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REVIEW

POLICIES AND REGULATIONS FOR PROMOTING MANURE MANAGEMENT FOR SUSTAINABLE LIVESTOCK PRODUCTION IN CHINA: A REVIEW

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KEYWORDS

integrated crop and livestock production, manure utilization, policy recommendations, sustainability, third-party service contractors,

HIGHLIGHTS

- Manure utilization is hindered by separate specialist crop and livestock production systems.
- Improving manure utilization requires organizations for manure exchange.
- Policies and action plans for improving manure utilization are critically reviewed.
- A manure chain approach with third-party contractors is recommended.

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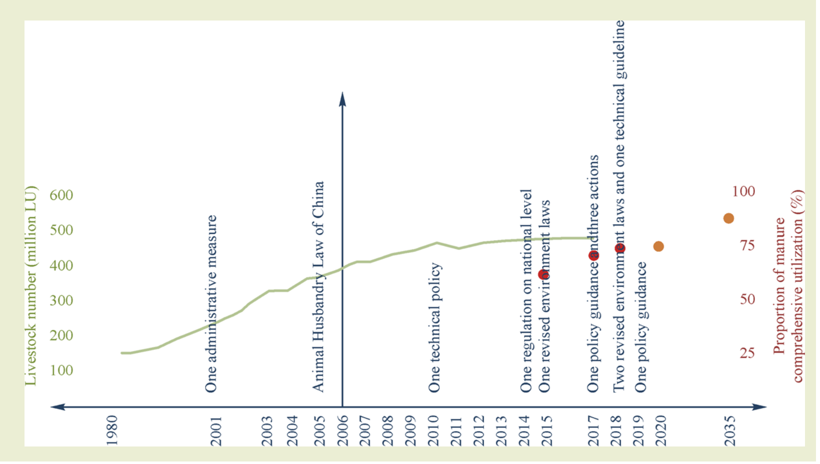
GRAPHICAL ABSTRACT



ABSTRACT

Livestock numbers in China have more than tripled between 1980 and 2017. The increase in the number of intensive livestock production systems has created the challenges of decoupled crop and livestock systems, low utilization of manures in croplands, and subsequent environmental pollution. Correspondingly, the government has enacted a series of policies and regulations to increase the sustainability of livestock production. This paper reviews the objectives of these policies and regulations and their impacts on manure management. Since 2017 there have been two policy guides to speed up the appropriate use of manures, three action plans for increasing manure recycling, and one technical guide to calculate nutrient balances. Requirements of manure pollution control and recycling for improved environmental performance of livestock production systems were included in three revised environmental laws. Most recent survey data indicate that the utilization of livestock manures was 70% in 2017, including that used as fertilizer and/or for production of energy. The targets for manure utilization are 75% in 2020 and 90% in 2035. To achieve these targets and promote ‘green livestock production’, additional changes are needed including the use of third-party enterprises that facilitate manure exchange between farms and a more integrated manure nutrient management approach.

1 INTRODUCTION

Livestock products contribute 17% to the total food energy consumption and 33% to the total protein consumption by humans globally but there are large differences between developed and developing countries[1]. In developed countries the *per capita* rate of consumption of livestock products is plateauing, but in developing countries the consumption of livestock products (and hence livestock production) is increasing[1–3].

The livestock industry in China has experienced rapid growth and a vast transition driven by economic incentives over the last four decades[3,4]. The number of livestock (livestock units) has increased threefold between 1980 and 2017. Livestock production has increased even more; total meat, egg and milk production increased 6.0, 10.7 and 12.0 times between 1980 and 2017[5,6]. The spatial distribution of manure nitrogen (N) and phosphorus (P) excretion by livestock (calculated by the total number of animals per category per province[7] and animal category-specific N and P production coefficients[8]) indicates that ‘hotspots’ of manure production are concentrated on the North China Plan and in central, south and east China.

Expansion of livestock production has resulted in increased pressure on the environment, notably through the release of odors, fine particulates ($PM_{2.5}$), ammonia (NH_3), nitrous oxide (N_2O), methane (CH_4) and nitrogen oxides (NO_x) to the atmosphere, and through N and P leaching to surface waters[9–16]. These emissions contribute to the greenhouse effect, eutrophication, acidification and loss of biodiversity[9–16]. Greenhouse gas (GHG) emissions from livestock production include CH_4 emissions from enteric fermentation and manure management, and N_2O emissions from manure stores and following manure applications to soils and excreta deposited on pasture by grazing animals. The GHG emissions increased from 207 Tg CO_2-eq in 1980 to 326 Tg CO_2-eq in 2017[5,6], and NH_3 emissions increased from 2.9 Tg in 1980 to 5.0 Tg in 2012[17].

