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UTILIZATION OF POULTRY DROPPINGS IN TERMS OF NON-WASTE TECHNOLOGY

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The processing of poultry droppings under anaerobic conditions, in special hermetic reactors – methane tanks is considered to be the most promising technology in terms of efficiency in agrochemical, environmental, and energy fields. Organic fertilizer in the methane tank is in the form of concentrated liquid, purified from disease causatives and weed seeds. It is easily absorbed by fermented plant mass and contains macro and micronutrients, amino acids and phytohormones that stimulate the development of the plant. The rare utilization of such facilities is explained by the lack of funds for their purchase. On the other hand, it is assumed that biogas is not a dominant factor in terms of economic efficiency, and organic fertilizer is also important. In this respect, the utilization of poultry droppings has also gained practical relevance.

The paper covers the discussion of the feasibility of utilizing poultry droppings as a non-waste technology. The methodological approach is based on the evaluation of more rational technological projects. In logical modeling, the rules drawn up by highly qualified specialists are used. The rules determine how to act in a certain situation. Such rules are considered favorable for non-skilled performers. The results of the studies have allowed analyzing the dynamics of nitrogen preservation depending on the utilization technology of poultry droppings and impact factors. Based on a mathematical model, a computer methodology for research on improving the energy efficiency of a poultry farm has been developed. The number of LEDs ($\alpha=20^0$, $I_0=20$ ***kd) for a 66×12 m poultry house using a computer program N=273 pcs., the number of LEDs (*** $\alpha=20^0$, $I_0=20$ ***kd) for a building with dimensions of 78×18 m N=259 pcs. The design parameters of the lamps are substantiated***

Keywords: mathematical modeling, fertilizer processing, nitrogen preservation, non-waste technology, organic fertilizer

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1. Introduction

Bird droppings are used irrationally and unecologically in the case of pile composting, storage in litter storage facilities, burning of manure to produce heat and electricity, anaerobic decomposition of compost components to produce biogas, drying of manure of various humidity, thermal drying to obtain dry bird droppings used as organic fertilizer, burning of manure, processing of manure by biofermen-tation in plants, vermicomposting, conducting pyrolysis and therefore there is no ecological and systematic approach to solving the problem of disposal of bird droppings. Poultry farms are forming an increasingly complex ecological situation, as accumulated bird droppings have become a serious source of environmental pollution. In this regard, specialized enterprises for processing bird droppings are needed.

For applied ecology, the utilization of poultry waste is of great importance. There are the following variants applied to the practice of poultry waste utilization in the world: organic fertilizer, vermiculture, and feed preparation.

The utilization of poultry droppings under anaerobic conditions, in special hermetic reactors – methane tanks is considered to be the most promising technology in view of efficiency in agrochemical (fertilizer preparation), environmental (neutralization and deodorization) and energy (fuel and electricity generation) fields [1].

It should be noted that the preparation of organic fertilizers can help resolve the critical problem in terms of soil fertility and agricultural crop productivity contributing to the rapid development of the agricultural sector. Despite the urgency of this problem, the use of technologically developed organic fertilizers decreased more than twice in comparison with the 1990s. The livestock and poultry farms of the republic produce millions of tonnes of manure and poultry droppings, which is 62 % of the total fertilizer demand. However, more than 25 % of this potential is not used. The main reason for this is that the economically feasible, constructive, and exploited simple technologies and techniques are not justified for specific economic conditions.

Under oxygen-free (anaerobic) conditions as a result of the activity of methane-producing bacteria, fermentation of poultry droppings occurs in the reactor at 39–40 °C, where the gas containing 60–65 % methane and 35–40 % carbon dioxide emerges [1]. The calculations revealed that from manure with 92 % moisture, 20 m^3 of biogas with a thermal capacity of 23–25 MC/m^3 can be obtained during 10–15 days. 50 % of this fuel can be used to maintain the required temperature in the methane tank, and the rest can be used for agricultural needs.

Organic fertilizer in the methane tank is in the form of concentrated liquid purified from disease causatives and weed seeds. It contains macro and micronutrients, amino acids and phytohormones that stimulate the development of the plant. Such fertilizers can be used in all types of soils where vegetables, fruits, berries, fodder plants, lawns, decorative plants, etc. are cultivated. World practice shows that when using such fertilizers in the cultivation of vegetables in irrigated soils (3–4 times, every 10 days), productivity increases by 2–3 times.

In our country, only a few farms use small methane tanks for the processing of cattle manure. The insufficient use of such facilities is due to limited financial resources. In addition, it has been assumed that the main economic effect of these installations is at the expense of biogas. In fact, biogas is not a dominant factor in economic performance. Here the organic fertilizer factor is not taken into account.

From this point of view, the utilization of poultry droppings has gained urgency for obtaining eco-friendly products. Therefore, the research that is devoted to the justification of the operating parameters of the device for the fermentation of bird droppings has great scientific significance. In this regard, specialized enterprises for processing bird droppings are needed. After analyzing the results of the research, an urgent problem arises: the solution and the right approach to solving the problem of recycling bird droppings. So, the proposed method of waste-free technology is relevant.

2. Literature review and problem statement

The abundance of technologies and techniques offered for the utilization of poultry droppings and the variety of capabilities of the facilities available make it necessary to search for more rational, more efficient and adaptable design methods for the given technological conditions.

