Research on the Feces-Bearing Capacity of the Farmland in Anhui Province of China

CAILIN ZHANG¹, XIAOLONG CHEN¹, DONGFU FAN², TONGQIAN KANG² and SHUYUN YANG¹,²,*

¹School of Resources and Environment, Anhui Agricultural University, 130 West Changjiang Road, Hefei 230036, Anhui, China
²Hefei Scientific Observing and Experimental Station of Agro-Environment, Ministry of Agriculture, P. R. China, Hefei 230036, China

ABSTRACT: Anhui is a typical province with rich produced agriculture in the south of China, which is economically typical among those less developed provinces in the central and western regions of China. Therefore, study on the feces loads of farmland in the province is significant for guidance of the central and western regions. This study investigated the fecal pollution loads of farmland resulting from farming of Anhui Province. The results indicated that the average annual livestock feces exertion was 59.59 million tons during 2006–2010, which was equivalent to 282,000 tons of N and 111,500 tons of P. And the results for human feces of rural residents were 23.84 million tons, 143,000 tons and 48,600 tons, respectively. The five-year average loads of feces, feces-derived N and P loads were 20.20 thm⁻², 102.91 kghm⁻² and 38.76 kghm⁻², respectively. There were respectively 22.1%, 13.0% and 63.6% of the total counties exceeding the corresponding loads bearing limits of feces, N and P. The average P loads of the whole province surpassed the limit for 10.7%. In conclusion, the loads of feces and N of farmland were high, and some areas were in pollution of feces and N, while most areas were in pollution of P, which must be controlled as soon as possible.

INTRODUCTION

Feces has become one of main non-point sources of rural pollution because the return to farmland aggravates the nitrogen (N) and phosphorus (P) loads of the farmland, most of which is over-fertilized in China (including Anhui Province) [1–5]. It was reported that there will be a large increase of feces amount in the following 15 years [6,7]. According to the past research, the rural non-point pollution source was a critical factor for water pollution, as over 850 out of 1200 major rivers investigated were affected and there was not any fish or shrimps in 2400 km of river [8,9]. Viewing from feces pollution on farmland in different regions, it aggravated gradually from the northwest to the southeast [1]. There were two categories of researches on the livestock feces pollution in China. The macroscopic research was normally done over the province, while the microscopic research focused on small watershed and pollution controls [1,10–15]. Several methods have been developed to study this area, but the integrated models similar to the decision support system regarding the capacity of waste loads in the Arroyo Colorado River watershed were rarely used [16].

Anhui Province is a typical agricultural province located within 600 km of the Shanghai economic circle, and the livestock and poultry breeding is an important part of the local economy. In addition, many livestock industries may be transferred to the province as the escalation of the industrial relocation in the Yangtze River Delta regions, because Anhui Province is rich in agricultural products, economically less developed and close to the Yangtze River Delta. Therefore, feces pollution can’t be ignored since it may result in further farmland pollution [17,18]. Anhui has a rural population of 53.63 million (2012) accounting for 7.95% of the country’s total rural population of China [19]. According to the investigations, most human feces was applied to fields, in addition to the livestock feces. Therefore, effects of human feces were also considered in this study.

At present, the unified national feces, nitrogen and phosphorus threshold criteria for farmland have not been set up yet. The standards put forward by domestic and foreign researchers vary greatly. Shanghai Academy of Agricultural Sciences put forward the standards of the livestock feces loads for rural farmland...
in Shanghai suburbs [20]. Some scholars believed that the bearing capacity of livestock feces for farmland is 30 t hm\(^{-2}\) [21]. Zhaoliang Zhu found that nitrogen application over 150–180 kg could cause environmental pollution [22]. According to the European Union (EU) specifications, the annual fecal nitrogen application limit is 170 kg hm\(^{-2}\), otherwise, nitrate leaching would occur [23].

In this paper, based on the data of rural population, livestock breeding and farmland of counties from 2006–2010, the feces excretion amount, total nitrogen (TN), total phosphorus (TP) and farmland loads of feces, N and P were estimated by the county level, and the environmental impacts of feces application on the farmland were analyzed with reference to feces, N and P limit. Results of the feces output and farmland loads should have practical significance for the control of non-point source of agricultural pollution and drawing up plans of livestock and poultry development.