Increased specialization of livestock systems has resulted in the decoupling of crop and livestock production systems[11,18–20] and in a reduction in manure use efficiency. Therefore, a greater integration of crop and livestock production systems is one of the key strategies for increasing the resource use efficiency of livestock manures[21]. To address the environmental challenges of livestock production, many countries including the United States of America (USA) and EU countries have introduced agri-environment policies and action plans to promote efficient and low emission livestock production systems since the 1990s[22–24].

This paper reviews the objectives and targets of agri-environment policies and regulations in China and assesses their impact on manure management. Based on the review, we propose a number of suggestions to further improve manure utilization. These suggestions provide a reference for the sustainable development of livestock production in developing countries including China.

2 CHALLENGES OF LIVESTOCK MANURE UTILIZATION IN CHINA

In recent years the Ministry of Agriculture and Rural Affairs (MARA), Ministry of Finance (MF), Ministry of Science and Technology (MST) and other ministries have actively promoted the utilization of livestock manure[25–27]. However, over 70% of farms including crop production and/or livestock production in China were specialized crop production systems or specialized livestock production systems in 2017[28]. This specialization has created barriers for effective manure utilization in croplands as indicated below.

2.1 Small crop farms separated from large livestock farms

Nutrients from organic manures supplied over 90% of the total nutrients applied to croplands in China in the 1950s[29]. The increase in demand for livestock products caused by the increased population and consumption *per capita* has led to a rapid increase in the proportion of large-scale livestock farms without cropland[4]. This has contributed to the separation of crop and livestock farms both in space and scale[30]. The proportion of pigs reared in farms with > 500 finishing pigs per farm increased from 8% in 1998 to 47% in 2017. In contrast, crop production is still dominated by small-scale farmers who often work part-time in the cities[31]. This situation is likely to continue for some time[31]. The area cultivated on farms with > 3.3 ha accounted for about 18% of the total cultivated area in 2016[31]. According to the *Technical Guideline for the Calculation of the Land's Capacity to Receive Livestock Manure*, an area of 3.3 ha can receive manure N produced by 500 finishing pigs[32]. The gap between the proportion of livestock farms with > 500 finishing pigs and the proportion of crop farms with over 3.3 ha results in a low utilization of livestock manure in croplands. Currently, only 30% of total excreted N and 48% of excreted P are returned to the land via manure application[11].

2.2 Variable and low nutrient contents in manures

Manure is an excellent source of the major plant nutrients including N, P, and K[33] and it provides many of the micro nutrients that plants require[34,35] together with organic matter for soil amendment, all of which contribute to boosting crop yields and nitrogen use efficiency (NUE)[36–41]. However, manure nutrient content and availability are often highly variable and unknown. Labels for composted manure may only provide a sum of all nutrients[19], and this is not sufficiently informative for precision fertilization.

Furthermore, the cost of applying manures is high, about twice that of mineral fertilizers[42], due to the large volume, high water and low nutrient contents, and especially the high transport costs, compared with mineral fertilizers. There is also a requirement for liquid manures to be treated before they can be used on croplands[43], and this increases the costs and may also reduce the nutrient value (especially N) if the manures are composted. Therefore, the market competitiveness of manures is much lower than that of mineral fertilizers.

2.3 Risks of heavy metals and antibiotics in manures

Another issue is the possible contamination of manures with trace metals (loid) and antibiotics[44,45]. The content of heavy metals (notably copper and zinc) of some pig and chicken manures exceeds the national requirements of the *Control Standard for Pollutants in Sludge from Agricultural Use* in some regions due to the use of feed additives[43,46]. Frequent applications of manure will result in the accumulation of heavy metals and antibiotics in soils and crops[44], with potential adverse effects on human health.

