FACTOR ANALYSIS OF ENVIRONMENTAL IMPACT OF MANURE UTILIZATION

Igor Subbotin, Aleksandr Briukhanov, Eduard Vasilev
Institute for Engineering and Environmental Problems in Agricultural Production – IEEP, Russia
itmo1652@mail.ru

Abstract. Modern livestock farms feature a large number of animals and subsequent significant environmental load. The biggest negative impact is on the atmosphere and on water bodies, with manure being the major pollution source. The proper choice of an effective low-cost manure handling technology with low nutrient loss ensures the environmentally sound operation of these farms. Manure utilization is understood as a set of activities, including manure processing, manure storage (if necessary) and soil application of produced organic fertilizers. It is important to deal with manure utilization as an integral whole, rather than to improve a separate process that has a minor contribution to the decrease of the overall negative impact of manure. The article considers the nitrogen loss during manure utilization depending on such factors as type of manure processing, manure storage conditions, soil application practices, moisture content of raw manure, nitrogen-carbon ratio in the raw manure, and quality of the staff. To identify the dependence of nitrogen loss from these factors a method of logical-linguistic modelling was applied, by which the expert data were formalized in a mathematical model. In view of the differences of processes, which take place during the storage and processing of liquid and solid manure, two models were considered - for liquid manure with the moisture content > 92 % and solid manure with the moisture content ≤ 92 %. The analysis of the coefficients of the obtained equations showed the significance of each factor and their mutual dependence. Most significant factors were the type of manure processing and the soil application method. The simulation study results were compared with the values obtained by measurements on operating farms, with the maximum inaccuracy being 5.35 %. The obtained equations may be used for express calculation of nitrogen loss and to forecast the variations of nitrogen loss under different manure handling technologies.

Keywords: manure utilization, environmental impact, manure handling, manure management, factor analysis.

Introduction

Modern livestock farms feature a large number of animals and subsequent significant environmental load. The biggest negative impact is on the atmosphere and on water bodies, with manure being the major pollution source. This problem is particularly relevant for the regions near large water bodies, which are subject to eutrophication. In this case, eutrophication is enhanced by both waterborne nitrogen and phosphorous and airborne nitrogen (ammonia). Baltic region agriculture is a significant source of nutrients that cause eutrophication of the Baltic Sea. In 2007, the Baltic Marine Environment Protection Commission (HELCOM) adopted the Baltic Sea Action Plan, which included, inter alia, the target reductions in nitrogen and phosphorus inputs for each country of the Baltic Sea catchment area [1]. In the HELCOM Copenhagen Ministerial Declaration of 2013 the quotas for the supply of nitrogen and phosphorus to the Baltic Sea for each country were revised, and full achievement of an ecologically safe level of nutrient inputs to the Baltic Sea is scheduled by 2021 [2]. The purpose of this study was to analyze the impact of manure utilization factors on manure nitrogen retention in order to find ways to reduce nitrogen losses (improve the retention) at the farm level.

Materials and methods

Manure utilization technology is understood as a set of activities, including manure processing, manure storage and soil application of organic fertilizers. Manure processing includes the processes aimed to kill the weed seeds and helminthes: long-term storage, composting, accelerated composting, methane fermentation, etc.

The desk research showed that the microbiological processes occurring in manure and contributing to nitrogen losses vary greatly, depending on manure moisture content. Therefore, it was decided to create two models – for manure with moisture content above 92 % and for manure with moisture content not more than 92 %. In the first case aerobic processes prevail in manure, in the latter case - anaerobic processes.

To create the factor model the method of logical-linguistic modeling was used [3]. This method allows to formalize the expert data and is based on the experimental design theory and fuzzy logic.

Using of this method in agriculture, which is characterized by high uncertainty and uneven factor values, has shown the possibility of obtaining models adequate to the studied objects on the basis of expert estimates [4; 5]. The method includes the following steps:

1. To identify the target indicator – dependent variable (including its dimension, range of possible values, and correlation between dimensional values and linguistic estimates). In our case, the target indicator is the level of nitrogen retention in the process of manure utilization.

2. To identify the factors, which affect the target indicator. The following factors affecting the manure nitrogen retention were considered:

1. Manure processing method (nitrogen retention level on the processing stage, %);
2. Manure storage method (nitrogen retention level on the storage stage, %);
3. Method of fertilization (manure nitrogen retention level on the stage of its application as a fertilizer, %);
4. Initial moisture content of manure, %;
5. Nitrogen-to-carbon ratio in manure (N:C);
6. Efficiency of personnel (quality of the work of personnel).