The purpose of [1] was to analyze the current state of the practice of handling poultry manure in Poland and to present future prospects in terms of technologies that allow closing the cycles of the cyclical economy and, thus, restoring nutrients and energy. The scope of the review focused mainly on the analysis of poultry farming and poultry manure production with special references to quantity, properties (for example, fertilizer properties), seasonality, etc., but the authors did not conduct a complete analysis of the use of poultry manure. The paper [2] critically analyzes the potential of largely underutilized biomass waste resources for biogas production as a waste-to-energy conversion technology to overcome the energy crisis in Pakistan, the author analyzes the ecological energy system but does not mention bird droppings, which is sufficient, and as is known, bird droppings are one of the main resources for biogas production. The study [3] is aimed at studying the use of poultry and household waste for the production of biogas. The current level of diesel fuel consumption is quite high, taking into account gas emissions and the rapid depletion of non-renewable fuel sources. The conducted research consists in adding a certain optimal amount of biogas from poultry waste to the gas mixture from the carburetor to reduce fuel consumption. The greatest potential for biogas production for a mixture of excrement of dairy animals and poultry is achieved at a ratio of 25 % CD+75 % PL, >50 % CD+50 % PL, >00 % CD+100 % PL. A two-component mixture of 20 % and 30 % biogas with air shows that the amount of diesel fuel consumption is decreasing, but unfortunately the authors do not fully disclose this technology and there is no analysis with the existing advantages. The parameters [4] of aerobic solid fraction fermentation of a mixture of solid swine manure, poultry litter with the addition of carbon-containing plant materials have been investigated. A bioreactor design has been developed. Qualitative rating of the process and the end product has been made by measuring such parameters as: process temperature, mixing process, air supply for aeration, pH and ash. A rational mixing mode for the mixture has been found by investigating the dependency of temperature and time of mixture fermentation, but no analysis of the unit and the principle of its operation was carried out. In [5], the authors investigated mainly disposal by incineration, resulting in the formation of greenhouse gases and NOx. These wastes are a source of nutrients that can be recovered using circular economy methods if recycling of materials is given priority over energy recovery. In order to use high-protein animal waste (containing bones, meat, feathers) as fertilizer, the waste was treated with acid solubilization and neutralized with a solution of potassium hydroxide, resulting in a liquid fertilizer with biostimulating properties for plant growth (due to the presence of amino acids). The analysis of the composition showed that the new fertilizers meet all the quality requirements established by law, contain ~0.5 % m/m of amino acids and are microbiologically pure. The fertilizer was enriched with trace elements to the level of 0.2 % m/m and tested for biological efficacy in germination tests and field studies. The authors conducted a full analysis of the proposed disposal method and noted the positive part, but the distinctive characteristics, as well as the more rationality of this method compared to existing ones, have not been done. Formal and informal methods are used to make decisions about designing. Making a formal decision is a creative process realized on the basis of accurate recommendations. These decisions are based on two main methods: logical modeling and optimization. The work [6] provides a method and device for drying and conditioning bird droppings or similar paste-like materials in the form of particles of selective microorganisms in the microbiological phase that are fixed on a stable molded carrier element, but the author analyzes the effectiveness for drying bird droppings and basically the principle of optimizing climatic conditions with conditioned air for the activity of microorganisms. In [7], the analysis of manure processing technology is carried out, which allows producing several types of the final product, unifying production, reducing economic costs and optimizing labor costs. The study [8] showed that poultry waste can be used as a suitable renewable medium for the growth of Chlorella sp. Consequently, the author analyzed the use of poultry waste, but unfortunately this technology and its advantages are not disclosed. The paper describes the use of bird droppings as a feed ingredient. The analysis [9] of this work showed that the research was aimed at the preparation of waste, but the technology and comparison with those used in the agricultural sector are not fully described.

Despite the large number of studies conducted, there are currently no scientifically sound universal technical and technological solutions that ensure the production of several types of end products using a single set of technical equipment. In [10], the effect of broiler droppings on the primary productivity and net yield of large carp fish during one year in four earthen fish ponds was studied. These studies showed the productivity of plankton, the number of phyto- and zooplankton, as well as the ratio of phytoplankton/zooplankton differed significantly in the treated and control ponds, but no studies were conducted to compare other forms, which would help to assess the positive aspects of this product. The proposed technology [11] of utilization of fresh bird droppings considered in the paper is completely new and has no analogs in the Russian Federation. It is based on the process of bioconversion of droppings from poultry farms using larvae of the black soldier fly (*Hermetia illucens L.*). The proposed system provides a solution to several problems: disposal of poultry waste (bioconversion: 4.9...6.3 kg/m^2/day), the use of dried fly larvae as a protein-rich feed additive in feed production (0.2...2.1 kg/day/m^2 of larvae). This method is unique, but the principal system that differs from the existing ones is not specified. The author [12] shows the ways of finding and implementing scientific and technical solutions that increase the efficiency of organic fertilizers by improving the quality of the mechanized process with resource conservation and greening of agricultural production. In the work, the research carried out is aimed at developing new and improving existing technologies and technical means that ensure maximum payback of fertilizers when obtaining programmed harvests and prevent environmental pollution, the reason for which is the urgent need to develop machine technologies for the rational use of organic fertilizers due to the action of objective factors – narrowing the boundaries of effective use of fertilizers, stricter requirements for environmental protection. The paper [13] analyzes the problem of effective use of poultry farm excrement on the use of new technologies for more efficient use of bird droppings, but does not specifically disclose the methodology, as well as technical means. In [14], the directions for improving technologies and technical means are analyzed, the main reason for which is the need to create new technologies for the use of fertilizers due to the action of objective factors, but the authors do not specifically address this area and there is no critical analysis of existing technologies, which allows us to conclude using the research methodology to find new ways to reduce costs and increase the quality of use of the proposed technologies.

As our research has shown, solving the problem of fermentation of poultry manure in poultry farms by substantiating the basic design and operating parameters is open and therefore we have made an attempt to analyze the shortcomings made by many authors and try to solve this problem.

3. The aim and objectives of the study

The aim of the study is to substantiate energy-resource-saving, environmentally safe technology of poultry production and its technical solution.

In order to achieve the aim, the following objectives were defined:

– to study the cooling depth of the air flow evaporator unit and the impact on performance;

– to investigate the physical, mechanical, and thermophysical properties of materials that participate in the heat exchange process.

4. Materials and methods

The object of the research was the technology of utilization of bird droppings. Depending on the nature of the study of technological processes, various mathematical methods of research are used.