2.4 Lack of enterprises and services for manure redistribution

In the Netherlands, private companies overseen by the government redistribute manures between livestock farms and crop farms. Livestock farmers have to pay 10–25 EUR·t^{-1} of manure to these trading companies, and crop farmers receive 1–14 EUR·t^{-1}, depending on manure quality and the distance between farms[47]. Each truck load of manure (about 30 t) is weighed and the N and P contents are determined. This type of trading/management scheme is not yet available in China. There are many challenges in establishing a professional manure redistribution system, such as (1) who should pay for the prolonged manure storage and application infrastructure, (2) who should pay for the manure transportation, (3) who should receive government subsidies, and (4) who should monitor and control the flow of manure and money. The lack of appropriate manure application equipment and manure storage facilities and the high costs of manure transportation[48,49] are barriers to the use of manures by crop farmers. All of these factors have contributed to a fractured manure management chain and to low manure nutrient utilization in Chinese croplands.

3 POLICIES AND MEASURES FOR IMPROVING MANURE MANAGEMENT

3.1 Experiences in the United States and the European Union

Many developed countries including the USA and some EU countries experienced a period of serious pollution during the rapid development of intensive livestock farming in the second half of the twentieth century. In response, governments and livestock industries implemented a series of policies, action plans and guidance to reduce the environmental burden from livestock production. Livestock manures are now considered as valuable sources of nutrients[33] and organic matter[38] which have to be stored in contained manure stores and have to be applied to croplands during the growing season according to crop nutrient demand. Major improvements have also occurred through increased animal productivity, animal breeding, and improved animal feeding and housing. However, the separation and concentrations of specialized livestock farms and crop production systems remains a bottleneck in improving manure management in these countries (see other papers in this special issue)

In the USA, farmers or their advisers have to make comprehensive nutrient management plans for addressing potential water quality and public health impacts associated with animal feeding operations[50,51]. When the nutrient supply via livestock manure exceeds the nutrient demand of crops, farms have to choose other methods to treat and use the manure. However, only small proportions of manures are processed in practice, for example by composting or anaerobic digestion[52].

Livestock farmers in the EU also have to make a nutrient management plan and have to comply with manure application limits and additional regulations related to manure storage and manure application timing and method, according to action plans to comply with the Nitrates Directive[24]. A uniform manure application limit of 170 $kg \cdot ha^{-1} \cdot yr^{-1}$ N has been set across the EU, although a derogation is possible for N-demanding crops with a long growing season (permanent crops)[24]. Application of fertilizers and manures is restricted to the growing season only. Further, farmers are encouraged to use low-protein animal feeds and reduce ammonia emissions by low-emission animal housing and manure storage systems, and by low-emission manure application (through injection, trailing hose or rapid incorporation into the soil)[53].

3.2 Government policies, laws and regulations in China

Until 2015, the main objective of government policies, laws and regulations related to manure management in China was simply pollution control. Since 2015, the objectives of the policies, laws and regulations have expanded to include pollution control and enhanced resource use efficiency.

The environmental problems caused by the rapid development of livestock production have emerged rapidly (Table 1). The NH_3 emissions from livestock production have increased from 2.9 Tg in 1980 to 4.8 Tg in 1997[17]. Non-CO_2 GHG emissions from livestock production have increased from 98 Tg in 1961 to 212 Tg in 1997[6,58]. The nutrients from organic manures as a percentage of to the total amounts of nutrients from fertilizers applied to croplands decreased from 47% in 1980[54] to 24% in 2008[55]. In consequence, N use efficiency in the food system has decreased steadily[4,59]. As a result, increasing quantities of livestock manures, sewage sludge and other organic resources have been neglected and not effectively re-utilized in crop production, but have instead been lost to soils, water and air[9–16].

In response, the government has gradually implemented policies and regulations related to manure management from 2000 (Table 2). In 2001 the EPA issued the *Administrative measures for prevention and control of livestock pollution* which set discharge limits and required intensive livestock farms to obtain a discharge license. The *Standard discharge of pollutants for livestock and poultry breeding* issued in 2001 regulated the maximum allowable discharge concentrations (COD, 400 $mg \cdot L^{-1}$; NH_3-N, 80 $mg \cdot L^{-1}$) and volumes per animal per day (pigs, 12–18 L; chickens, 0.5–0.7 L; cattle with dry collection systems, 170–200 L). The permissible discharge volume limits on farms with a flush system are: pigs, 25–35 L; chickens, 0.8–1.2 L; cattle, 200–300 L[60].

The FAO report *Livestock's Long Shadow: Environmental Issues and Options,* published in 2006[61], and the adoption of the sustainable development goals (SDGs) by all United Nations member states in 2015 have boosted the thinking about sustainable livestock production in China[62]. Gradually, manure pollution control measures have been replaced with policy and advice to promote manure resource recycling and use (Table 3).

