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Method for selection of pig manure processing technologies

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Abstract. The criteria, which take into account both economic and environmental indicators, were suggested for assessment of technologies and selection of the most reasonable solution. The method of Pareto optimization was applied. Technologies suited for the North-West Russia were considered to design a mathematical model and to obtain the required indicators for the criteria calculation. The technology of multi-stage processing of pig manure with cyclic sedimentation tanks was studied in more detail based on a separate, specially designed three-level mathematical model. The objective function was the eco-economic index of nitrogen, which is the ratio between the economic benefit from the marketed yield increment and the costs of nutrients retention in the organic fertilizers applied to soil under the harvested crop yield. The resulting simulation data were substantiated by experimental studies. A mathematical model and an algorithm for selecting the best-suited technology were designed. As the calculation process involved a large bulk of data, the WEB programming was used. Simulation results demonstrated 90% accurate choice of technology. The designed model was tested for the conditions of a pig complex in Leningrad Region with the manure output of 150 t per day and no own farmland for organic fertilizer application. Calculations proved the economic and ecological effectiveness of the multi-stage processing of pig manure: operating costs per one ton of produced organic fertilizer were reduced 1.8 times, fuel costs – 1.4 times and labour costs – 3.3 times. The chosen technology also featured higher ecological safety coefficient. Estimated ecological and economic effect of introduction of this technology amounted to 5936 thousand roubles per year.

Key words: manure management, processing method, algorithm, mathematical model, pig farm.

INTRODUCTION

Currently manure utilisation is one of the issues, which influences the effective operation of pig farms, and at times even hampers their development.

The detailed study of the current situation in pig farming in the North-Western Federal District of Russia shows that many pig farms do not have enough their own cultivated land to apply the produced organic fertilizers; often the distance between the fields and the pig farms exceeds 15 km (Shalavina, 2015). At the same time large-scale pig farms produce significant amount of liquid manure, e.g. a pig farm with 100,000 pigs produces above 365 thousand tons of liquid manure per year.

Leningrad Region is ranked among the pork production leaders in the North-Western Federal District (Figs 1 & 2) (http://www.gks.ru/).

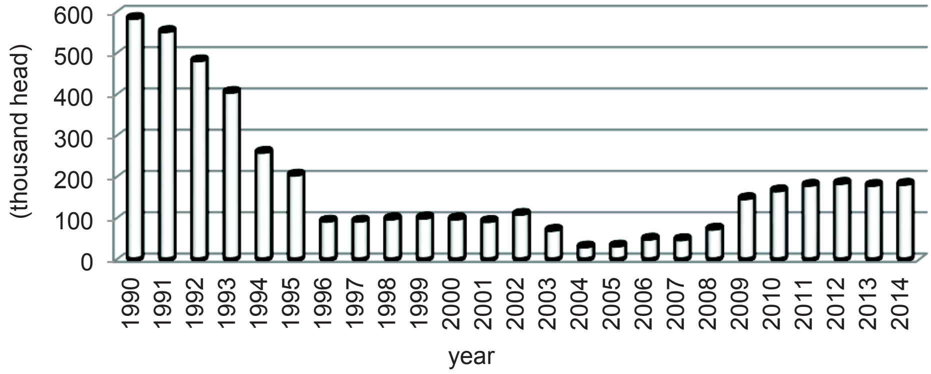

Figure 1. Dynamic pattern of average annual number of pigs in Leningrad Region.

