Technologies selection to prevent and control excrement pollution from livestock and poultry farming in Huang-Huai-Hai Region

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Abstract: Taking nitrogen, phosphorus, heavy metals and antibiotics as selection indicators, the fuzzy matter element analysis based on the entropy weight method was used to evaluate and select the technologies to prevent and control excrement pollution from intensive livestock and poultry farming in the Huang-Huai-Hai (HHH) Region, with the combination of Euclid approach degree. The results showed that the N change rate and the passivation rate of heavy metals in the excrement pollution treatment technologies accounted for higher weights, indicating that the difference between N and heavy metals in different treatment technologies was large. When choosing treatment technology, priority could be given to the technologies to prevent and control N and heavy metals. According to the final evaluation results, the technology of multi-level ecological and in-depth treatment was better for the liquid manure, while the technology of reactor composting was better for the treatment of solid manure.

1. Introduction

The livestock and poultry farming in China is in a period of transition from traditional [1] to industrial livestock farming [2]. Regional and intensive large-scale breeding farms have gradually been built, and the amount of livestock and poultry excrement has been increased year by year [3]. During the period of processing livestock and poultry excrement, serious environmental pollution has been caused due to the inability to treat animal excrement from breeding in a timely and effective manner [4] [5]. The Huang-Huai-Hai (HHH) Region is a typical representative of intensive cultivation areas and the pollution from animal manure discharge load ranks first among similar regions in China. In 2017, the HHH Region produced 288 million tons of livestock manure and 180 million tons of urine, and the emissions of N and P from livestock and poultry breeding accounted for 1/3 of the total amounts in the whole country (The Statistics Yearbook, 2018). There may be exist the pressure difference of excrement treatment in this Region. How these differences affect the environmental impacts from the livestock and poultry farming in this Region is not well understood and requires further studies. Therefore, we address the following key questions. (1) What are the differences in the excrement treatment among various kinds of the livestock and poultry farms? (2) What are the key pollutants for the treatment of excrement from the livestock and poultry farming in this Region?

2. Methods and material

The matter-element theory was put forward by Chinese professor Cai Wen in 1983. It is a science between mathematics and experiment. On the basis of matter-element analysis, Xiao Fangchun [7]
proposed a new analysis method, called "fuzzy matter-element analysis", based on the fuzzy set theory in 1995, which can solve the problem of fuzzy incompatibility.

The main pollutants are antibiotics, heavy metals and, nutrients nitrogen and phosphorus in manure. Using these four pollutants as selection indicators, a comprehensive evaluation of the fuzzy matter-element model can be carried out. The relevant data on live pigs, dairy cows and chicken farms in the Huanghuaihai area are collected by literature and consulting experts.

Steps of fuzzy matter element analysis:

1. Create fuzzy matter element matrix. If the farm has n evaluation indicators C1, C2, ..., Cn and corresponding fuzzy value v1, v2, ..., vn, then call R the n-dimensional fuzzy matter element. If there are n-dimensional fuzzy matter-element combinations of m farms, it constitutes m-things n-dimensional composite matter-element Rmn, referred to as:

   \[ R_{mn} = \begin{bmatrix} M_i \\ C_k \\ v_{ik} \end{bmatrix} \]

   Where: Mi is the i-th farm, i=1,2,...,m; Ck is the k-th evaluation index, k=1,2,...,n; vi is the fuzzy value corresponding to the k-th evaluation index of the i-th farm.

2. The fuzzy value of the membership degree is determined based on the preference. The corresponding fuzzy value of each individual evaluation index is subordinate to the degree of membership of the corresponding fuzzy value of each corresponding evaluation index of the standard scheme, which is called the preferred degree of membership (μik). Because μik is generally a positive value, the following indicators are generally used:

   The bigger the better: \( \mu_{ik} = \frac{v_{ik}}{\max(v_{ik})} \)
   The smaller the better: \( \mu_{ik} = \frac{\min(v_{ik})}{v_{ik}} \)

   Where: \( \mu_{ik} \) is preferential membership degree; \( \max(v_{ik}) \), \( \min(v_{ik}) \) are the maximum and minimum values of all the \( v_{ik} \) values of each evaluation index in each thing. Thereby constructing the fuzzy matter-element matrix of preferred membership degree.

3. Construct difference square fuzzy matter element matrix. A very important factor in comprehensive evaluation is that the weight of fuzzy value assignment reflects the degree of influence of each index on the optimal result. Therefore, the mean square error method is used to determine the evaluation index. \( \mu_0k \) is the optimal value in the preferred membership matrix, and the standard fuzzy matter-element \( R_0n \) is composed of \( \mu_0k \). \( \Delta_{ik} \) represents the square of the difference between \( R_0n \) and the fuzzy matter-element of the preferred membership degree, that is, \( \Delta_{ik} = (\mu_{0k} - \mu_{ik})^2 \), which constitutes the difference-squared composite fuzzy matter-element.