**MATERIALS AND METHODS**

**Basic Data**

The rural population, livestock and poultry breeding, farmland areas and related information came from “Anhui Statistical Yearbook” of 2007–2011 [24]. According to the characteristics of Anhui Province, the pigs, draft cattle, beef cattle, cows, horses, sheep, donkeys, mules, chicken, hens, ducks, geese, rabbits and human beings were researched. Comparison study of the present economic level in the rural areas of Anhui indicated that it was close to that of Shanghai City in 1980s. Therefore, feces parameters of Shanghai rural residents at that period were adopted in this article (Table 1) [25].

Anhui has 114 county-level units. In the article, districts under various municipalities were merged into county-level areas since most municipal areas are rather small, which may affect the comparability of different areas. For example, the total area of Tongling City, including five districts, is only 1083 km\(^2\). So it was considered as one county-level region. After merging, there were 77 county-level regions with similar areas.

**Calculation Parameters**

There are no national standards for the daily feces exertion amount of different livestock and poultry in China at present. In this paper, the feces excretion parameters were the average data of previously published work. Feces and nutrition amounts were estimated based on the parameters and the corresponding TP and TN contents of livestock and human feces (Table 1) [12,14,21,26,27].

**Estimation Method**

The method to estimate the annual feces amount of a county was as follows: using the following formula to calculate certain livestock (human beings) feces excretion amount first [21]:

\[ Q = B \times T \times X \]  

where \( Q \) is annual feces excretion amount, \( B \) is feeding amount (population amount), \( T \) is calculation period and \( X \) is excretion parameter. Then, all livestock and human feces amounts were summed up.

The method to estimate the pure nutrition amount in feces of a county was as follows: calculating the nutrition amount in the feces of an animal first with the following formula:

\[ A = Q \times c \]  

where \( A \) is the nutrition amount, \( Q \) is the feces excretion amount and \( c \) is the nutrition contents in the feces of an animal per unit mass. Then, all the nutrition amounts were summed up.

**RESULTS AND DISCUSSION**

**Feces Exertion Amount and the Contents of TN and TP in Anhui Province during 2006–2010**

The results of the total feces amount (TF) and the

---

**Table 1. Feces Excretion Parameters, Nutritional Contents (TN, TP) of Different Livestock and Poultry.**

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Feces Excretion Parameters</th>
<th>TN (%)</th>
<th>TP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft cattle</td>
<td>10.10 t a(^{-1})</td>
<td>0.351</td>
<td>0.082</td>
</tr>
<tr>
<td>Beef cattle</td>
<td>7.70 t a(^{-1})</td>
<td>0.351</td>
<td>0.082</td>
</tr>
<tr>
<td>Cow</td>
<td>19.40 t a(^{-1})</td>
<td>0.351</td>
<td>0.082</td>
</tr>
<tr>
<td>Horse</td>
<td>5.90 t a(^{-1})</td>
<td>0.378</td>
<td>0.077</td>
</tr>
<tr>
<td>Donkeys and mules</td>
<td>5.00 t a(^{-1})</td>
<td>0.378</td>
<td>0.077</td>
</tr>
<tr>
<td>Pig</td>
<td>1.93 t a(^{-1})</td>
<td>0.238</td>
<td>0.074</td>
</tr>
<tr>
<td>Sheep</td>
<td>0.87 t a(^{-1})</td>
<td>1.014</td>
<td>0.216</td>
</tr>
<tr>
<td>Broiler chicken</td>
<td>36.50 kga(^{-1})</td>
<td>1.032</td>
<td>0.413</td>
</tr>
<tr>
<td>Laying hen</td>
<td>53.30 kga(^{-1})</td>
<td>1.032</td>
<td>0.413</td>
</tr>
<tr>
<td>Duck and goose</td>
<td>39.00 kga(^{-1})</td>
<td>0.625</td>
<td>0.290</td>
</tr>
<tr>
<td>Rabbits</td>
<td>41.40 kga(^{-1})</td>
<td>0.874</td>
<td>0.297</td>
</tr>
<tr>
<td>Human being</td>
<td>127.75 kga(^{-1})</td>
<td>0.600</td>
<td>0.204</td>
</tr>
</tbody>
</table>

*Note: N and P contents of duck and goose were averaged.*
Research on the Feces-Bearing Capacity of the Farmland in Anhui Province of China

The corresponding TN and TP amounts in Anhui Province during 2006–2010 were estimated by the livestock and poultry feeding, feces excretion parameters and P, N contents.

The average annual total feces exertion of livestock and poultry during 2006–2010 was 59.59 million tons, with a compound annual increase of 7.97%, which was equivalent to 282,000 tons of average TN and 111,500 tons of average TP, respectively. The feces exertion, TN, TP of Anhui within these 5 years presented relatively slow upward trend, which was in correspondence to the livestock and poultry breeding increase (Figure 1).