The Chinese government has introduced two policies, named *Policy Guidance on Accelerating the Resource Utilization of Animal Manure* and *Guiding Opinions on Promoting the Land Application of Livestock Manure and Strengthening the Pollution Control according to Law,* to speed up the appropriate utilization of livestock manures in croplands and has set an initial target of 75% manure recycling by 2020 (Table 3). The government has also provided a technical guide to calculate the maximum number of animals per farm based on the land area per farm and the balance of manure nutrient supply and crop nutrient demand. Further, nitrogen vulnerable zones have been proposed[30].

Table 1 Changes in the utilization of livestock manures in China from 1980 to 2018

Item	1980	2000	2008	2018
Farms matching proportion of manure facilities[a] (%)	–	< 20[e]	63	80[f]
Percentage of manure comprehensive utilization[b] (%)	–	–	–	74[f]
Percentage of nutrients applied to croplands derived from manures (%)	47.1[c]	30.6[c]	23.6[d]	–

Note: [a]Refers to the percentage of the number of livestock farms with manure treatment and spreading equipment within the total number of livestock farms. [b]Refers to the ratio of utilized manure as resources (like compost, biogas and land application) to the amount of fresh manure production. [c]Value according to Zhang[54]. [d]Value according to Niu & Ju[55]. [e]Value according to EPA[56]. [f]Value according to MARA[57].

Table 2 Government laws, regulations, policies and actions in China aimed at promoting the sustainable development of livestock production until 2015

Year	Names of policies, laws and regulations	Objectives/Targets	Implementation level
2001	Administrative Measures for Prevention and Control of Livestock Pollution (No. 9 of EPA)	• Environmental protection plan • Discharge license	National implemented
2005	Animal Husbandry Law of the People's Republic of China—Revised in 2015	Managing livestock production according to law	National implemented
2014	The Regulation on the Prevention and Control of Pollution from Large-scale Livestock and Poultry Operations	• Designated prohibited area • Economic incentives	Implemented
2015	Environmental Protection Law of the People's Republic of China	Implementation of discharge license	Implemented at intensive farm

Table 3 Government laws, regulations, policies and actions in China aimed at promoting the sustainable development of livestock production implemented after 2015

Year	Names of policies, laws and regulations	Objectives/Targets	Implementation level
2017	Policy Guidance on Accelerating the Resource Utilization of Animal Manure (2017 No.48)	Comprehensive utilization rate of livestock manure is planned to reach over 75% by 2020	High degree of realization
2017	Policy Guidance on the System and Mechanism of Innovating and Promoting the Green Development of Agriculture	Determine the calculation principle of farm scale by manure application requirement	Medium degree of realization
2018	Law of the People's Republic of China on the Prevention and Control of Water Pollution—Revised in 2018	Discharged limits of livestock is 300 $mg \cdot L^{-1}$ for COD and 30 $mg \cdot L^{-1}$ Kjeldahl N	Medium degree of realization due to the lack of technical specifications
2018	Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution—Revised in 2018	Odor control	–
2018	Specification for the Construction of Facilities for the Manure Resource Utilization in Livestock Farms (2018 No.2)	To standardize the volume of farm manure storage facilities	Implemented
2019	Guiding Opinions on Promoting the Land Application of Livestock Manure and Strengthening the Pollution Control according to Law (2019 No.84)	The targets for manure utilization are 80% in 2025 and 90% in 2035	Just started

In 2017, a policy guidance document was issued to accelerate the utilization of livestock manures in croplands. This involved the establishment of a livestock manure use system and the development of mechanisms to improve integration of crop and livestock systems by 2020[27]. It also set the target for manure utilization to be at least 75% by 2020. Hence, a minimum of 75% of produced livestock excreta needs to be applied to cropland by 2020. Further, at least 95% of large-scale livestock farms must have infrastructure for manure treatment[27].

Another guide to promote manure application to cropland and to strengthen pollution control was issued in 2019[25]. This guide sets the targets for comprehensive utilization of livestock manures at 80% by 2025 and at 90% by 2035. Specific measures have been promoted to achieve these targets, namely the application of manure at appropriate times and rates to match crop demand, strengthening of third-party service organizations, and upgrading facilities and equipment for the effective application of manures to land.

