Application of Digital Technologies in the Development of a Ration for Feeding Productive Animals

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Abstract. To make management decisions, it is necessary not only to have reliable data, but to adequately and timely analyze them as well. Applying digital technologies in agriculture, decision support systems for diet formulation with mathematical exactness will allow planning animal's feeding taking into account many factors (animal genotype, age, seasonality, etc.). The growth and development of animals, their productivity depend primarily on the level of balanced feeding. The article proposes a computer system methodology for evaluating and optimizing the diet of animal feeding based on a structural-parametric model. The advantage of the structural-parametric model of animal feeding is that it considers the whole variety of factors of nutrients influence on the processes occurring in the animal's body, depending on its current physiological state; allows one to establish patterns, the knowledge of which with a sufficient degree of confidence speaks about possible deviations in feeding, the reasons for their occurrence; allows one to find a solution to replenish the imbalance in the required macro- and micronutrients. The use in agriculture of science-intensive decision support systems based on knowledge of the subject matter experts and strictly verified mathematical methods will increase the productivity of animals and provide a high-quality product with the ability to trace the trophological chain from the field to the counter.

1. Introduction

The concept of Society 5.0 assumes the use of smart technologies in all spheres of human life [1-2]. Smart technologies are aimed at increasing the quality of life by improving working conditions, reducing costs, etc.

Today, the main elements of digitalization in agriculture include: 1) electronic cards of the animal, feedstuff and formulated feed databases, etc.; 2) agricultural AI-based machinery and equipment, etc.; 3) predictive analytics will make it possible to predict crop yields and animal productivity.

It is worth noting that the use of advanced technologies in cultivation of fodder and cereals, the preparation of fodder and their proper feeding will increase the productivity of farm animals and poultry.

A review of papers in Scopus, PubMed, MEDLINE, Web of Knowledge, Google Scholar, IEEE Xplore, Science Direct, eLibrary(RSCI) databases [3-21], showed that research teams have found that high-quality feeding of productive animals provides not only good health of the animal, normal reproductive functions, but also high productivity (for example, for cattle, this is milk yield and weight increase).
Nutritional balance is an important aspect of diet formulation. Ivashov et al. [5] established the necessary and sufficient range of nutritional value indicators in the diet formulation. The minimum value of measured indicators shall be at least 15. The authors state that feeding employees should pay attention not only to protein, phosphorus and calcium, but also not to forget about other nutritional indicators, including essential or limiting amino acids. For example, methionine amino acid in the diet of dairy cattle for increase in milk yield and protein percentage in milk. For more details on the norms for feeding farm animals and poultry, see paper [6].

Calculation, analysis and optimization of the animal's feeding by all specified indicators of food nutrients and the cost implies big data processing. The information should be structured and contained in databases. This is another application of digital technologies in agriculture.

It is possible to automate calculation of daily allowance per animal using information technologies, mathematical modeling and methods of linear, stochastic, nonlinear and genetic programming [9-11]. A workplace automation using information technologies, application program packages will help a feeding employee to choose a diet with consideration of the animal breed, genotype and the fodder base available on the farm (green feed, hay, straw, silage, etc.), their chemical composition.

This paper's purpose is to determine the methodological foundation for compiling a diet using a structural-parametric model. By managing nutrition, one can achieve certain goals related to weight gain, milk yield, etc.

2. Materials and methods
The structural-parametric model is a block matrix [23, 24]. Operators of functional relations within the selected groups of parameters are located along the main diagonal. Independent parameters of one group are the identity matrix on the main diagonal. If there is a relationship between the parameters, then the off-diagonal elements of the selected blocks describe the interaction operators both within the groups and between the parameters of other groups. In this case, the off-diagonal cells of the original block matrix correspond to operators of direct and indirect intergroup influence of individual parameters belonging to different functional groups.