The feces exertion of rural residents was changed from 23.56–24.04 million tons in the 5 years, with a rate of annual change less than or equal to 1.83%. The five-year average feces exertion was 23.84 million tons, which was equivalent to 40% of the livestock feces. Converted TN and TP of the five-year average were 143,000 and 48,600 tons, respectively, about half of which was from livestock. This result showed that the rural human feces amount was necessary to be considered in the study of farmland feces loads due to its large production. Meanwhile, human feces amount was approximately a constant. Thus, livestock feces was the priority of the study on farmland feces loads.

The average annual TN and TP of human and livestock feces were 425,000 and 160,100 tons in these 5 years, respectively, which were equivalent to 83.17% and 65.25% of N and P fertilizer applications in Anhui Province during this period. Therefore, rational and effective application of feces to farmland is beneficial for both fecal pollution solvation and the reduction of chemical fertilizer application.

Farmland Feces Loads of Various Counties in Anhui Province during 2006–2010

The provincial average livestock feces loads of farmland during 2006–2010 was 14.43 thm−2 [Figure 2(a)]. Shexian, Jixi, Xiuning and Taihu exceeded the application standards (30 thm−2) and Shexian was the highest (54.76 thm−2). Only the loads of 37 counties were lower than 15 thm−2. The south and west areas of Anhui Province had higher loads since the farmland was smaller, or the industry or tourism was the leading industry. The counties in the north of the Huaihe River and the east of the province had loads lower than 15 thm−2, suggesting these areas had potentials to enlarge the livestock scales.

The average farmland feces loads of the province
was 20.20 thm\(^{-2}\) after addition of human feces [Figure 2(b)]. Hefei was the highest of 85.07 thm\(^{-2}\). 17 counties or 22.1% of the total counties including Shexian and Ma’anshan exceeded 30 thm\(^{-2}\), in which there were more than 4 counties exceeding 30 thm\(^{-2}\) without consideration of human feces. Only 8 counties including Lujiang were lower than 15 thm\(^{-2}\), and less than 37 counties considered only farmland livestock and poultry feces. These results indicated that human feces played a critical role in farmland feces contaminations, and the results would be seriously distorted if only livestock and poultry feces were considered.

**Farmland N Loads of Various Counties in Anhui Province during 2006–2010**

The pure nitrogen loads converted from livestock feces of Anhui Province was 68.27 kghm\(^{-2}\) on average during 2006–2010 [Figure 3(a)], in which Shexian was the highest of 180.11 kghm\(^{-2}\) and exceeded the EU standards of 170 kghm\(^{-2}\). Meanwhile, Ningguo and Dangshan exceeded 150 kghm\(^{-2}\). The results of nitrogen loads were not always the same as that of the livestock feces loads because the nitrogen contents of feces varied with different livestock species, which also varied greatly in different counties. For example, Ningguo fed mainly poultry with higher fecal nitrogen contents, and the nitrogen loads converted from the feces was 167.73 kghm\(^{-2}\), ranking in the second place in the province, though its livestock feces loads was not high. Livestock industry of Xiuning was mainly pig feeding. Though its feces loads was higher than that of Ningguo, its nitrogen loads was lower (111.12 kghm\(^{-2}\)) due to the low nitrogen contents of pig feces. The more concentrated the livestock industries were, the more concentrated the distribution of feces tended to be. The counties with high N loads were wholly polluted, while there was only spot pollution in the counties with low N loads.

The average farmland feces N loads was 102.91 kghm\(^{-2}\) after addition of human feces [Figure 3(b)]. Hefei (503.14 kghm\(^{-2}\)) and Ma’anshan (398.79 kghm\(^{-2}\)) ranked in the first two places, and far exceeded the average local N fertilizer application (173.33 kghm\(^{-2}\) and –125.88 kghm\(^{-2}\)). Besides, another 8 counties, such as Shexian and so on, exceeded the EU standards. The N loads of 10 counties including Shitai were about 150–170 kghm\(^{-2}\). 20 counties were in pollution, accounting for 26% of the total counties, indicating that the farmland feces N pollution was serious.

**Farmland P Loads of Various Counties in Anhui Province during 2006–2010**

Phosphorus has poor mobility and is easy to be accumulated in the soil. Therefore, both the phosphorus contents from feces application and the phosphorus level of soil should be considered when appraising the environmental effect of feces phosphorus. The pure phosphorus contents from feces application should not exceed 35 kghm\(^{-2}\), otherwise, the surplus phosphorus will enter the surface runoff through leaching which will cause water eutrophication [28,29].

