogen and phosphorus during the handling and land application is the core of manure management in the Netherlands. In China, the environmental quality of dairy farms is also under government administration, but the focus is on the discharge. Table 3 summarizes some regulations about manure handling. Since 2001, several regulations about the management of manure have been implemented. Documents were issued from different government departments, and the standards for manure utilization grew tighter. In regions of Europe where large densities of animals exist (e.g. parts of the Netherlands, France, Spain and Italy), the European Union and national governments issued numerous regulations to reduce the negative effect of manure pollution. Some states of the USA (e.g., North Carolina, Iowa and Minnesota) are in a similar situation.

The manure policy in the Netherlands since the 1980s focuses on the reduction of ammonia emission and protection of the groundwater and surface water quality with respect to nitrogen and phosphorus, whereas Chinese policy focuses more on the reduction of microbiological risks. The system of application standards is the cornerstone of the Dutch manure policy, which aims to reduce the negative environmental effects from the application of animal manure and synthetic fertilizer on agricultural land and protect the quality of groundwater and surface water nitrogen has two application standards on agricultural land. The first application standard is for nitrogen from animal manure: a maximum of 170 kg-N/hm^2/a. The second application standard is for the total nitrogen (nitrogen from animal manure and nitrogen from synthetic N-fertilizer): maximum 385 kg-N/hm^2/a, depending on crop nitrogen uptake[11]. In terms of application standards for phosphate (P_2O_5), the phosphate content of a fertilizer equals the phosphorus content multiplied by 2.29 (P_2O_5 = P×2.29). The application standards for phosphate (P_2O_5) depend on the soil phosphate level and vary between 50 and 100 kg/hm^2/a (50-75 kg/hm^2/a for arable land and 80-100 kg/hm^2/a for grassland). No distinction is made between phosphate from animal manure and phosphate from synthetic fertilizer, given that phosphate cannot be lost by volatilization. Without soil analysis which justifies a higher dose of phosphate, only the lowest application standards are allowed (in this case, 50 kg/hm^2/a for arable land and 80 kg/hm^2/a for grassland).

Table 3 Some environment regulations relevant to livestock production

Regulation	Year	Document catalogue	Administration department
Administration Method on Pollution Prevention for Livestock Production	2001	No.9 policy paper	NEPA
Technical Standard of Polltion Prevention For Livestock Production	2001	HJ/T81-2001	NEPA
Discharge Standard of Pollution for Livestock Production	2001	GB18596-2001	NEPA and GAQSIQ
Critira fo Evaluating Environmental Quality of Livestock Farms	2004	CB/T 19525.2-2004	GAQSIQ and SAC
Technichal Standard for Non-hazardous Treatment of Animal manure	2006	NY/T1168-2006	MoA
Technical Specification for Pollution Treatment Projects of Livestock Farms	2009	HJ497-2009	MoA
Technical Guidelines for Agricultural Solid Wastes Pollution Control	2010	HJ588-2010	MoA
Techinical Policy of Pollution Prevention forLivestock Production	2010	NO.151 policy paper	MoEP
The planning of Pollution Prevention for Livestock Production fro '12th five-year'	2012	/	MoEP
Discharge Standard of Pollution for Livestock Production（Second version）	2014	GB18596-2001	NEPA and AQSIQ

Note: NEPA: National Environmental Protection Administration; GAQSIQ: General Administration of Quality Supervision, Inspection and Quarantine of China; SAC: Standardization administration of China; MoA: Ministry of Agricultue; '/': data not available.

3.2 Manure handling on field visited farms

(1) Farm A—with an anaerobic digestion pattern (ADP)

On Farm A, manure was periodically collected from the cowshed by tracks and then stored in the intermediate storage tank at the end of the cowshed. A faecal suction truck transported the manure from the tank to the anaerobic digestion plant inside the dairy farm. A plug flow mesophilic anaerobic digestion process degraded the manure and produced biogas, and the biogas was, subsequently, used to generate electricity and provide heating for the farm. The anaerobic digestion effluent was separated using a screw separator, and the solid fraction was further dried using a mechanical device. The treated solid manure was naturally dried by a composting, and this is used for two purposes: organic fertilizer and bedding materials in cowsheds and in outside yards. The separated liquid from the anaerobic unit was kept in a long-term and open storage facility until the fertilizer season. This farm was located in a grassland which provided capacity to receive the manure. The transportation of the solid and the liquid manure did not require a high cost input, and the entire manure handling process on Farm A is illustrated in Figure 1. In China dairy farm, the anaerobic digestion was not very popular. But with the fast development of big size dairy farm, the anaerobic digestion technology will be choose as a suitable method to recovery the bioenergy and to reduce the dry matter of dairy manure.