When conducting logical modeling, we mainly used general rules that were developed by highly qualified specialists. The rules of which determined the necessary action under certain conditions.

The computer programs we used had several advantages. The first one is a quick answer to the question, and the second is the possibility of conducting a large-scale experiment, which is often impossible to conduct on a real object. Our research has shown that the provision of technical means of agriculture requires specific models of mathematical optimization, since mathematical models can be conditionally divided into analytical and statistical variants. In the first case, the key quantitative indicators of technological operations are tied to analytical dependencies. The system of these equations is considered as an analytical model. When developing a statistical model (simulation model, Monte Carlo model), it was taken into account that there is a random element in technological operations that is not defined, but it obeys the law of distribution of random variables. The presence of non-linearity, dynamism and the probable nature of a number of events allow the statistical model to correspond to reality and conduct an express experiment on a fast time scale, exploring it.

However, classical regression analysis, when the specifics of agricultural work are neglected, causes the model to be faulty and even inconsistent, making it impossible to use.

In general, the regression equation is expressed by the following formula:

$$y = a_0 + \sum_{i=1}^{n} a_i x_i. \quad (1)$$

Obtaining the correct values of the a_i coefficient based on the results of the passive or active experiments solves the problem of statistical model identification. The least squares method was proposed by Gauss as an algorithm for solving this problem.

The method is based on the minimum sum of deviation squares for the experimental and calculated values of the function:

$$S = \sum_{j=1}^{n} \left(y_j - \overline{y}_j \right)^2 \to \min, \quad (2)$$

where y_j – experimental value; $\overline{y}_j$ – values calculated by (1).

The statistical significance of the coefficients is determined by the Student's criterion (t):

$$t_i = \frac{\beta}{\sigma_{ai}} \geq t_{ced}\left(\nu, P\right), \quad (3)$$

where t_i – calculated value of the criterion; σ_{ai} – error of the coefficient "a_1"; t_{ced} (v, P) – v degree of freedom and P table value of the criterion for reliability.

If the condition (3) is met, the coefficients are considered significant for probability P.

The significance and adequacy of the entire regression equation are assessed by the Fisher's criterion (F):

$$F_{hes}=\frac{\sigma_{ad}^2}{\sigma_y^2}\le F_{ced}\left(v_1,v_2,P\right), \tag{4}$$

where

$$\sigma_{ad}^2=\frac{1}{N-m}\sum_{i=1}^{n}\left(y_i-\overline{y}\right)^2,$$

F_{ced} – v_1 and v_2 degrees of freedom and table value of the Fisher equation for probability level P;

N – number of observation points;

m – number of regression coefficients;

$\overline{y}$ – points calculated by the regression equation.

If inequality (4) is met, then the mathematical model is considered significant [13, 14].

To solve problems with the implementation of linear programming methods, we used the more common one because of its simplicity and universality, since in linear dependence changes are formed only in the first degree and there is no mathematical operation associated with obtaining them.

When conducting the research, we used linear programming of problems, which was expressed by linear equations. This method allowed us to solve the linear programming problem with a limited number of steps, since each of these steps consists of algebraic transformations in accordance with the accepted rules.

We also used differential rent methods and potentials to solve linear programming problems. And when determining the economic and mathematical model of transportation, we used it in the distribution of technical means depending on the task. In the mathematical model, nonlinear programming is used to solve problems where variables are not the first order or there is the production of the variables [16, 17]. Quadratic programming is the most commonly used. This method is based on the maximum (minimum) of quadratic function when there are linear constraints in the solution of economic planning problems.

One of the types of mathematical modeling is dynamic programming. This programming method is used when the analyzed variables are viewed in dynamics, and their solution is in the form of the time dependence of the target function [17, 18].

The analysis of dynamical systems plays an important role in the research on the mechanization of agricultural production processes. Dynamical systems include all moving mechanical systems, technology, and technical facilities, the process of development within a limited time interval and the boundaries of coordinates, automatic control of heat and humidity modes in greenhouses, livestock and poultry buildings.

Differential equations (linear and nonlinear) are used as the basic model for the above systems:

$$\dot{X}=F\left(A,x,y,t\right), \tag{5}$$

where $\dot{X}$ – vector of derivatives of the first degree;

x, y, t – argument vectors of the system equations;

A – unknown coefficients of the model.

There were multiple studies on the identification of dynamical systems [17].

The optimization of the composition, structure, and use of agricultural machinery can be solved by applying a network model [18] as a type of logical model. [19–21] successfully applied the network graphics method to poultry and manure processing technology. The optimization of the technological problem was implemented based on the "minimum operating costs". The general expression of this issue is as follows:

$$\left.\begin{aligned}
&\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{m=1}^{M}C_{ijklm}X_{ijklm}+\sum_{p=1}^{P}\sum_{m=1}^{M}C_{pm}X_{pm}+\\
&\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{m=1}^{M}B_{ijklm}X_{ijklm}REN_{ijklm}+\\
&+\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{m=1}^{M}B_{ijklm}X_{ijklm}REN_{ijklm}^{TO}+\\
&+\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{m=1}^{M}N_{ijklm}X_{ijklm}P+\\
&+\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{m=1}^{M}N'_{ijklm}X_{ijklm}P_T\to\min,
\end{aligned}\right\} \tag{6}$$

where C_{ijkln} – operating costs of the manure harvesting system, people/hour;

X_{ijkln} – number of technical means to perform the operation of manure transportation through the system;

m – as a system;

l – in manure (in an organic fertilizer);

j – during the period;

C_{pm} – employee's salary according to the system, AZN/h;

X_{pm} – number of employees of a certain degree;

B_{ijklm} – book value of technical means, AZN;

REN_{ijklm}, REN_{ijklm}^{TO} – respectively, depreciation and maintenance costs of technical means, AZN/h;

N_{ijklm} – engine power of a specific technical device, kW;

N'_{ijklm} – power of internal combustion engine tools, kW;

P – cost of 1 kWh of electric energy, AZN;

P_{T} – cost of 1 kg of fuel, AZN.