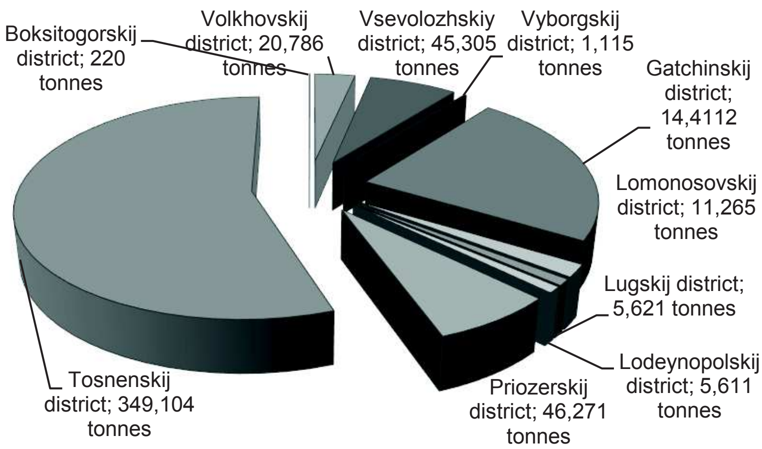

Figure 2. Annual manure output in the districts of Leningrad Region.

The problem of effective processing of pig manure was initially raised in 1980s, when large-scale pig breeding complexes were put into operation, such as 'Novyi Svet', 'Novgorodskiy', 'Vostochnyi' and others. At that time Russian researchers N.G. Kovalev, N.M. Marchenko, V.N. Afanasiev, V.V. Kaljuga and others did a lot to improve the technologies for manure utilization (Afanasiev et al., 1977; Kovalev et al., 1998; Kaljuga et al., 2011; Rabinovich et al., 2015). The relevant European experience was also considered (Singh et al., 2006; Salomon et al., 2012; Selimbasic et al., 2012).

In order to generalize and systematize information the available pig manure processing technologies were analysed (Fig. 3).

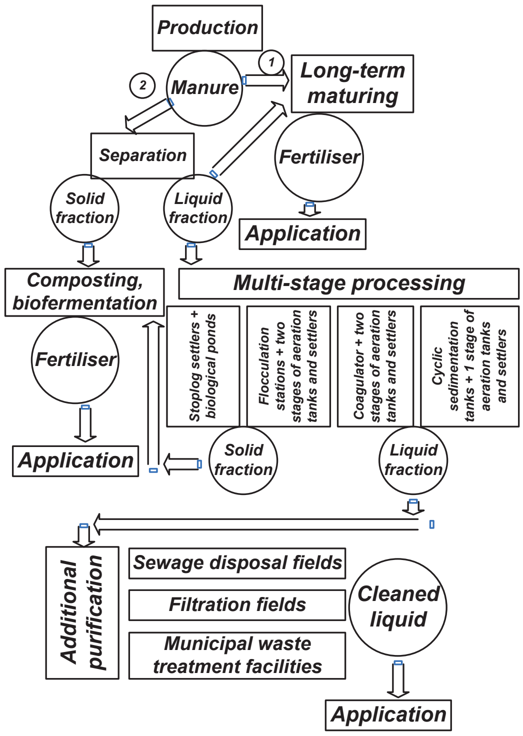

Figure 3. Technologies for pig manure processing.

According to Figure 3 there are two basic approaches to pig manure processing: long term maturing and separation into fractions with subsequent individual processing of solid and liquid fractions. These approaches have their own advantages and disadvantages depending on conditions of use. For example, some technologies might require significant land areas for application of organic fertilizers; some feature excessive power consumption, or require specific chemicals. All of that imposes certain constraints on the usage of these technologies under conditions of particular livestock complexes.

MATERIALS AND METHODS

To select pig manure processing technology, which is best suited for specific farm conditions, an algorithm was developed (Fig. 4).

'Farm Data' block includes information about production factors, resources, technical and technological characteristics. 'Database' block contains normative and informative references and the data on machines and equipment. 'Restrictions' block contains the criteria for selecting the optimal technology with due account for the farm potential.