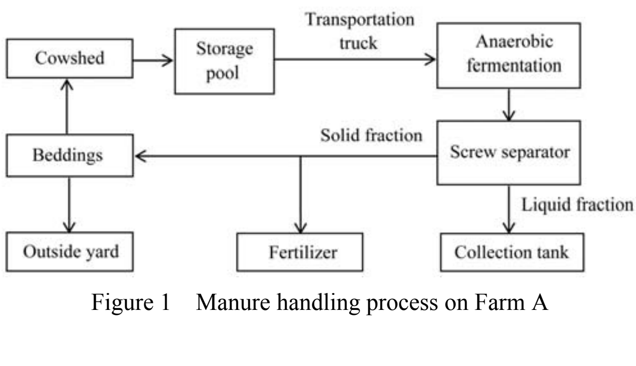


Figure 1 Manure handling process on Farm A

(2) Farm B—with a closed collection system and composting pattern (CCCP)

On Farm B, the manure was collected from the cowshed and then separated using a screw separator, a system which was similar to Farm A. The manure separation resulted in a liquid fraction and a solid fraction with a higher dry matter content. The solid fraction of the manure was then treated by a composting unit under controlled conditions using a machinery aerator, a composting process control and a second composting unit. The brown solid manure was a good organic fertilizer for agricultural application. After long-term storage in a solar greenhouse room, the matured compost was sold at a marked business price. The liquid fraction of the separated manure was piped into an open storage facility for storage of approximately six months. The storage bottom was made from impervious material.

(3) Farm C—with a covered lagoon and separation pattern (CLSP)

On Farm C, an automatic scraper was used to clean the floor and collect manure in the cowshed. The collected manure was then dropped into an underground ditch, where the manure was flushed into a buffer tank and then separated by a screw separator. After the separation, the solid fraction was transported to a composting plant, which was responsible for its final disposal and use as a commercial organic fertilizer. Some of the compost was used as cow bedding materials, but it was mostly used as organic fertilizer. The liquid manure from the separator was returned to the cowshed and flushed into an underground ditch. The excess liquid manure was piped into a covered lagoon for about six months between fertilizer seasons. The biogas produced in the lagoon was collected and safely treated, and the covered lagoon prevented ammonia gas emission. After long-term storage, the liquid manure was used for land application as organic fertilizer. The manure handling process was mostly in a closed system, and odour emission was prevented. A covered lagoon for liquid manure storage requires a high cost input and is not extensively used on farms in China but open manure storage should be prevented due to ammonia, odour and methane emission. The manure handling process on Farms B and C is illustrated in Figure 2.

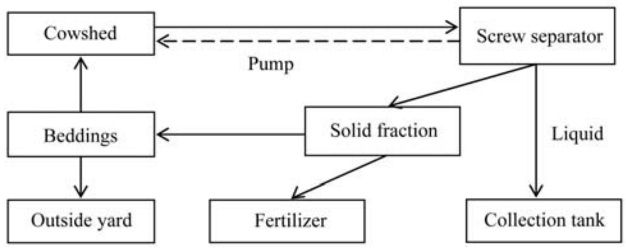


Figure 2 Manure process on Farms B and C

(4) Farm D—with bio-drying and open storage pattern (DSP)

On Farm D, the manure was first collected by a tractor mounted scraper and then kept in an outdoor intermediate manure collection basin. The manure was transported by a truck to a manure buffer tank, where the manure was diluted by the liquid for piping into the screw separator. After the separation, the solid fraction was naturally dried by biological activity. Some of the dried manure was used as bedding materials in the cubicles. The rest of manure was treated as waste due to the presence of sand. The liquid fraction of the manure was piped into two open storage tanks for long-term storage. The storage bottom was impermeable, thereby preventing groundwater pollution.