One of the main tasks in researching the mechanization of agricultural production processes is to build an accurate statistical model (solution of the identification problem), to investigate it and optimize its application to specific criteria and production conditions. Various heuristic methods are used to solve the problem of identification for application to dynamical systems, but the least squares method still remains a universal mathematical method. Different algorithms and methods are used in practical calculations. But all of these issues have something in common – they all belong to the search class. For example, search for the last number of variables in hyperspace provided by users. Various methods were compared and their capabilities were analyzed. As a result of comparative analysis, recommendations were developed to address these issues.

5. Results of the study on the utilization of poultry droppings

5. 1. The study of the cooling depth of the air flow evaporator unit and the impact on performance

One of the factors determining the effective operation of the super cooler is the flow-pressure characteristic of the fan used.

The volume of air supplied by the fan is especially important. This indicator affects the intensity of physical processes in the air ducts of the refrigerator. At the same time, it determines not only the cooling depth, but also the cooling efficiency of the auxiliary evaporator unit.

The dependence given in Fig. 1 shows that the evaporator unit varies depending on the specified air flow. It should be noted that the temperature and humidity parameters of the incoming air at this time were stable.

Based on the determination of the cooling capacity, a directly proportional dependence of the desired parameter on the air flow is obtained.

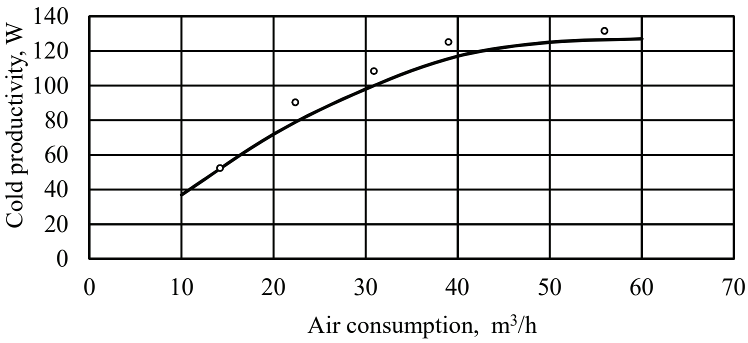

Fig. 1. The effect of air consumption on cooling capacity

At certain values of air flow (35 m^3/h or more), the decrease in the intensity of cooling is explained by a decrease in the cooling depth. This changes as the fan performance increases, as shown in Fig. 2.

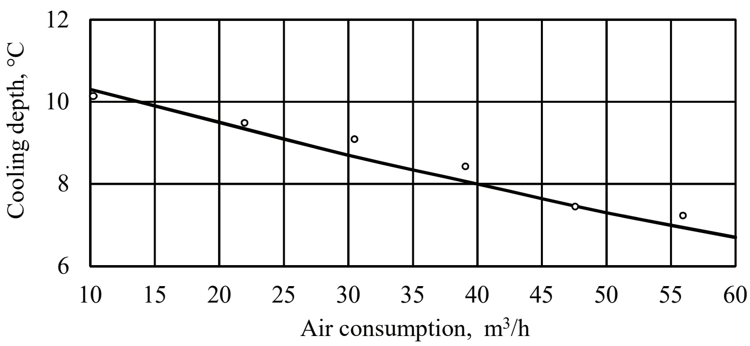

Fig. 2. The effect of air flow on cooling depth

It can be seen from the above graph that the cooling depth decreases inversely with the increase in air flow. This is explained by the fact that with an increase in the efficiency of the fan, there is a sharp increase in air velocity at fixed sizes of cooling channels. This is due to the fact that it quickly passes through the channel and as a result of reduced thermal and physical processes is not able to get enough moisture. Thus, even the air at the outlet of the evaporator lacks moisture, which means that the temperature is higher.

However, the analysis of the presented dependencies shows that with an increase in the air supply per unit of time by 5–6 times, the cooling capacity of the unit increases almost 4–5 times, despite a decrease in the cooling depth by 3...5 °C.

It can be concluded that in some cases there is no need to achieve the maximum cooling depth, since the second air flow has a decisive influence on the cooling capacity.

Undoubtedly, as the thermal balance shows, in order to achieve a certain temperature in a closed volume, the value of the incoming air temperature should be slightly lower than the standard for this building.

Based on this, it can be concluded that there is no need to obtain the maximum cooling depth when designing cooling units. It is enough to choose a mode in which the air inside the building is supplied with air of the required temperature with a minimum reduction in cooling capacity.

5. 2. Investigation of the physicomechanical, thermophysical properties of materials involved in the heat exchange process

The utilization of poultry droppings is usually assessed based on nitrogen preservation or loss. Nitrogen balance evaluation is used for this purpose. Based on nitrogen balance, agricultural enterprises of many countries are evaluated using 37 agricultural indicators.

The effectiveness of the use of nutrition obtained as a result of the calculation is considered to be a generalized environmental indicator. The higher this coefficient, the less the loss of organic fertilizer, and pollution of the environment and water.

The main disadvantage of this method is that it is not possible to analyze individual processes, especially those that result in more nitrogen losses due to the utilization of poultry droppings. Many studies point to the difficulty of assessing nitrogen dispersed in the environment and the need for numerous expensive experiments.

To determine nitrogen preservation during the utilization of poultry droppings, the method of the formation of expert knowledge as a logical-linguistic model in multidimensional systems has been used.

Based on the results of the experiments, there is a fundamental difference in the processing of solid and liquid manure. Aerobic and anaerobic processes occur in the first and second cases, respectively. Due to differences in the characteristics of the processes, nitrogen losses are different. Therefore, two separate models (Y_1 and Y_2) were used for the calculation of nitrogen preservation during the processing of poultry droppings with contrasting humidity (>92 % and <92 %).