3. Results and discussion
Mathematical models are used to maximize milk yield and weight gain. Models, depending on the study's purpose, differ in formulation, solution and complexity. A detailed review of methods and models developed by researchers and nutritionists for formulation of animal diets considering various aspects over the past 60 years is presented in paper [15].

As a rule, linear and stochastic solution methods are used to solve the problem [12-14, 19]. However, in a number of papers non-linear methods are used [17-18, 20], for example, in [16] for the impact of nutrients in order to maximize the milk yield of animals; in paper [21] a genetic algorithm, multi-swarm particle swarm optimization (MSPSO) to increase the diversity of particles and prevent premature convergence in PSO, is used to formulate animal diets while considering floating costs, nutrient requirements, balanced amino acids; in paper [22], the particle swarm method (PSO) is used to optimize the cost of formulated feed.

This paper proposes to use the methodology of structural-parametric modeling.

The structural-parametric model of animal feeding will allow 1) considering all the variety of factors of nutrients influence on the processes occurring in the animal's body; 2) establishing patterns, dependencies, the knowledge of which will allow stating with a sufficient degree of confidence about possible deviations in the feeding diet and the reasons for their occurrence; 3) finding a solution to replenish the imbalance in essential food nutrient.

A parametric description of a farm animal includes positions from an animal card with selected groups of characteristics and properties, indicators of physiological state. Based on the parametric description, an Animal Information Card is developed - a convenient tool for identifying an animal and obtaining reliable information.
Thus, a breeding card of a sow includes the following: name, breed/blood relationship, place and date of birth, stage of performance, fecundity direction, related group, live weight, body length, heart girth, height at crest, chest depth, chest width, fat depth, etc. A breeding card of an ewe includes the following data: breed group, fecundity direction, breed, generation, date of birth, the number it was born with, place of birth, production group, etc.

Physiological characteristics and condition of the animal are determined by veterinarians. Based on the veterinary examination, a conclusion is made about the conditions of keeping the animal and the receipt of the necessary nutrients and energy with the feed. As there is a relationship between feeding and the physiological state of the animal.

The list of nutritional indicators that are part of nutritional, biological and energy value should be included in the parametric model of the diet.

As a rule, these are energy feed units, dry matter, protein (digestible and crude ones), amino acids (lysine, methionine, tryptophan), crude fat, nitrogen-free extractives (sugar, starch, organic acids, hemicellulose, inulin), etc.

The knowledge and information contained in the parametric descriptions make it possible to build a structural-parametric model of animal feeding. The relationships' matrix includes three main blocks: the physiological state of the animal, diet indicators, environmental factors, and many relationships within the blocks and between blocks and groups of factors. Each individual block has its own parameters and attributes. For example, the "Physiological state of animal" block includes positions taken from the parametric description of a given species (group) of animals.

The processing of statistical data and current information about the animal state, the balance of the diet makes it possible to carry out a detailed analysis and assessment of the diet. The solution algorithm comes down to the following stages.

The first stage involves filling in the structural-parametric matrix, establishing links between the observed parameters. An array of initial data $x(i, j)$ is formed.

The second stage is associated with preparation of a correlation matrix based on the initial data

$$r_{ij} = \frac{1}{n-1} \sum_{k=1}^{n} \frac{(x_{ij} - \bar{x}_i)(x_{kj} - \bar{x}_j)}{\sigma_i \sigma_j}, \quad i, j = 1, m$$

where $\bar{x}_i, \bar{x}_j$ are the average values of the $i$-th and $j$-th factors; $\sigma_i, \sigma_j$ are mean square deviations.

The importance of correlation coefficients' values is checked by Student t-test ($p<0.05$).