(5) Summary of current patterns

Each farm had its own manure handling system, i.e. ADP, CCCP, CLSP and DSP. All the four farms are medium and large in size (1700-8500 milking cows per farm, Table 1), and the solid/liquid separation was used as the first step of the treatment. For the manure collection, both semi-automatic tractor mounted scrapers and automatic scrapers were used. Farms B and D are newer than Farms A and C.

Communication with the farm owners revealed that manure collection via automatic scrapers is useful and easy. The farms under investigation mostly used scrapers to reduce labor and increase the removal efficiency of manure. Moreover, the scraper was used with an underground manure piping system. The manure was transported in a closed system, and the emissions were significantly reduced. On the four farms, only one farm used a covered lagoon for long-term liquid manure storage.

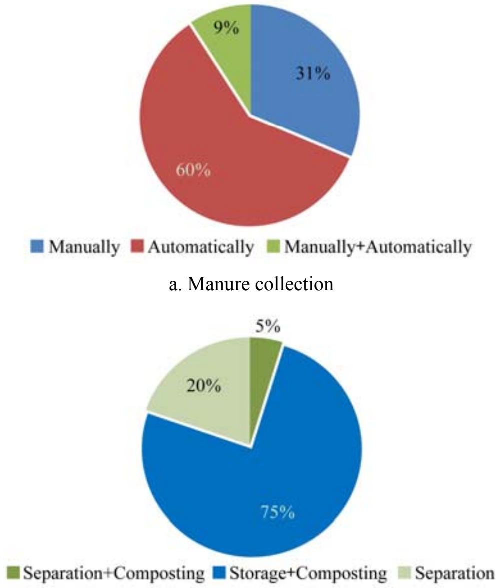
The manure storage is a major source of ammonia emissions, and widely used open storage is not recommended for new plants[12]. The ammonia lost in storage also lowers the value of manure as a nitrogen fertilizer. Manure storage covers are generally placed over liquid storage units to provide a physical barrier between the liquid manure surface and the atmosphere. Manure storage covers are classified as impermeable and permeable. Impermeable covers can reduce ammonia emissions between 85% and 99%[13], but are expensive and require more management. The capital cost of impermeable and permeable covers are \$1.08-3.76 per m^2 and \$0.32-1.08 per m^2, respectively[14]. Straw can be used as an alternative cover. The effectiveness of straw covers in reducing NH_3 emissions ranges were between 37% and 90%[15].

Natural drying and controlled manure composting are common methods for treating solid manure. Dried manure can be used as bedding materials in cowsheds or outdoor outside yards, but manure cannot be used if the sand in the bedding is collected as a mixture. Material obtained from the separation of slurry has been used as bedding for dairy cows in dry climates in the US since the 1970s[16,17]. In the UK, the Department for Environment, Food, and Rural Affairs and the Scottish Office has allowed the use of this bedding under controlled conditions. Meanwhile, Wales and Northern Ireland prohibit this practice due to the microbiological risks from manure[18]. The most important consideration with regard to biological safety is that the manure must not originate from other dairy farms. Also in China, recycled solid fraction of manure is commonly used as bedding materials. In terms of chemical pollutants, no control standard is implemented for heavy metal in recycled beddings. In the US Environmental Protection Agency Toxic Equivalent Levels, Hg should be less than 0.09 mg/kg, Pb should be less than 0.2 mg/kg, and Cd should be less than 0.01 mg/kg. As for microbial content, the total amount of mould should be less than 5×10^4 colony-forming units and *Escherichia coli* should be less than 5×10^2 colony-forming units in pasteurized beddings[19].

In the Netherlands, untreated manure can be used on agricultural land without any restrictions with regard to microbiological status, except for a mandatory waiting period between manure application and the harvesting of crops, fruits and vegetables.