Based on the information model, the following list of factors affecting the target function is defined:

– X_1 – nitrogen preservation level during the processing phase, %;

– X_2 – nitrogen preservation level during storage, %;

– X_3 – level of nitrogen preservation in the soil during fertilization, %;

– X_4 – humidity of the processed material, %;

– X_5 – carbon-to-nitrogen ratio in the processed material;

– X_6 – quality of work.

It is important to note that the given factor was chosen taking into account the systematic approach to the studied phenomenon, from the quality of raw materials used throughout the technology chain to the method of fertilizing the soil. The variables X_4 and X_5 characterize the raw material (input factors), X_1 and X_2 – technology of processing and storage of the raw material, X_6 is an external factor affecting the entire technological chain.

The individual reflection scale was developed for the spatial variables (Y_1 and Y_2) and for each variable. These are important for the comparison of the linguistic scale (upper arm of the axis) in the numerical (bottom of the ordinal axis) scale and in the standardized format at the interval [–1, +1].

The following symbols are used in the linguistic scale:

– *A* – low level of preservation;

– *OA* – lower intermediate level of preservation;

– *O* – intermediate level of preservation;

– *OY* – upper intermediate level of preservation;

– *Y* – high level of preservation.

Where appropriate, intermediate values (for example, "*A*–*OA*" are located between *A* and *OA*) are used to increase the accuracy of the evaluation. The numerical axis has values in the corresponding unit of measure. The scale has a whole range of values and can accept factor variables. The direction of the numerical axis is chosen so that the least favorable value of the factor corresponds to "–1" in the scale. Similarly, standardized "–1" for the target function corresponds to the worst preservation of nitrogen, and "+1" to the best (most accessible).

Fig. 3 presents the scale for the dependent variables (Y_1 and Y_2).

The minimum values for preservation are 25 % and 19 %, which correspond to the *A* linguistic value (low level of preservation).

The maximum values are 81 % and 75 % and correspond to the *Y* linguistic value (high level of preservation). Similar scales were also developed for independent variables.

Fig. 4 depicts the scale for the X_1 variable factor during the processing of semi-fluid manure.

This variable factor reflects the level of preservation, depending on the processing technology. Experts have identified low level (1) and more favorable preservation (5) technologies for nitrogen.

The scale presented in Fig. 2 describes the following technologies:

1) processing through long-term storage;
2) passive composting;
3) active composting;
4) processing in a chamber-type reactor;
5) processing in a drum-type bioreactor.

Fig. 5 depicts the opposite position scale for the X_2 variable factor. The factor space is set similarly to the X_1 space. All methods were evaluated according to the rules chosen by experts: 1 – the least suitable method for nitrogen preservation, 4 – the most suitable method for nitrogen preservation.

Storage methods:

1) field areas;
2) waterproofed areas;
3) waterproofed areas with covering material (wood bran, etc.);
4) covered waterproofed areas.

Similarly, an opposite position scale is set for the X_3 factor (soil fertilization factor) (Fig. 6).

Methods for soil fertilization:

1) fertilizing the soil and plowing in less than a day or not plowing;
2) fertilizing the soil and plowing in less than a day;
3) fertilizing the soil and plowing in less than 4 hours;
4) fertilization along with cultivation;
5) fertilization along with plowing;
6) fertilization along with plowing (by turning the layer).

Fig. 7 shows the scale of the X_4 factor (humidity of the processed material, %) for solid or semi-fluid material. According to experts, the higher the moisture content, the greater the nitrogen loss.

Depending on the C: N ratio in the starting material, the nitrogen preservation factor is formed by the scale given in Fig. 8. According to experts, when the ratio is low (10:15), nitrogen preservation decreases, but when it is greater, nitrogen preservation increases and the highest value is obtained when the ratio is equal to 30.

Fig. 9 shows the linguistic scale for the quality of the workforce. According to experts, a higher quality of work increases nitrogen preservation, and, on the contrary, lower quality of work reduces nitrogen preservation.

Table 1 presents a survey matrix that is linguistically formed and completed by expert evaluations.