Requirements to improve the environmental performance of livestock production were issued in one regulation and three revised environmental laws in China. *The Regulation on the Prevention and Control of Pollution from Large-scale Livestock and Poultry Operations* was the first national level legislation specific to agriculture and environmental protection[63]. This regulation was formulated to minimize and control pollution from livestock and poultry operations, boost the comprehensive use and safe treatment of livestock manures, guarantee the physical health of the general public and promote the sustainable and healthy development of livestock husbandry. The regulation introduced a specific approach to the comprehensive use and discharge standards for livestock manures, including the requirement of new and expanded livestock farms to undertake an environmental impact assessment (EIA), and to specify waste treatment measures and manure storage capacity. Manure application rates must consider the capacity of the land to safely receive livestock manures and public health criteria.

The *Environmental Protection Law* revised in 2014 introduced the regulatory regime for discharge permits[64]. Enterprises and institutions discharging pollutants in excess of the prescribed national or local discharge standards are required to pay levies that are used for the treatment of polluted surface waters.

The *Law on the Prevention and Control of Atmospheric Pollution* was revised in 2018. The revised version stipulates the development of circular agriculture and provides support for manure treatment[65]. This law requires all livestock farms and communities to collect, store, transport and use sewage sludges, manures and livestock carcasses in a timely manner and use safe treatment practices to prevent the emissions of odor, nitrogen oxides (NO_x) and GHGs.

The *Law on the Prevention and Control of Water Pollution* (2018) supports the construction of facilities for the safe treatment of manures and wastewaters on livestock farms and in communities[66]. It stipulates that livestock farms and communities must ensure the normal operation of their facilities for the safe treatment of manures and ensure that wastewater discharge meets the required standards (total N, 40 $mg \cdot L^{-1}$; NH_3-N, 25 $mg \cdot L^{-1}$)[67] or meet the quality standard for cropland irrigation water in China[43]. If livestock wastewater is applied through irrigation channels the water quality of the nearest irrigation water intake downstream must be guaranteed to meet the water quality standard for irrigation. Local governments are responsible for organizing the collection, centralized treatment and subsequent use of livestock manures in counties with small scattered livestock farms.

4 ADDITIONAL ACTIONS FOR IMPROVING MANURE MANAGEMENT

In addition to the governmental policies, laws and regulations discussed in section 3.2, a series of additional actions and financial incentives have been implemented to improve the effectiveness of the government policies, laws and regulations.

The *Action Plan for Water Pollution Control* (2015) aims at closing or relocating livestock farms in designated (prohibited) areas (Table 4). This plan has led to the transfer of numerous livestock farms from areas close to rivers and lakes to areas with dryland and relocation of pigs from the south to the north of Chain to protect watercourses[68]. An action plan for the recycling (land application) of livestock manures (2017–2020) introduced seven technological options: (1) full manure collection and land application, (2) specialized biogas plants, (3) composting of solid manures, (4) treatment of manures with high-rise fermentation beds, (5) litter recycling, (6) wastewater recycling, and (7) treatment of manures to meet discharge standards[26] (Fig. 1). Livestock farms must choose one or more of these seven options.

Enhanced livestock manure utilization and recycling has been funded from 2017. The government subsidies are 30, 45 and 60 million CNY for farms with 0.1 to 0.5, 0.5 to 0.99 and > 1.0 million pig equivalents, respectively (a pig equivalent is defined by the amounts of manure N and P excreted by a fattening pig of 70 kg in one year). A total of 586 counties (out of a total of 3000 counties in China) with large livestock farms have been granted subsidies[69,70]. In addition, subsidies have been provided to poultry farms to reduce the spillage of drinking water, and to pig farms to reduce the amounts of flushing water used[60]. Subsidies have also been provided for odor control and for closed storage and treatment of liquid manures from 2020[71].

Another action plan has stimulated the replacement of mineral fertilizers by organic fertilizers in the production of fruit, vegetables and tea in 100 counties through subsidies worth one billion CNY[72]. The goal is to reduce mineral fertilizer consumption by 20%–50% in fruit, vegetable and tea production by 2020.

A Technical Guideline for the Calculation of the Land's capacity to Receive Livestock Manure was released in 2018 and provides a standard calculation method for recycling manures[32]. It is based on the nutrient input-output balance. The nutrient requirements of crops are determined according to crop type and yield, soil fertility level, and the proportion of nutrients supplied by manures. The nutrient supply from livestock manures is determined according to the number of livestock, livestock-specific excretion factors, and the manure collection and treatment.