3.3 Solid/liquid separation in 195 questionnaires

Based on the 195 questionnaires, 116 farms use automatic manure collection (both automatic and tractor mounted scrapers). The results of the manure separation and treatment are shown in Figure 3.



a. Manure collection

b. Manure treatment

Figure 3 Findings from questionnaires research

Labor is used to collect manure on a total of 61 farms, generally those of smaller size. A total of 18 farms use mixed-collection patterns, wherein the manure needs to be cleaned from the cowshed. As mentioned earlier, the solid/liquid separation is the first step in manure treatment. The high separation efficiency will significantly reduce the amount of solids in the liquid fraction and reduce the volume of the storage tank. Moreover, the covered storage of the liquid fraction will also reduce the activity of the aerobic microorganisms and prevent emission control from dairy farms, such as those of ammonia gas and methane (collected as biogas). Separation efficiency on Farm B was calculated, wherein the TS in the screw separator was around 5.1%; the TS in the liquid fraction was 2.5%; and the solid fraction was 23.6%. After composting, the TS in the solid fraction increased to 35.2%. In this separation system, the mass percentages in the liquid and solid fractions were 87.7% and 12.3% of the total feeding volume, respectively. The dry solid mass percentages in the liquid and solid fractions were 57% and 43%, respectively. These values are comparable to separation efficiencies found in the Netherlands for screw-press separation of dairy manure[20,21].

3.4 Solid, nutrients and metals in manure samples

3.4.1 Solid content before and after separation

On Farm A, a two-stage separation process occurred in the dewatering unit. First, manure was separated by a normal screw separator and then conveyed to the second device that removed part of the remaining moisture from the solid fraction by heating the manure. According to the sampling analysis, the solid fraction had a high solid content and was suitable for recycled bedding materials. On Farm C, the solid content in the manure after dehydration was up to 92.2%. Dry livestock manure has a comparable heating value as brown coal and can be combusted by incineration[22].

The solid content is shown in Figure 4, and the TS values on Farms A, B, C and D were 9.36%, 5.09%, 10.4% and 16.8%, respectively. In cowsheds, water is supplied to cool the temperature but the water quantity varied from one farm to another. On Farms A, B and C, rice husk was used as bedding materials. A large amount of sand was mixed with manure, which lowered the organic content as VS to TS ratio. The organic part of TS on Farms A, B, C and D were 77.6%, 77.5%, 79.1%, and 42.3%, respectively.

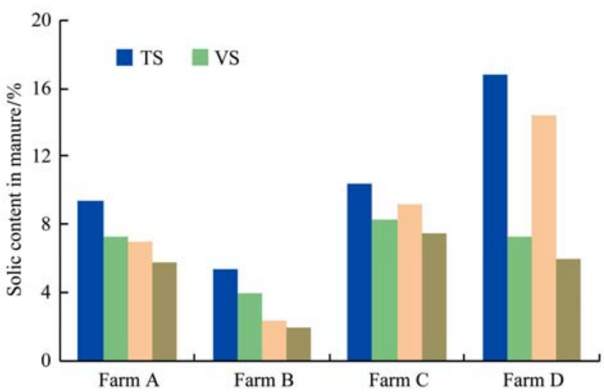


Figure 4 Solid content on four farms manure

3.4.2 Nutrients in manure

Manure slurry is rich in primary plant nutrients. For example, cattle slurry in the Netherlands has a total nitrogen of 4 kg/t, TP (P_2O_5) of 1.6 kg/t, and total potash (K_2O) of 6 kg/t on average (wet basis)[11]. Solid manure fractions from slurry separation have higher nutrient levels, whereas liquid fractions have lower nutrient levels. An efficient manure separator removes the larger part of the phosphate from the slurry into the solid fraction, but the larger part of the nitrogen and potash remains in the liquid fraction.

In China, livestock manure refers to pigs, cattle, poultry and sheep. Based on 170 manure samples in 20 provinces, the nutrient content of N, P, K, Zn and Cu was analyzed. The N, P, K, Zn and Cu content in the pig and poultry manure was significantly higher than that of cows and sheep, but the potassium content was nearly the same[23]. The phosphorus content in pig and chicken manure was higher than average, and the average ratio of nitrogen to phosphorus was 1.7:1. Close attention should be paid to the balance of N and P nutrients during the bio-fertilizer application to meet crop needs and to prevent losses and subsequent soil and water pollution.