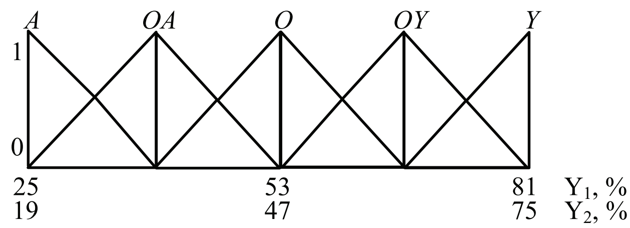

Fig. 3. Scale for Y_1 and Y_2 target functions

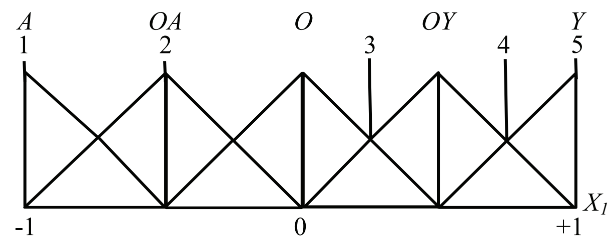

Fig. 4. Linguistic scale for the X_1 variable

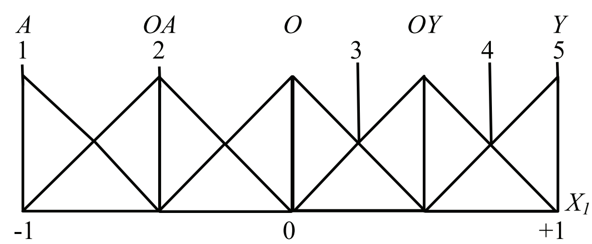

Fig. 5. Linguistic scale for the X_2 variable

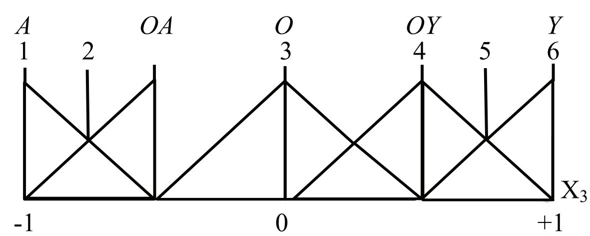

Fig. 6. Linguistic scale for the X_3 variable

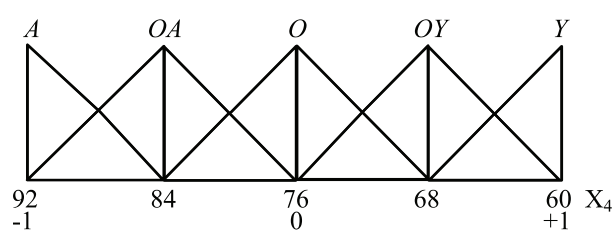

Fig. 7. Linguistic scale of the X_4 variable

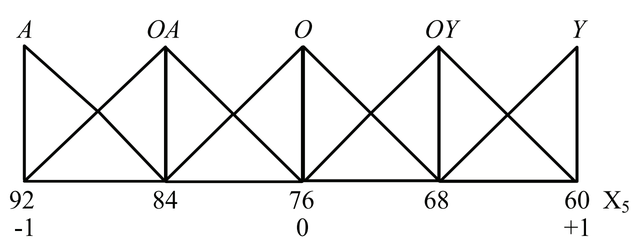

Fig. 8. Linguistic scale of the X_5 variable

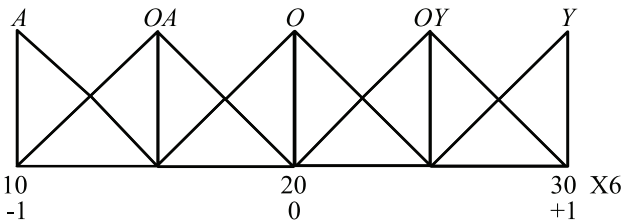

Fig. 9. Linguistic scale of the X_6 variable

Table 1

Linguistical survey matrix with expert data

X_1	X_2	X_3	X_4	X_5	X_6	Y_1	Y_2
–1	–1	–1	–1	–1	–1	*A*	*A*
1	–1	–1	–1	–1	1	*OA–O*	*OA–O*
–1	1	–1	–1	–1	1	*A–OA*	*A–OA*
1	1	–1	–1	–1	–1	*O*	*O*
–1	–1	1	–1	–1	1	*OA*	*OA–O*
1	–1	1	–1	–1	–1	*OY*	*O*
–1	1	1	–1	–1	–1	*O*	*OA–O*
1	1	1	–1	–1	1	*OY–Y*	*OY*
–1	–1	–1	1	–1	1	*A–OA*	*A–OA*
1	–1	–1	1	–1	–1	*OA*	*OA*
–1	1	–1	1	–1	–1	*O*	*A–OA*
1	1	–1	1	–1	1	*OY*	*O*
–1	–1	1	1	–1	–1	*OA*	*OA–O*
1	–1	1	1	–1	1	*OA–O*	*O–OY*
–1	1	1	1	–1	1	*O–OY*	*OY*
1	1	1	1	–1	–1	*OY*	*OY–Y*
–1	–1	–1	–1	1	1	*OA*	*OA*
1	–1	–1	–1	1	–1	*O–OY*	*OY*
–1	1	–1	–1	1	–1	*A–OA*	*OA–O*
1	1	–1	–1	1	1	*O–OY*	*O*
–1	–1	1	–1	1	–1	*OA–O*	*OA*
1	–1	1	–1	1	1	*OY–Y*	*OY–Y*
–1	1	1	–1	1	1	*O–OY*	*O–OY*
1	1	1	–1	1	–1	*OY*	*OY*
–1	–1	–1	1	1	–1	*O*	*OA–O*
1	–1	–1	1	1	1	*OY*	*O*
–1	1	–1	1	1	1	*O*	*OA–O*
1	1	–1	1	1	–1	*OA–O*	*OA*
–1	–1	1	1	1	1	*OY*	*O*
1	–1	1	1	1	–1	*OY*	*OY*
–1	1	1	1	1	–1	*O–OY*	*O–OY*
1	1	1	1	1	1	*Y*	*Y*

The linguistic values for Y_1 and Y_2 (Fig. 1) have been converted to numerical values and presented in Table 2.

Based on the results of expert evaluations, the following two polynomial expressions were obtained:

$$Y_1=54.75+7.44X_1+3.5X_2+5.69X_3+1.75X_4+4.81X_5+ +3.06X_6+3.94X_1X_4+1.31X_2X_3+1.75X_2X_4+ +4.81X_2X_5++2.19X_2X_6+1.75X_5X_6+1.75X_1X_2X_6- -2.19X_1X_3X_6+1.75X_2X_3X_5, \quad (7)$$

$$Y_2=48.31+5.69X_1+3.5X_2+6.56X_3+1.75X_4+1.75X_5+ +1.76X_6-1.75X_1X_2+2.63-306X_2X_5+ +2.63X_3X_4+1.31X_1X_2X_4-2.19X_1X_2X_5+ +1.31X_1X_2X_6+2.63X_1X_2X_4+3.06X_2X_3X_4. \quad (8)$$