At this step, opposition scales were created for each factor variable, which set the correlation between linguistic and numerical values and a standardized interval [-1; +1]. For example, Figure 1 shows the opposition scale for the factor variable x_1 – "manure nitrogen level on the processing stage" for solid manure.

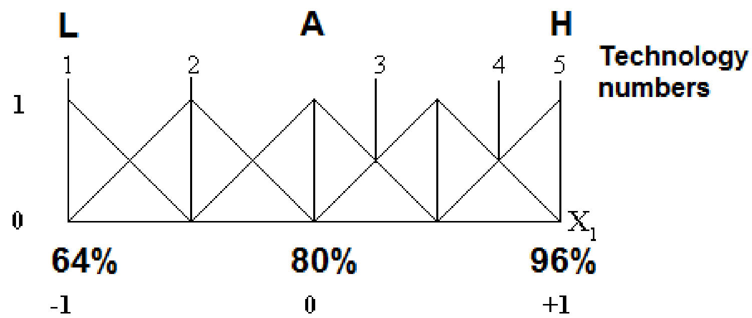

Fig. 1. **Opposition scale for the factor variable x_1**

"L", "A" and "H" (low level, average level, high level) are the values of this variable in linguistic form, 64 %, 80 % and 96 % - are the corresponding values in numerical form. In this case, the low value of nitrogen retention in the processing technology #1 (64 %) corresponds to the linguistic value "low level". Similar opposition scales were created for each factor. To construct an opposition scale of the "manure moisture content" factor, the hypothesis was used that increasing of manure moisture content reduces nitrogen retention in manure. To construct the opposition scale of the "nitrogen-to-carbon ratio" factor, the hypothesis was used that with higher ratio (within the standard range of values), manure nitrogen retention is also higher.

3. To create a matrix and fill it in by the expert with relevant knowledge and experience. At this step, the experts considered combinations of different values of factor variables and evaluated the target indicator (nitrogen retention) in them. The matrix was compiled using standardized values of factor variables. Doing the assessment, the experts were guided by their experience, including known reference materials and experimental results. Part of the matrix is shown in Figure 2.

Expert evaluations are expressed in linguistic form. Opposition scales for the target indicator were constructed on the basis of the desk research results and are shown in Figure 3.

The values "L", "BA", "A", "AA", "H" (low level, below average level, average level, above average level, high level) and intermediate values ("L-BA", "BA-A", etc.) are used, then the resulting estimates are transformed into a numerical form in accordance with the opposition scale shown in Figure 3. Y_1 – is level of nitrogen retention in manure with the moisture content above 92 %, Y_2 – is level of nitrogen retention in manure with the moisture content not more than 92 %.

	x_1	x_2	x_3	x_4	x_5	x_6	Y
1	-1	-1	-1	-1	-1	-1	
2	1	-1	-1	-1	-1	1	
3	-1	1	-1	-1	-1	1	
4	1	1	-1	-1	-1	-1	
5	-1	-1	1	-1	-1	1	
6	1	-1	1	-1	-1	-1	
31	-1	1	1	1	1	-1	
32	1	1	1	1	1	1	

Fig. 2. **Matrix for gathering expert evaluations**

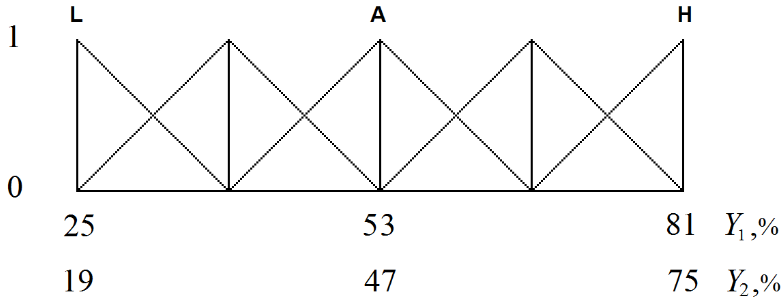

Fig. 3. **Opposition scale for manure nitrogen retention values (target indicator)**

4. To process the expert evaluations by the regression method (Least-squares method or a similar method can be used) and to construct the closed-form objective function, which reflects the dependence of the target indicator on the factor variables.

5. To analyze the adequacy of the objective function to the initial data and to acquire new information on the phenomenon under study by interpretation of the equations obtained.