At the third stage, an array of linear multiple regression coefficients is formed with check of importance by Fisher-Snedecor F-test ($p<0.05$) for elements with a strong correlation ($r_{ij} \geq 0.5$).

$$x_i = \sum_{j=0}^{n} P_{ij} x_j$$

The fourth stage is necessary for a comparable assessment of deviations and relationships between factors of different physical nature and dimensions. Based on regression coefficient matrix $P_{ij}$ between the $i$-th and $j$-th factor a dimensionless performance matrix of relationship $C_{ij}$ is calculated.

$$C_{ij} = P_{ij} \frac{\Delta X_i^0}{\Delta X_i^j}, \quad i, j = 1, n$$

where $\Delta X_i^0, \Delta X_i^j$ are acceptable variations.

The fifth stage is associated with the formation of a structural-parametric model. The matrix of relationships $C_{ij}, i=1,n$ is multiplied by the vector of the current deviation $\Delta Z_1, ..., \Delta Z_n$ [24].
where $Z_i = \frac{X_i - X_i^0}{\Delta X_i^0}$ are dimensionless quantities of measured parameters; $X_i, X_i^0$ is the current (actual) and reference value of the $j$-th parameter in the $i$-th group; $\Delta X_i^0$ is the tolerance.

On the main diagonal of the formed matrix, there is a relative deviation vector of the controlled values. Off-diagonal elements $C_{ij}\Delta Z_j$ reflect the contribution of the $j$-th factor to the deviation of the $i$-th factor.

Identification of the animal state is reduced to a consistent search for the cause-effect relation of the abnormal state. Deviations from the standard diet indicators, which resulted in possible deviation of the physiological state parameters of the farm animal.

The solution algorithm (figure 1) is reduced to finding the maximum diagonal element $\Delta Z_i$ from the array of deviations. Memorizing its serial number $p$. The transfer to line $p$ followed by finding the maximum value in line $p$. Thus, the reasons that caused deviation of the $i$-th factor of the state of the agricultural animal are revealed.

**Figure 1.** Block diagram of the algorithm for diagnosing the abnormal state of nutrition system.

To exclude the looping of cause-effect relations, it is necessary to form an array of indices of the diagonal elements $i_k$, included in the "link line". A loop occurs when two elements of this array coincide. The cause of the occurrence can be both inside and outside the loop. Further search for the
cause is associated with an exit from the loop. For this, it is necessary to break the last communication node. Element \( S_{gp} = 0 \) and memorizing its value \( f_{gp} \) and address in index arrays \( Ind_{g1} \), \( Ind_{g2} \).

When iterating over the elements of the \( g \)-th line, the flow of the algorithm (program) will either stop at the last node of the cycle (the reason is inside the loop), or go further along the steps of the new cycle (the reason is outside the loop).

Further identification of the cause-effect chain of the next \( k+1 \)-th effect is associated with the restoration of the interrupted connection of the \( j \)-th cycle of the previous line, that is \( S_{Ind_{j1}, Ind_{j2}} = f_j \).

**Determination of other factors for the next \( k \)-th effect.** To find other factors, it is necessary to equate the first maximum contribution to zero. And the procedure is repeated in a similar way. The next largest maximum element of the \( k \)-th line is selected, i.e. the next largest contribution to the \( k \)-th effect.

The informational basis should be a database containing information about feed, formulated feed, feed mixtures; detailed norms for feeding farm animals, considering the breed and climatic zone; electronic cards (passports) of an animal, as well as a knowledge base on the scientific foundations, methods and techniques for compiling a diet for feeding farm animals and poultry, depending on the species, breed and class of animals.

4. Conclusion

The proposed structural-parametric model of feeding a productive animal includes two main blocks: the physiological state of the animal, the diet parameters. Knowledge of nutrients influence dependencies and patterns in the numerical terms on the physiological state, productivity helps to choose the right diet for the animal, taking into account various factors and restrictions. The identification algorithm allows one to establish a hierarchy in occurrence of an abnormal condition.

Numerous observations over a number of years show that, without the use of digital technologies, it is almost impossible to consider all factors when drawing up a diet; to optimize it according to various criteria using mathematical modeling methods; to evaluate economic factors (reduction of feed costs) and ecological or environmental factors (nitrogen and phosphorus excretion).

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