The average farmland P loads converted from live-
Research on the Feces-Bearing Capacity of the Farmland in Anhui Province of China

To take measures to make the livestock feces harmless and resourceful, the feces will aggressively affect the healthy farming development, pollute the near farmland, water bodies and threaten the ecological environment seriously. The paper, aimed at working out the present situation of feces pollution, N pollution and P pollution in Anhui Province to provide scientific basis for the development of pollution control measures, and making reasonable plan and scientific decisions. The related pollution control measures need to be further researched.

Affected by the livestock feed varieties, breeding periods and seasons, weather, management levels and other factors [24,28], there is a certain error between the estimated feces amount and actual feces exertion. According to the factual investigation of Anhui Province, the buffaloes were considered as draft cattle and the yellow cattle were considered as beef cattle. However, a few yellow cattle were used as draft cattle before their slaughter, resulting in lower feces estimation as the excretion parameter is larger when yellow cattle were considered as draft cattle than that of beef cattle.

The raising numbers of ducks and geese were calculated by means of the poultry numbers minus chicken numbers, a small amount of poultry less than geese and ducks in volume and emission were counted into the amount of geese and ducks, resulting in larger feces estimation of ducks and geese.

CONCLUSION

The average annual total livestock feces exertion
was 59.59 million tons from 2006 to 2010, equivalent to 282,000 tons of N and 111,500 tons of P. The average annual total human feces exertion was 23.84 million tons, equivalent to 143,000 tons of N and 48,600 tons of P. The human feces and its N and P were 28.6%, 28.3% and 25.4% of the total statistic feces respectively. Most feces was applied to farmland in its original form and had great environmental impacts on the farmlands. To study the environmental effects of feces in Anhui Province, rural human feces must be taken into consideration.

The average farmland feces loads of the province was 20.20 thm$^{-2}$ in the five years. 17 counties out of 77 exceeded the limit of 30 thm$^{-2}$, with Hefei at the highest of 85.07 thm$^{-2}$. Human feces pollution played an important role in feces pollution of the whole province. Feces loads was in high levels and there were prevalent feces contaminations over the province.

The average farmland N and P loads of livestock feces in the five years were 68.27 kghm$^{-2}$ and 26.99 kghm$^{-2}$, respectively, with only the N loads of Shexian surpassing the EU limit of 170 kghm$^{-2}$ while 29 counties exceeding the P load limit of 35 kghm$^{-2}$. This showed there were great differences in the farmland bearing capacities, and N and P pollution risks from the feces were also different. In addition, different livestock species resulted in different farmland N and P loads and feces loads. The N loads of the counties mainly engaged in poultry exertion were higher than those of pig exertion.

The average annual N and P loads in the five years were 102.91 kghm$^{-2}$ and 38.76 kghm$^{-2}$ respectively after taking into account of human feces. The average N loads of the province was equal to 60.5% of the EU limit. There were 10 counties and cities exceeding the EU limit, with Hefei and Ma’an Shan over the local average nitrogen fertilizer applications. The average P loads of the whole province was more than the limit, with 49 counties surpassing the limit, accounting for 63.6% of the total counties. The P loads of Hefei and Ma’an Shan were the highest.

ACKNOWLEDGEMENTS

I deeply appreciate teacher Yang, my supervisor, for his consistent and illuminating instruction. He walked me through the process of the writing. Without his constant encouragement and guidance, the paper wouldn’t have reached the present form. Meanwhile, I would like to express my gratitude to China clean development mechanism fund (CDMFUND), who funded us to finish the work.

AUTHOR CONTRIBUTIONS

These authors contributed to the conception of the study, analysis and manuscript preparation, data analyses and manuscript writing and the analysis with constructive discussions. Teacher Yang guided the entire work.

NOTES

The authors declare no competing financial interest.

REFERENCES


Research on the Feces-Bearing Capacity of the Farmland in Anhui Province of China


30. The national agricultural technology extension service center. 1999. China organic fertilizer nutrients, Beijing, China Agriculture Press. http://baike.baidu.com/link?url=tNn4qSEp7QaAyJOTcD1ugNZNgtCWBsXnw5mG1OUArGLoaGUGdJ407B_7_PfLJ-n0RsJ1nxYexRy-xOehgXKx_s. (In Chinese)