Two groups of experts were created (separate group for each studied case).The number of experts in the groups was 15 and 17 people. Within the groups of experts the Institute for Engineering and Environmental Problems in Agricultural Production (IEEP) experts, the leading specialists of the Society for Assistance of Sustainable Rural Development (Russian NGO) as well as competent farm managers were included.

Results and discussion

Application of the logical-linguistic method resulted in two equations of nitrogen retention – for the manure with moisture content above 92 %:

$Y_1 = 54.75 + 7.44x_1 + 3.5x_2 + 5.69x_3 + 1.75x_4 + 4.81x_5 + 3.06x_6 - 3.94x_1x_4 + 1.31x_2x_3 + 1.75x_2x_4 - 4.81x_2x_5 + 2.19x_2x_6 + 1.75x_5x_6 + 1.75x_1x_2x_6 - 2.19x_1x_3x_6 + 1.75x_2x_3x_5$;

and for the manure with moisture content not more than 92 %:

$Y_2 = 48.31 + 5.69x_1 + 3.5x_2 + 6.56x_3 + 1.75x_4 + 1.75x_5 + 1.75x_6 - 1.75x_1x_2 + 2.63x_2x_3 - 3.06x_2x_5 + 2.63x_3x_4 + 1.31x_1x_2x_4 - 2.19x_1x_2x_5 + 1.31x_1x_2x_6 + 2.63x_1x_3x_4 + 3.06x_2x_3x_4$;

Analysis of the obtained equations allowed to compare the significance of the factors and to assess their mutual influence. Proceeding from the received equations, the factor #1 (Manure processing method) has the greatest influence on nitrogen retention in liquid manure; factor #3 (Fertilization method) has somewhat less importance. For semi-liquid and solid manure, the most important is factor #3 (Fertilization method); factor #1 (Manure processing method) has somewhat less importance. The least significant factors are factor #4 (Initial moisture content of manure within the ranges “less than 92 %” and “above 92 %”) and factor #6 (Efficiency of personnel). Improving the quality of the work of personnel engaged in manure utilization, while other factors remain unchanged, does not have a significant effect on nitrogen retention. The presence of multiplication of factor variables in the equations means that these factors mutually affect the target indicator. For example, the presence of the element of the Y_2 equation "$+3.06x_2x_3x_4$" means that the improvement of factors #2, #3, #4 gives not proportional, but greater effect (synergistic effect). The presence of a negative coefficient before factor variables multiplications, shows that increase of each factor value will eventually give a disproportionately smaller effect. The difference between single and multiple coefficients determines the degree of nonlinearity of the function. Figures 5 and 6 show the surfaces of dependences of nitrogen retention on factor variables x_1, x_4 and on factor variables x_4, x_5.

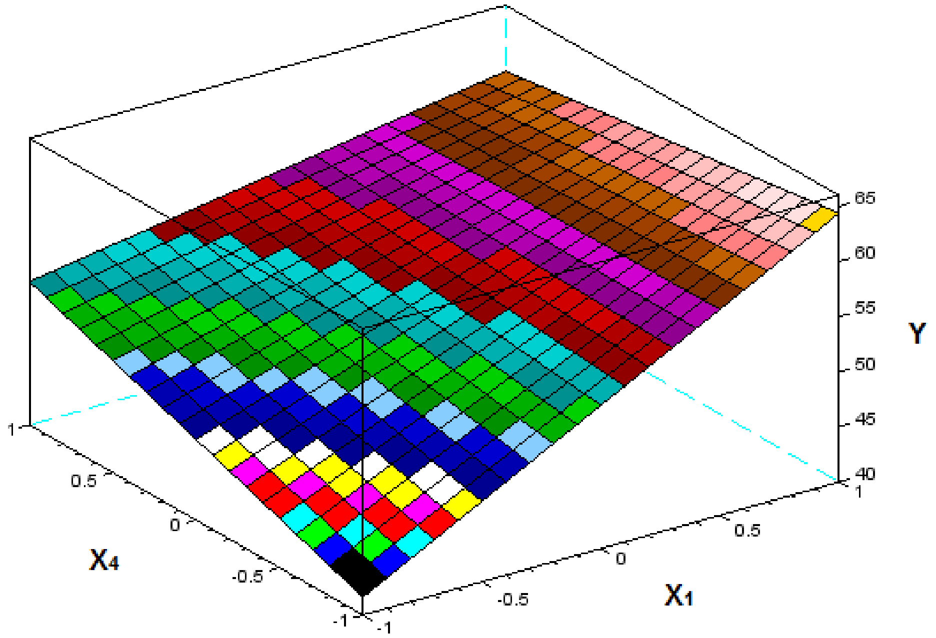

Fig. 4. **Surface of dependence of nitrogen retention on selected manure processing technology and initial moisture content**

Comparison of the calculated values on the basis of the obtained equations with the real values obtained by the balance method with sampling showed a maximum error of 5.35 % that makes it possible to use these equations for the express-estimation of the nitrogen retention level.