4. Determination of weight. The weight reflects the importance of an indicator, the degree of difference in the attribute values of various indicators, and the reliability of the attribute values of the indicators. It is an important parameter in the evaluation system. Entropy is a measure of the disorder degree of the reaction system. In the evaluation plan, the greater the disorder degree of an indicator, the greater the difference of its response, the greater the weight, and vice versa, the smaller the weight. Entropy method is an objective weighting method, which can effectively avoid the subjective influence of people.

   The construction of the judgment matrix is the same as the construction of the fuzzy matter element. Then normalize the judgment matrix:

   The bigger the better: \( a_{ik} = \frac{(v_{max} - v_{ik})}{(v_{max} - v_{min})} \)
   The smaller the better: \( a_{ik} = \frac{(v_{ik} - v_{min})}{(v_{max} - v_{min})} \)

   When there are n evaluation indexes and m evaluated things, the entropy of the k-th evaluation index is determined as:

   \[ H_k = \frac{1}{\ln m} \sum_{i=1}^{m} f_{ik} \ln f_{ik} \]  \hspace{1cm} \text{(1)}

   \[ f_{ik} = \frac{e^{1+a_{ik}}}{\sum_{i=1}^{m} e^{1+a_{ik}}} \]  \hspace{1cm} \text{(2)}
3. Selection of treatment technologies for excrement pollution in different kinds of livestock and poultry farming

In the HHH Region, treatment technologies for excrement pollution from different kinds of livestock and poultry farming were different, as shown in Table 1, Table 2 and Table 3. Treatment technologies for excrement pollution in pig and dairy cow farming could be divided into solid manure treatment technologies and liquid manure treatment technologies, while only consider the technologies to treat solid manure in the chicken farming because most of the manure produced by chickens was solid, as shown in Table 4 and Table 5. The solid manure was returned to the field after treatment. Considering that the content of N and P in solid manure was increased after treated, the treatment technologies would be better with higher increase rate. The treated liquid manure will be discharged if it could reach the standards or be recycled, so the technologies would be better with higher removal rate of N and P in liquid manure.

Table 1. Changes of N, P, antibiotics and heavy metals in pig excrement from different treatment technologies (%)

|                | Stack composting | Trough composting | Natural composting | Reactor composting | Anaerobic digestion | Fermentation bed | Industrial treatment | Oxidation pond |
|----------------|------------------|-------------------|--------------------|--------------------|---------------------|------------------|---------------------|---------------|
| N change rate  | 44.60-58.50%     | 8.10% reduction   | 7.0-55.9% reduction| 6.38-14.68% reduction| 67.22-84.31% reduction| 21.5-44.1% reduction| 7.8-25.4% reduction| 7.4-24.7% reduction|
| P change rate  | 26.10-29.70%     | 3.60% reduction   | 2-28.2% reduction  | 21.22% increase    | 59.70-93.45% reduction| 14 reduction     | 39.5-72.1% reduction| 61.6-73% reduction|
| Antibiotic removal rate | 76.95% reduction| 91.98% reduction | 83.83% reduction  | 91.60% reduction  | 64.98% reduction   | 82% reduction   | 83.58% reduction  | 100% reduction |
| Changes in heavy metal content | 25.18% increase | 25.18% increase | 22.90% increase | 44.5% reduction  | 12.25% reduction  | 26.73% increase | 99.37% reduction  | 29.5% reduction |

*The unmarked data in the table comes from experimental data

Table 2. Changes of N, P, antibiotics and heavy metals in dairy cow manure produced by different control (%)

|                | Anaerobic engineering | Advanced treatment | Ecological purification | Stack composting | Trough composting | Natural composting | Container composting |
|----------------|-----------------------|--------------------|-------------------------|------------------|------------------|---------------------|----------------------|
| N change rate  | 21.70% increase       | 94.89% reduction   | 82.59% reduction        | 26.20% reduction | 13.04% reduction | 18.50% increase     | 27.80% increase |
| P change rate  | 39.00% increase       | 98.53% reduction   | 72.39% reduction        | 25.73% increase  | 21.60% increase  | 99.00-100.00% increase | 11.00% increase |
| Antibiotic removal rate | 53.00-86.15% reduction| 57.67-100.00% reduction| 47.74-76.87% reduction| 86.50-100.00% reduction| 81.83-100.00% reduction| 28.29-32.28% decrease|
| Passivation rate of heavy metals | 25.78-45.76% | 83.00-85.00% | 86.50-89.45% | 46.31-98.17 | 3.80-7.00% | 1.92-2.09% | 26.29-32.28% |