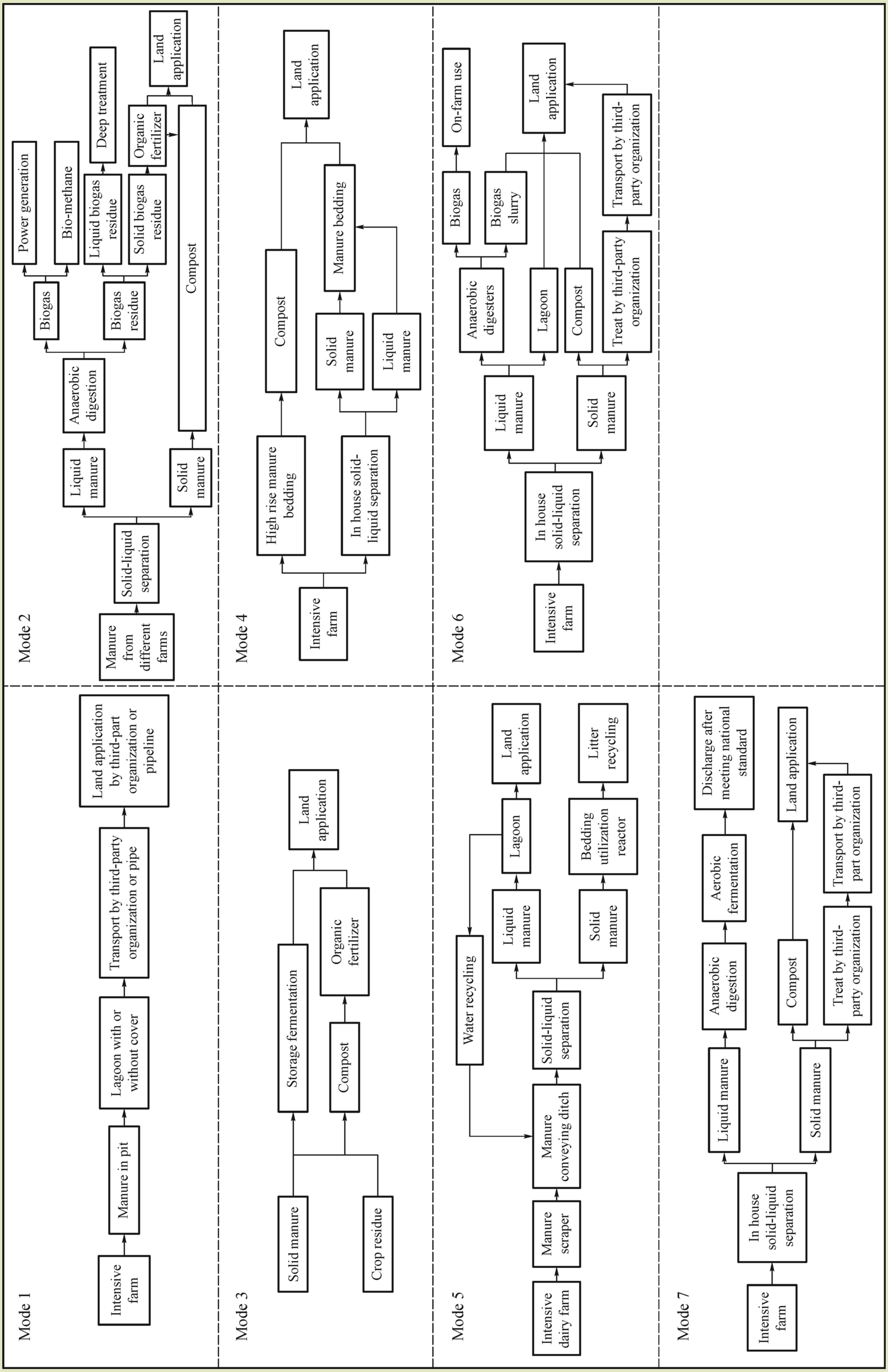


Fig. 1 Seven typical technological modes of manure management for large-scale land-less livestock farms in China. Source: MARA[26].