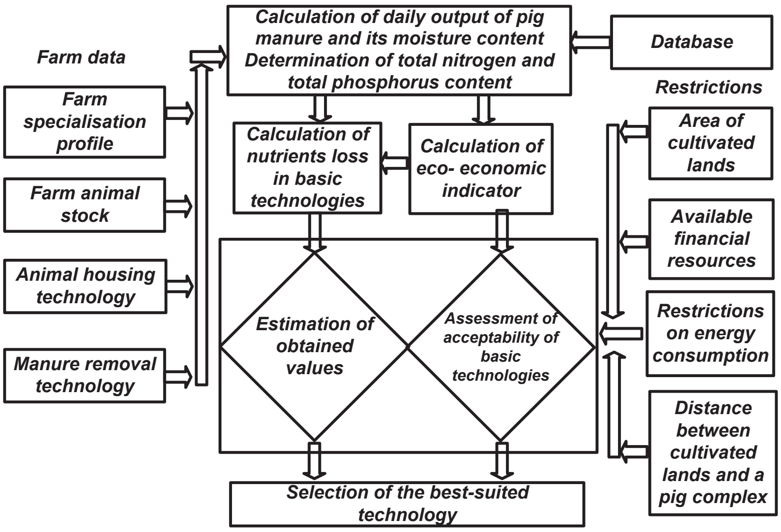

Figure 4. Pattern for selecting a technology of pig manure processing.

Based on literature review, the following criteria were accepted to select a technology:

1. Economic criterion:

$$Z = SCC + SOC, \quad (1)$$

SCC – specific capital costs, thousand roubles per ton; SOC – specific operating costs, thousand roubles per ton.

2. Ecological criterion – mass of retained nutrients in produced organic fertilizer:

$$M_{NP} = M_N + M_P = M_{N1} - L_N + M_{P1} - L_P, \quad (2)$$

M_N – mass of retained total nitrogen in organic fertilizer, t; M_P – mass of retained total phosphorus in organic fertilizer, t; M_{N1} – mass of total nitrogen in pig manure, t; L_N – loss of total nitrogen at all stages of the technology, t; M_{P1} – mass of total phosphorus in pig manure, t; L_P – loss of total phosphorus at all stages of the technology, t.

Pareto analysis was applied to compare the pig manure processing technologies by the above criteria.

Technologies suited for the North-West Russia were considered to design a mathematical model and to obtain the required indicators for the criteria calculation. The technology of multi-stage processing of pig manure with cyclic sedimentation tanks was studied in more detail (Fig. 5), based on a separate, specially designed three-level mathematical model (Shalavina & Briukhanov, 2015).

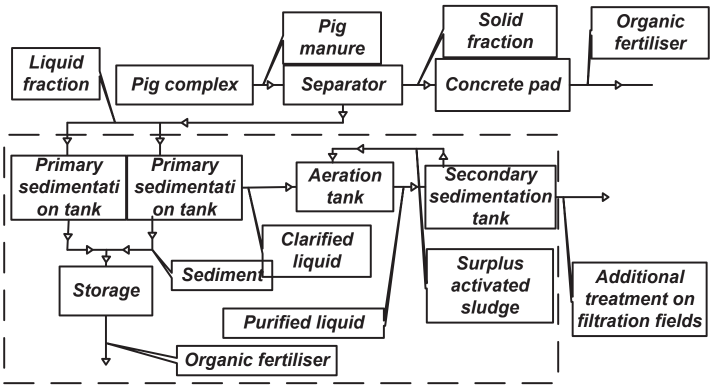

Figure 5. Technology for multi-stage processing of pig manure using batch sedimentation tanks (useful model patent of the Russian Federation No. 139469).

The objective function was the eco-economic index of nitrogen, which is the ratio between the economic benefit from the marketed yield increment and the costs of nutrients retention in the organic fertilizers applied to soil under the harvested crop yield:

$$K_{ЭЭ_N} = f(X1_i, X2_i, X3_i) = \frac{N_P}{K_{spvj} + E_{spvj}}, \tag{3}$$

$X1_i$ – redistribution of mass during *i-th* technological operation, t; $X2_i$ – redistribution of nitrogen during *i-th* technological operation, t; $X3_i$ – redistribution of phosphorus during *i-th* technological operation, t; N_P – net profit, thousand roubles; K_{spvj} – capital costs of nutrients retention under *j-th* technology, thousand roubles; E_{spvj} – operating costs of nutrients retention under *j-th* technology, thousand roubles.

$$N_P = C_n - C_{В} = f(X1_i) \tag{4}$$

C_n – cost of yield increment from the entire area, where organic fertilizers were applied, thousand roubles; $C_{В}$ – self-cost of yield increment owing to fertilizer application, thousand roubles.