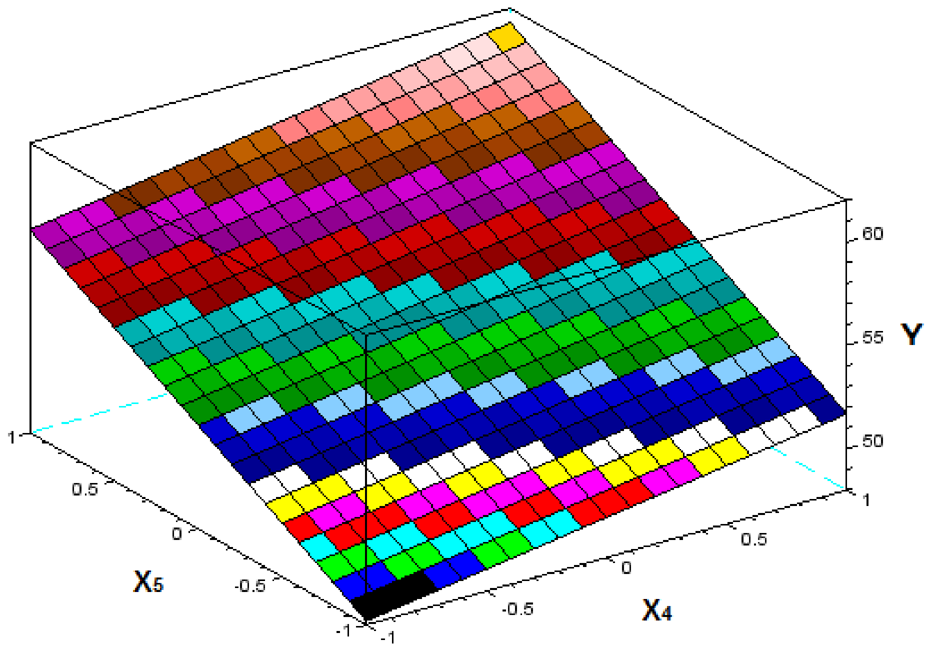

Fig. 5. **Surface of dependence of nitrogen retention on the initial moisture content and nitrogen-to-carbon ratio**

Conclusions

1. The obtained data on the influence of the considered factors show that the greatest increase in the nitrogen retention level can be achieved by using the best manure processing and fertilization technologies. The least significant factors are the initial moisture content of and efficiency of personnel.
2. The simulation study results were compared with the values obtained by the measurements on operating farms, with the maximum error being 5.35 %. The obtained equations may be used for express calculation of nitrogen loss and to forecast the variations of nitrogen loss under different manure handling technologies.

References

1. Baltic Sea Action Plan - HELCOM. [online] [17.03.2017]. Available at: http://helcom.fi/baltic-sea-action-plan
2. Ministerial Declaration - HELCOM. [online] [17.03.2017]. Available at: http://helcom.fi/Ministerial2013/ministerial-declaration
3. Спесивцев, А.В. Метод извлечения и формализации экспертной информации (Method of extraction and formalization of expert information). Management under uncertainty: Monograph, St. Petersburg: Publishing house SPbGETU «LETI», 2014, 304 p. (In Russian).
4. Briukhanov A. Yu., Trifanov A. V., Spesivtsev A. V., Subbotin I. A. Logical-linguistic modeling in addressing agro-environmental challenges. Proceedings of conference “2016 XIX IEEE International Conference on Soft Computing and Measurements (SCM)”, May 25-27, 2016, St.Petersburg, Russia, pp. 164-166.
5. Popov V.D., Spesivtsev A.V., Sukhoparov A.I., Spesivtsev V.A. Use of logical-linguistic models to predict the retained biological potential of grasses during their conservation. Proceedings of conference: Proceedings of conference “2016 XIX IEEE International Conference on Soft Computing and Measurements (SCM)”, May 25-27, 2016, St.Petersburg, Russia, pp. 244-246.