Table 4 Actions in China for promoting the sustainable development of livestock production

Year	Names of actions	Objectives/Targets	Implementation level
2015	Action Plan for Water Pollution Control	Closed or relocated the livestock farm in prohibited areas	Over 0.26 million livestock farms were closed or relocated by 2019
2017	Action Plan for the Recycling (Field Application) Livestock Manure (2017–2020)	• Comprehensive utilization rate of livestock manure is planned to reach over 75% by 2020 • The matching rate of manure treatment facilities in large-scale farms reached more than 95%	High degree of realization. and basically achieved
2017	Action Plan for Replacing Chemical Fertilizer with Organic Fertilizer on Fruits, Vegetables and Tea	• Reduce chemical fertilizer by > 20% by 2020 • The organic matter content of fruit, tea and vegetable soil reached 1.2%, 1.2% and more than 2% by 2020, respectively	High degree of realization. and basically achieved
2017	Work Plan for Promoting the Whole County's Utilization of Livestock Manure (20187–2020)	Select more than 200 large livestock counties to matching the target in 2020	High degree of realization and basically achieved
2018	Technical Guideline for the Calculation of the Land's Capacity to Receive Livestock Manure (2018 No.1)	Develop the calculation method of land capacity of manure on regional and farm level based on the nutrient balance	Low degree of realization due to the lack of technical guidelines

5 ASSESSMENT OF THE POLICIES, LAWS, REGULATIONS AND ACTIONS

5.1 Main effects

Total manure recycling was < 60% in 2015[73] and as much as 70% by the end of 2017. Manure treatment facilities for large-scale farms were present on < 20% of the total number of large farms in 2000[56] and on 80% in 2019[57] (Table 1).

Water use and spillage have been greatly reduced on pig and poultry farms. As a consequence, the total volume of manure has also decreased dramatically. This has facilitated the transport of manure to crop farms[60].

The amount of mineral fertilizer used in tea, vegetable and fruit production in the aforementioned 100 counties has dropped by 18%, and organic fertilizer use has increased by 50%, and this has increased resource use efficiency[72]. Organic fertilizers have also contributed to increases in soil organic matter content[36–41] and to an improved quality of agricultural products (higher contents of micronutrients)[36–41]. However, farmers often perceive that the subsidies are too small and the pilot areas that have benefited from the subsidies are often limited in scale and duration. There is still a lack of suitable manure application machinery because of high purchase costs.

5.2 Critical appraisal

Although a series of policies for enhanced manure recycling have been implemented, most of these have targeted large intensive farms only. While this is understandable with an increasing proportion of livestock being reared in these intensive systems, there are still numerous less intensive livestock farms in China[42]. As a result, the policies have had no impact on the many small and medium-sized livestock farms. Unified design and construction criteria of manure treatment facilities are often lacking and have resulted in non-standardized construction of treatment facilities and continuing direct discharge of liquid slurries to surface waters. In addition, although treatment facilities have been built on farms there is little control and verification of manure management practices.

A complicating factor in China is the great diversity of environmental conditions, notably in climate and geomorphology. Current policies, laws, regulations and actions do not address this diversity in sufficient detail. In the north, slurries are often stored uncovered in the open in backyards or in open ponds to promote evaporation in the dry climate. This drying strategy reduces the risk of slurries polluting watercourses in this region but rates of ammonia volatilization are high. These practices are not possible in wet southern China.

Another complicating factor is the lack of knowledge about typical manure composition, and best manure management practices among farmers, advisors and government officers. This also leads to imprecise definitions that are not operational in practice. For example, in China manure recycling has been defined as the fraction of manure produced by livestock that is applied to croplands, and a target of 90% manure recycling has been set for 2035. In practice, manures will be stored and treated before application and significant fractions of the nitrogen, organic carbon and water will be lost via volatilization, leaching, decomposition and evaporation. The question is then how to verify that 75% of all livestock excreta will be applied to croplands by 2020, 80% by 2025 and 90% by 2035. It is unclear whether 'manure recycling' has been defined in terms of manure volume, mass, or nitrogen or phosphorus content.

A rethink is also needed regarding the government incentives to improving manure management. Subsidies are now provided to large livestock farms to build manure stores and manure treatment facilities that result in commercial organic fertilizers. However, there are no specific measures to ensure the continued operation of treatment facilities once built, and there are too few incentives to promote the effective utilization of the manure products generated. The main barriers against crop farmers using manures are the high costs of transportation, lack of manure application equipment, and lack of qualified labor (lack of trained/educated farmers to make the best use of manure nutrients) for manure application[19]. As a result, treatment facilities on livestock farms are often not in operation due to technical failures, high operational costs, lack of product marketing, and lack of control of product quality. And although government reports indicate that manure recycling has increased from < 60% in 2015 to 70% by the end of 2017[73], it remains unclear how manure recycling has been defined.