*The unmarked data in the table comes from experimental data
Table 3. Changes of N, P, antibiotics and heavy metals in chicken manure produced by different control (%)

|                | Fermentation bed | Anaerobic fermentation | Natural composting | Stack composting | Trough composting | Reactor composting |
|----------------|------------------|------------------------|--------------------|------------------|-------------------|-------------------|
| N change rate  | 9.50-29.20       | 4.72 increase          | 4.90-5.80 increase | 6.60-11.80       | 13.20-20.80       | 2.20-15.60         |
| P change rate  | 0.50-0.98 increase | 4.52 increase        | 8.00 reduction to 10.70 increase | 1.00-10.70 increase | 4.10-32.14 increase | 1.67-24.55 increase |
| Antibiotic removal rate | - | 57.68-87.60 | 79.60-99.00 | 54.95-88.05 | 75.37 | 80.00-85.00 |
| Passivation rate of heavy metals | - | 6.12-13.84 | 19.86-52.32 | 18.92-50.02 | 18.92-50.02 | 14.22-35.64 |

*The unmarked data in the table comes from experimental data

Table 4. Changes of N, P, antibiotics and heavy metals in solid manure of different animals produced by different control (%)

|                | N increase rate | P increase rate | Antibiotic removal rate | Passivation rate of heavy metals |
|----------------|-----------------|-----------------|-------------------------|----------------------------------|
| Pig            |                 |                 |                         |                                  |
| Stack composting | 51.55           | 27.9            | 100                     | -25.18                           |
| Trough composting | -8.1            | -3.6            | 91.99                   | -25.18                           |
| Natural composting | -31.45          | -15.3           | 83.83                   | -22.9                            |
| Reactor composting | -10.53         | 21.22           | 91.6                    | 44.5                             |
| Dairy cow      |                 |                 |                         |                                  |
| Stack composting | -26.2           | 25.73           | 88.83                   | 72.24                            |
| Trough composting | -13.04          | 21.6            | 99                      | 5.27                             |
| Natural composting | 18.5            | 22.49           | 90                      | 2.01                             |
| Container composting | 27.8           | 11              | 86                      | 29.29                            |
| Fermentation bed | -19.35          | 0.74            | -                       | -                                |
| Anaerobic fermentation | 4.72      | 4.52            | 72.64                   | 9.98                             |
| Natural composting | 5.35            | 1.35            | 89.3                    | 36.09                            |
| Stack composting | -9.2            | 5.85            | 71.5                    | 34.47                            |
| Trough composting | -13.2           | 18.12           | 75.37                   | 34.47                            |
| Reactor composting | 8.9             | 12.82           | 82.5                    | 24.93                            |
| Chicken        |                 |                 |                         |                                  |
| Fermentation bed | -19.35          | 0.74            | -                       | -                                |
| Anaerobic fermentation | 4.72      | 4.52            | 72.64                   | 9.98                             |
| Natural composting | 5.35            | 1.35            | 89.3                    | 36.09                            |
| Stack composting | -9.2            | 5.85            | 71.5                    | 34.47                            |
| Trough composting | -13.2           | 18.12           | 75.37                   | 34.47                            |
| Reactor composting | 8.9             | 12.82           | 82.5                    | 24.93                            |

*The negative sign (-) in the increase rate of N and P indicates that the content of N and P decreases; the negative sign (-) in the passivation rate of heavy metals indicates that the content of heavy metals increases

Table 5. Changes of N, P, antibiotics and heavy metals in liquid manure of different animals produced by different control (%)

|                | N removal rate | P removal rate | Antibiotic removal rate | Passivation rate of heavy metals |
|----------------|----------------|----------------|-------------------------|----------------------------------|
| Pig            |                 |                 |                         |                                  |
| Anaerobic digestion | 75.77          | 76.58          | 64.98                   | 12.25                            |
| Oxidation pond | 16.05           | 67.3           | 64.98                   | 29.5                             |
| Industrial treatment | 16.6           | 55.8           | 83.58                   | 99.38                            |
| Dairy cow      |                 |                 |                         |                                  |
| Anaerobic engineering | -21.7         | 39              | 70                      | 35.77                            |
| Advanced treatment | 94.89          | 89.53          | 79.37                   | 84                               |
| Ecological purification | 82.59         | 72.39          | 57.22                   | 87.75                            |

*The negative sign (-) in the N increase rate means that the N content decreases

A positive value indicated that there was an increase of the content of N and P in solid manure, while a negative value indicated that there was a decrease in the content of N and P in solid manure. The content of N and P in liquid manure was converted to the removal rate of nitrogen and phosphorus. A positive value meant there was a decrease in the content of N and P in liquid manure, and a negative value meant there was an increase in the content of N and P in liquid manure. According to the collected data (See Table 4), the stack composting and trough composting in pigs solid manure treatment of had a good effect on the increase rate of nitrogen and phosphorus, and the reactor composting had a good effect on the removal rate of antibiotics and heavy metals. The four solid manure treatment technologies had good removal effects on antibiotics. Among the technologies for the prevention and control of pig liquid manure, anaerobic digestion technology was very effective to remove the nitrogen and phosphorus, and industrial treatment technology had a good removal or passivation rate for heavy metals and antibiotics.