Table 2

Survey matrix with expert data

X_1	X_2	X_3	X_4	X_5	X_6	Y_1	Y_2
–1	–1	–1	–1	–1	–1	25	19
1	–1	–1	–1	–1	1	46	40
–1	1	–1	–1	–1	1	32	26
1	1	–1	–1	–1	–1	53	47
–1	–1	1	–1	–1	1	39	40
1	–1	1	–1	–1	–1	67	47
–1	1	1	–1	–1	–1	53	54
1	1	1	–1	–1	1	74	61
–1	–1	–1	1	–1	1	32	26
1	–1	–1	1	–1	–1	39	40
–1	1	–1	1	–1	–1	53	33
1	1	–1	1	–1	1	67	47
–1	–1	1	1	–1	–1	39	40
1	–1	1	1	–1	1	46	54
–1	1	1	1	–1	1	60	61
1	1	1	1	–1	–1	67	68
–1	–1	–1	–1	1	1	39	33
1	–1	–1	–1	1	–1	60	61
–1	1	–1	–1	1	–1	32	40
1	1	–1	–1	1	1	60	54
–1	–1	1	–1	1	–1	46	33
1	–1	1	–1	1	1	74	61
–1	1	1	–1	1	1	60	54
1	1	1	–1	1	–1	67	47
–1	–1	–1	1	1	–1	53	40
1	–1	–1	1	1	1	67	54
–1	1	–1	1	1	1	53	40
1	1	–1	1	1	–1	46	33
–1	–1	1	1	1	1	67	47
1	–1	1	1	1	–1	67	54
–1	1	1	1	1	–1	60	61
1	1	1	1	1	1	81	75

Taking into account the adequacy of the obtained regression equations, the analysis revealed new features of the factors. Thus, prior to formalization, experts believed that the target function is highly influenced by the quality of the work (X_6) of the personnel.

However, this hypothesis was disproved after the formalization. The nitrogen preservation factor during the soil fertilization phase, on the contrary, was underestimated (especially, for the manure with moisture content less than 92 %). In addition, significant interactions between X_2 and X_5 were identified. This again underlines the importance of a systematic approach to the object under study. Fig. 10 shows the surface of the response function as a result of the numerical experiment.

The average values of all the variables except X_1 and X_4 have been designated. Factor X_1 corresponds to the *X*-axis, X_4 factor to the *Y*-axis, Y_1 target function to the *Z*-axis.

This surface clearly shows that nitrogen preservation (*Z*-axis) is more dependent on the processing technology factor (Y_1) than on the moisture content of the initial material (X_4).

Fig. 11 shows the surface of the numerical experiment results recorded with the average values of all the variables except X_4 and X_5. The results of this experiment allow a comparison of the effects of the carbon to nitrogen ratio factor and the moisture factor of the initial material on nitrogen preservation. The surface clearly shows that nitrogen preservation depends more on the C:N (X_5) ratio than the moisture content of the initial material (X_4).

Factor analysis shows that nitrogen preservation is mainly influenced by X_1, X_3, X_5, X_2 factors and X_2X_5, X_2X_3, X_1X_4 factor pairs during utilization of liquid poultry droppings. Factor Y_1 corresponds to the Y-axis, factor Y_2 target function to the Z-axis.

When during the utilization of solid and semi-fluid droppings, the moisture content is less than 92 %, nitrogen preservation is more influenced by X_3, X_1, X_5, X_2 and factor pairs X_2X_3, X_2X_5, X_3X_4.

The results of these studies provide an opportunity to analyze the dynamics of nitrogen preservation depending on the utilization technology of droppings and the impact factors. The evaluation of nitrogen preservation allows determining the technology's effectiveness criteria.

Correlation coefficients of expert and calculated values were found to be 0.93 and 0.95, respectively. This shows that they have a high degree of compliance and a high expert level.

The comparison of calculated and actual values of nitrogen preservation for specific poultry factories (Table 3) demonstrates the high adequacy of the developed model.

Only the coefficients of the regression equation with a degree of significance were checked for adequacy by evaluating the correlation between the values of the expert and the report. The correlation coefficients of the expert's values and the report were 0.93 and 0.95, respectively. This shows that they have a high degree of compliance and a high degree of expert qualification.

Table 3

Comparison of calculated and actual values of nitrogen preservation

Factories	Factors						Nitrogen preservation	
	X_1	X_2	X_3	X_4	X_5	X_6	Actual, %	Calculated, %
Samukh poultry farm	–0.50	–0.25	–0.75	0.69	–0.50	0.00	38.40	39.86
Samukh poultry farm	–0.50	–0.25	–0.75	1.00	0.20	0.00	39.76	41.89
Ismayilli poultry farm	–0.50	–1.00	–1.00	0.81	0.00	–0.50	39.10	39.33

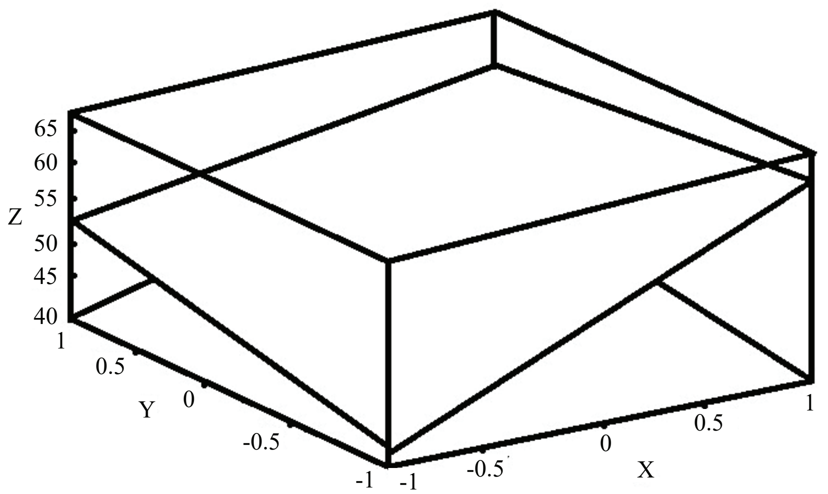

Fig. 10. The surface of the nitrogen preservation dependence on the selected processing technology and moisture content of the source material