6 CONCLUSIONS AND OUTLOOK

The livestock sector has developed very rapidly in China during the last two decades in response to the increasing demand of animal-sourced food. This development has created a manure nutrient surplus at the farm and regional levels, especially as a result of concentrations of large landless livestock farms which import feed from elsewhere. The government has strongly facilitated the modernization and intensification of the livestock sector and has also implemented a series of policies and incentives for the appropriate handling and treatment of livestock manures. However, manure management remains a major challenge. The main bottlenecks to effective manure utilization are (1) the spatial separation of large intensive landless livestock farms from the many small-holder crop farms, (2) the lack of third-party organizations, governmental institutions and appropriate technology for transporting manure from livestock farms to crop farms, (3) the lack of small-scale manure spreading machinery and a manure nutrient recommendation system and associated training to guide farmers and advisers on manure nutrient application to crops, and (4) the lack of governmental incentives for the end-users to adopt the use of animal manure products.

Improved integration of crop and livestock production systems is fundamental to increasing the effective use of animal manure resources. This integration is also an important means of reducing agricultural non-point source pollution and delivering national agricultural 'green' development goals[74–78]. Improvement of manure recycling and effective utilization in crop production have the potential to greatly reduce the use of synthetic fertilizers, to improve soil quality and crop nutrition and maintain high yields (through the supply of organic matter and secondary nutrients and micronutrients), and to decrease the eutrophication of surface waters and ammonia and GHG emissions to the atmosphere. This, however, requires great improvements in manure management practices, and hence in government policy measures. A rethink of current policies is needed.

It is imperative to develop policies and support programs to enhance the sustainability of livestock production and manure management practices. This will require: (1) establishment of comprehensive region-specific and farm type-specific nutrient management plans, based on accurate accounts of nutrient input-output balances; (2) a partial redirection of financial support from manure producers and manure treatment industries to manure users, and from investments in treatment facilities to end-users or third-party contractors (support for operational costs); (3) an institutional framework for the effective control and transportation of manures from producers to users, involving intermediate third-party enterprises, with governmental co-ordination using different specialized service models; and (4) strengthening third-party service organizations (contractors) to promote manure application to croplands in an economical and environmentally sound manner. The diversity among livestock farms is very large, from smallholders with a few pigs to large farms with thousands of pigs, and very large industrial enterprises with millions of pigs. These different enterprises have their own challenges in manure management and will need to adopt different specialized service models[42] (Table 5).

Government support for the livestock sector has to be embedded into policies aimed at improving manure management based on nutrient accounting through the entire manure management chain[19,48] to ensure that all manure nutrients from intensive livestock production are properly collected, stored, and applied to arable land at appropriate rates and times and with

Table 5 Linking crop and livestock production, as a function of livestock farm size[42]

Item		Size of livestock farm		
		Households and small farms	Medium and large farms	Huge livestock company
Organization modes of linking crop and livestock production		Linking crop and livestock production through farmer cooperatives	Linking crop and livestock production through specialized service (e.g., contractors, manure treatment center)	On-farm crop and livestock integration through renting additional cropland and investing manure treatment facilities
Key role of different production sectors to realize the organizational modes	Government	• Village or town set up the cooperatives • Invest equipment for manure transportation and application • Provide technical guidance and sampling inspection on the manure use and effect	–	–
	Livestock sector	Establish manure storage facilities	Sign an agreement with a third-party specialized service organization	• Built industrial waste treatment plant to generating renewable energy, heat and fuel, and organic fertilizer • Rent agricultural land for manure application
	Crop sector	Receive manure application for free	Buy manure from third-party specialized service organization	Charge land rents from livestock company
	Manure application	Cooperative is responsible for manure transporting and returning to the field and establishing application records	Third-party specialized service organization is responsible for manure storage, transporting and land application	Livestock company is responsible for manure transporting and land application

appropriate methods. A recording system is needed, supported by government and research institutes, to assist accurate manure nutrient accounting.

Improving the performance of livestock production and manure management is an important target of the Agricultural Green Development program. With great attention and strong support of manure resource recycling program from policy, research, and farm, vast improvements can be made in the sustainability of livestock production and manure management with benefits for cropping farms, soil health and reduced negative impacts on water and air quality.

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Compliance with ethics guidelines

Sha Wei, Zhiping Zhu, Jing Zhao, David R. Chadwick, and Hongmin Dong declare that they have no conflicts of interest or financial conflicts to disclose. This article is a review and does not contain any studies with human or animal subjects performed by any of the authors.

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