In 2013, in terms of livestock manure, pig manure accounted for 36.71%, poultry accounted for 19.14%, sheep accounted for 19.10%, cattle accounted for 15.44%, and dairy cows accounted for 9.61%[24]. Despite the highest excretion rate per single head among the main livestock, the total quantity of dairy cows is comparatively smaller than those of other animals in China, which leads to a relatively small number of dairy cow dung resources[25].

The nitrogen contents in dry matter of Farms A, B, C and D were 53.13, 15.75, 20.85 and 52.82 g-N/kg (Figure 5), respectively. Meanwhile, the phosphorus contents as P_2O_5 were 1.95, 1.6, 4.39 and 1.33 g/kg, respectively. The total organic nutrient (N+P_2O_5) was 57.6, 19.4, 30.9, and 55.9 g/kg, respectively. According to the National Nutrient Standard on Bio-fertilizer (National Standard, 'Disposal of sludge from municipal wastewater treatment plant—control standard for agricultural use' CJ/T 309-2009) and (National Standard 'Organic Fertilizer' NY525-2012), all manure, except that on Farm B, met the requirements to be classified as a bio-fertilizer. In the two standards, the minimum threshold of the total nutrient (N+P_2O_5+K_2O) was 30 g/kg and 50 g/kg. The average potash content in cow manure in 20 provinces in China was 19.6 g/kg (K_2O) in dry weight[23]. The standard CJ/T 309-2009 was issued by Ministry of

Housing and Urban-Rural Development and the NY525-2012 was issued by the Ministry of Agriculture.

Potassium content was not determined on the four farms. As a result, the manure on Farm B could still meet the fertilizer standard. For the standard NY525-2012, the organic fertilizer refers to manure treated by composting. In China, manure in both liquid and solid cannot be used as ‘Organic Fertilizer’ as defined in NY 525-2012 without composting based treatment. Although manure can provide both organic and inorganic nutrients, the liquid fraction of manure after separation can only be used in agricultural land.

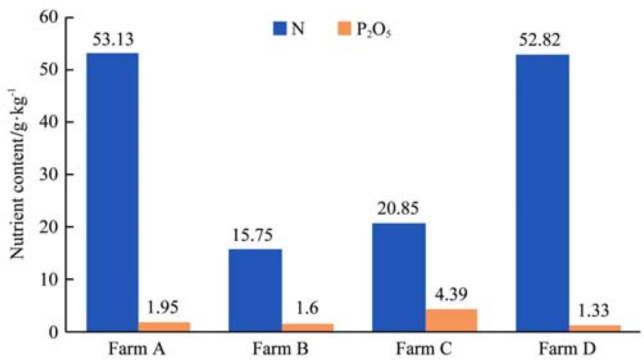


Figure 5 Nutrients in manures (g/kg-DM)

3.4.3 Metals in manure

In China, manure application in agricultural land is considered dangerous due to antibiotics and heavy metals. Indeed, the metals are the major factor limiting the application of manure as fertilizer. Currently, no specific standards are implemented with regard to metals in manure for safe application. The current study analyzed metals, such as Ad, Cr, Cu, Ni and Zn, in manure on the four farms (Table 4).

Table 4 Metals in manure (g/kg-DM)

	Farm A	Farm B	Farm C	Farm D	CJ/T 309-200	NY 525-2012
As	/	/	/	/	<30	≤15
Cd	0.04	0.16	0.14	0.03	<3	/
Cr	5.9	13.2	16.0	23.4	<500	≤150
Cu	208.0	50.8	111.0	91.9	<500	/
Hg	/	/	/	/	<3	≤2
Ni	21.20	6.15	7.62	33.90	<100	/
Pb	/	/	/	/	<300	≤50
Zn	155	203	277	110	<1500	/

Compared with the standard CJ/T 309-2009 and NY 525-2012, all the metals were below the threshold. Cu and Zn were the dominant metals, but the manure was still safe compared with the high standard limit. Jia et al.[1] recently analyzed the metals (Cu, Zn, Cd, As, Pb, Cr, Ni and Hg) in cattle manure from 17 farms. Results showed that all the eight metals in their manure samples were below the standard and below those in pig and chicken manure. For agricultural land application, cattle manure is safe, and metals are not considered an issue.