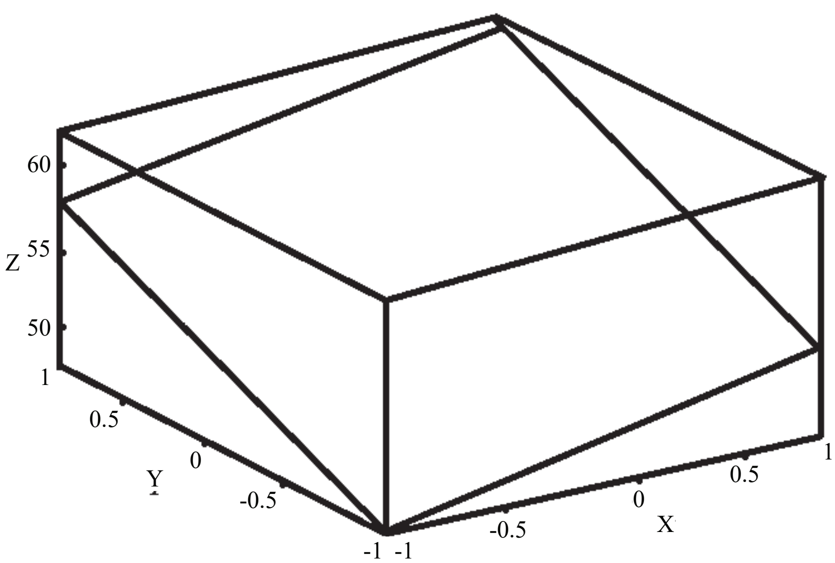

Fig. 11. The surface of the nitrogen preservation dependence on the C:N ratio and moisture content of the initial material

A comparative assessment of the reported and actual values of nitrogen reserves at specific poultry farms (Table 3) on the example of feed fertilizer processing technology showed the high adequacy of the developed model.

Thus, the accumulated knowledge about the legality of processing poultry manure, the developed methodology and models that allow determining the level of nitrogen preservation allow us to evaluate the technology of economic and ecological utilization of feed for specific farms [22–31].

6. Discussion of the results of the study on the disposal of bird droppings

The research results obtained by us are based on the analysis of modern ways of temperature and humidity regime in poultry houses. To this end, we analyzed the optimization of the composition, structure and use of agricultural machinery by applying a network model as a type of logical model, and also successfully applied the method of network graphics to poultry farming and mature processing technology. Also, based on the determination of the cooling capacity (Fig. 1), we obtained a graph of the directly proportional dependence of the required parameter on the air flow (Fig. 2) and found that at certain values of the air flow, the cooling intensity decreases, which is explained by a decrease in the cooling depth, and this changes as the fan performance increases. We also compiled a scale for dependent variables, where the minimum values for maintaining them are 25 % and 19 %, which corresponds to the A linguistic value (low level of preservation) and the survey matrix was compiled, formed linguistically and supplemented with expert assessments (Fig. 3).

The study of the cooling efficiency of the evaporator air flow showed that a decrease in the intensity of the cooling efficiency at certain values of air flow, i.e. at 35 cubic meters/hour or more, explains the decrease in the cooling depth.

As a result of plotting the air flow rate depending on the depth and performance of the cooling effect, it was found that with an increase in the volume of air by 5–6 times, the cooling performance increases by 4–5 times, although the cooling depth decreases by 3–5 °C. All this allows us to conclude that there is no need to obtain the maximum cooling depth when designing cooling units.

The most important elements in refrigerators that evaporate water directly are boards. They largely determine the effectiveness of the device. They continuously moisten the surface with water vapor. For this reason, the material of the boards should be easily and evenly wetted with water. The capillary rise should be at least 18–20 cm in 30 minutes when water is supplied from below. The plates must be water-retaining and absorb a sufficient amount of water. They must be strong, as they are the weakest element of the device and are exposed to all kinds of negative influences (due to constant contact with water). In other words, it should not swell and should be chemically stable in water.

At the same time, it is necessary to take into account economic and environmental factors (it should not be expensive, the harvested material should be affordable, its preparation should not be difficult in the organization, environmental safety should be ensured).

The weak points of our research are a wider range of analysis of this area, as well as the results obtained, and the conditions for the applicability of the proposed solutions. Therefore, in the future, in order to eliminate these shortcomings, we plan to analyze the stability of solutions to changes in influencing factors.

7. Conclusions

1. Based on the determination of the cooling capacity, we obtained a graph of the directly proportional dependence of the required parameter on the air flow and found that at certain values of the air flow, the cooling intensity decreases, which is explained by a decrease in the cooling depth, and this changes as the fan performance increases. With an increase in the air supply per unit of time by 5–6 times, the cooling capacity of the unit increases almost 4–5 times, despite a decrease in the cooling depth by 3...5 °C. It can be concluded that in some cases there is no need to achieve the maximum cooling depth, since the second air flow has a decisive influence on the cooling capacity.

2. A mathematical model of the energy balance in water-evaporating air coolers has been developed, the main distinguishing feature of which is taking into account the specific evaporative properties of the heat exchanger plates.

Based on the formation of expert knowledge about fuzzy multidimensional systems, a method and a mathematical model of nitrogen preservation during zygote burial have been developed by the logical-linguistic method. It is determined that the main factors affecting the preservation of nitrogen are: the processing method is X_1, the storage method is X_2, the method of application to the soil is X_3, the soil moisture is X_4, the ratio of carbon and nitrogen in the treated mixture is X_5 and the quality of workers is X_6.

According to the results of research, the following is recommended for production:

– the use of refrigeration units and heat recuperators with improved and justified parameters as a result of research for the maintenance of 30,000 laying hens with an average weight of 1.6 kg per head in a cage and the possibility of generating heat of about constant 322.6 kW, this allows you to maintain the necessary temperature and humidity inside the building throughout the year;

– increasing the economic efficiency of the poultry farm, taking into account the impact of production conditions on the environment and the use of machine technology for flax utilization, which ensures environmental safety;

– application of the developed LED lighting and computer software in poultry farms.

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