In dairy cow solid manure treatment technologies, natural composting and reactor composting had good effects on nitrogen and phosphorus, and stack composting had good treatment effects on the...
removal of antibiotics and passivation of heavy metals. Advanced treatment of dairy cow liquid manure had a good removal rate of nitrogen, phosphorus, antibiotics and passivation of heavy metals.

After averaging the data in Table 3, the rate of increase in nitrogen and phosphorus would be considered. Negative values indicated a decrease in nitrogen and phosphorus content in solid manure. The general function of the fermentation bed was to improve the environmental sanitation in the breeding house, but there was an accumulation effect of heavy metals and antibiotics in the fermentation bed. Therefore, chicken solid manure should be treated with the combination of fermentation bed and the composting. Reactor composting had a good treatment effect on the increase of nitrogen and phosphorus, the removal of antibiotics and the passivation of heavy metals in chicken excrement.

Among the solid manure treatment technologies in pig farming (see Fig. 1), the increase rates of P and the removal rate of heavy metals accounted for a higher weight value, indicating that the change rates of P and heavy metals between different technologies in the treatment of pig solid manure were quite different. But different results were found in the solid manure treatment technologies in dairy cow and chicken farming. The increase rate of N accounted for the largest proportion, indicating the increase rate of N between the technologies to treat dairy cow solid manure was quite different. The weight value of N and heavy metals was relatively large, indicating that the change rate of N and heavy metals was quite different among the various treatment technologies for chicken solid manure. However, among the liquid treatment technologies, N accounted for the largest weight, followed by heavy metals, indicating that these two indicators were quite different in the liquid manure treatment technologies for three kinds of livestock and poultry.

![Graphs and figures](a)Weight of pig control technology; (b)Weight of dairy cow control technology; (c)Weight of chicken control technology

Figure 1. Weight of excrement pollution treatment technologies in livestock and poultry farming

According to the results of Euclid approach degree (shown in Fig. 2), the reactor compost in the solid manure control technology for pig excrement was much better than other treatment technologies, followed by the stack composting, but the effect of natural composting was much poor; anaerobic digestion and oxidation pond technology in the treatment of had better treatment effects. Different
results were found in the treatment technologies for dairy cow excrement and chicken excrement. The treatment technologies of natural composting, stack composting to treat dairy cow solid manure were closer to the ideal treatment technology, while advanced treatment technologies for liquid manure was better than other technologies, such as anaerobic engineering. The treatment technologies of the reactor composting to treat chick solid manure was closer to the ideal treatment technology, while the anaerobic fermentation was worse.

![Image](image_url)

(a) Euclid approach degree of pig control technology; (b) Euclid approach degree of dairy cow control technology; (c) Euclid approach degree of chicken control technology

Figure 2. Euclid approach degree of pollution control technology in livestock and poultry farming

4. Conclusion

In general, the N change rate and the passivation rate of heavy metals in three kinds treatment technologies for excrement pollution from livestock and poultry farming accounted for a higher weight, indicating that there was a larger gap in N and heavy metals between different treatment technologies, while the removal rate of antibiotics occupied a smaller weight in each treatment technology. Therefore, when selecting treatment technology, priority should be given to prevention and control of N and heavy metals. From the collected data, various treatment technologies could remove the antibiotics, but with closer removal rate between technologies, so the priority of prevention and control would not be considered.

According to the final evaluation results of the fuzzy matter-element model, the multi-level ecological and in-depth treatment for the liquid manure pollution in pigs and dairy cows farming was closer to the ideal treatment of liquid manure; among the treatment technologies for solid manure in three kinds of livestock and poultry, the treatment effect of reactor composting and stacking composting were better than other technologies. The fuzzy matter element model could consider ‘the larger the better’ for heavy metals and antibiotics, N and P in solid manure, and ‘the smaller the better’ for N and P in liquid manure. This method is useful to assess various technologies to treat animal excrement, whether they could fix nitrogen and phosphorus before returning to the field or reducing the excrement pollution before emitted.
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