3.5 Possibilities of improving manure handling

3.5.1 Preventing nitrogen loss using a covered system

Techniques for mitigating the nitrogen loss of recycled manure applied to land have been developed to conserve the nutrient content in manure and avoid ammonia emission. In the Netherlands, cattle slurry is the main type (~80%) of livestock manure[26]. Solid cattle manure is usually stockpiled or composted for an extended period before land application. Up to 50% of the initial nitrogen is lost during storage or composting of solid manure[27,28]. Furthermore, considerable losses of nitrogen may occur during and after surface application of solid cattle manure to land. These losses are caused by the emission of ammonia gas and represent an environmental risk. Thus, immediate covering with soil and irrigation immediately after manure application can reduce NH_3 emission and improve herbage N uptake[29]. In addition, slurry storage lagoons have to be covered to reduce ammonia emissions. In the Netherlands, cattle slurry is applied to both grass and arable land with low emission equipment, such as slurry injection. In contrast with the Netherlands, where slatted floors are common, scraping manure from solid concrete floors is a common practice on dairy farms in China. Ammonia emission from a scraped solid floor is similar to the emissions from a slatted floor, and methane emission from a solid floor is lower than that from a slatted floor with slurry storage underneath. In terms of the lower methane emission of a solid floor, methane emission from outdoor manure storage also has to be considered[30]. The management of surplus manure is important in order to avoid nutrient loss as when more nutrients are applied than necessary for crop growth, the surplus nutrients cannot be used by plants and will be lost. Nitrogen is lost to the atmosphere by ammonia volatilization and nitrous oxide emission, or to groundwater and surface water by nitrate leaching. Phosphorus is lost through runoff into surface water, or by fixation (the formation in the soil of poorly soluble phosphorus compounds), especially in acidic soils. To avoid over fertilization, the surplus manure must be transported to another region where it can be used as fertilizer on agricultural land.

3.5.2 Establishing the manure nutrient application standard

In China, sufficient land area is not always available to apply manure from large-scale dairy farms. The cheapest way is to store slurry (a mixture of urine and faeces) under slatted floors, but his method of storing manure is uncommon in China. Slurry systems are suitable for enclosed backyard barns and applied in areas with abundant land and in mechanized farming systems that require less labor. The recommended fertilization standards for nitrogen and phosphate from animal manure and chemical fertilizers vary within and across regions, depending on crop, climate and soil conditions. The nitrogen and phosphate content of animal manure and soil in the root zone need to be determined in advance by chemical analysis. This requirement also applies to other nutrients and minerals.

In the Netherlands, around half a hectare of land per milking cow is needed to apply the manure within the legal phosphate application standards[31]. If the cattle farm has insufficient land, surplus manure has to be transported to other (arable) farms. In Germany, because of the national commitment to renewable energy, anaerobic digestion (biogas production) is encouraged[16]. However, biogas production is not considered to be a manure treatment in Europe because by definition, the remaining effluent is still animal slurry, and all the nutrients (N, P_2O_5, K, etc.) remain in the digestate.

4 Conclusions

Solid and liquid separation was very useful treatment which was used on many Chinese dairy farms. Further treatment of the liquid fraction and the resource utilization of the solid fraction of separated dairy manure should be proceeded. Deliberate spatial planning for new livestock farms in relation to the available surface area of agricultural land for manure application could help prevent over-fertilization. Currently, the national and local standards on manure focus on the limits of manure discharge in order to prevent water pollution; however, extending the existing regulation with standards on maximum manure nutrient application rates is recommended. Dairy manure has the potential to be used as fertilizer because of its organic nutrient content and low metal content. On medium and large-size dairy farms, solid/liquid separation has been extensively applied, and long-term storage has been used to keep liquid manure between fertilizer seasons. However, distribution of knowledge on the nutrient levels in these organic fertilizers in relation to the nutritional needs of crops is necessary. Only then can manure application be adjusted to crop needs. This includes the interpretation by farm managers of the results of chemical analysis and contents of both organic and chemical fertilizers. The emission from the open storage unit also needs further attention. In this way the environmental impact and emissions associated with intensive farming can be significantly reduced.

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