$$K_{spvj} = \frac{\sum_{i-1}^{Kop}(Z_{si} + Z_{oi})}{M_{NP} - L_j} = f(X2_i, X3_i) \tag{5}$$

Kop – number of technological operations in the technology; i – index number of a technological operation; Z_{si} – total capital costs of facilities for *i-th* technological operation, thousand roubles; Z_{oi} – total capital costs of equipment and machines for *i-th* technological operation, thousand roubles; L_j – mass of nutrient loss per year under *j-th* technology, t.

$$E_{spvj} = \frac{E_{spvgj}}{M_{NP} - L_j} = f(X2_i, X3_i) \tag{6}$$

E_{spvgj} – operating costs of nutrients retention, thousand roubles.

$$X1_i = f(t_i, Q), Q \epsilon [50,300] \tag{7}$$

$$X2_i = f(t_i, N, Q), Q \epsilon [50,300], N \epsilon [2000,6000] \tag{8}$$

$$X3_i = f(t_i, P, Q), Q\epsilon[50{,}300], P\epsilon[500{,}1500] \quad (9)$$

t_i – time length of the *i-th* technological operation under: i = 1 – technological operation of primary sedimentation; i = 2 – technological operation of aeration with secondary sedimentation; i = 3 – technological operation of long term manure maturing.

Q – mass of daily output of the liquid fraction of pig manure, t; N – total nitrogen content in the liquid fraction of pig manure, mg kg^{-1}; P – total phosphorus content in the liquid fraction of pig manure, mg kg^{-1}.

RESULTS AND DISCUSSION

To obtain the indexes required for the criteria calculation the laboratory studies were conducted. The following technological operations were considered: primary sedimentation, aeration with secondary sedimentation, and long-term manure maturing. The obtained data were processed by the mathematical statistics method in the *STATGRAPHICS® CenturionXV* program. The study results of primary sedimentation and aeration are shown in Figs 6–11.

The primary sedimentation process was studied for 10 day period. It was found that the maximal volume of clarified liquid was formed during the seven days of primary sedimentation (Fig. 6), with the total nitrogen content in the sediment reaching 78% (Fig. 7) and total phosphorus content reaching 85% (Fig. 8).

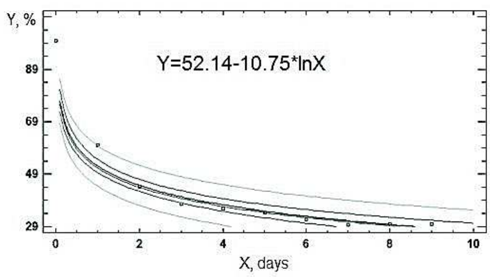

Figure 6. Ratio of sediment mass Y to liquid fraction mass depending on time X, %.

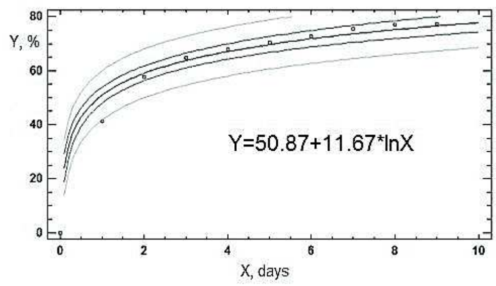

Figure 7. Total nitrogen in the sediment mass Y depending on time X, %.

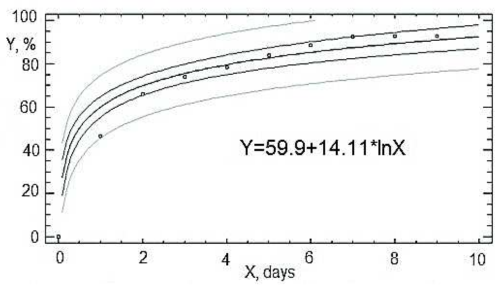

Figure 8. Total phosphorus in the sediment mass Y depending on time X, %.

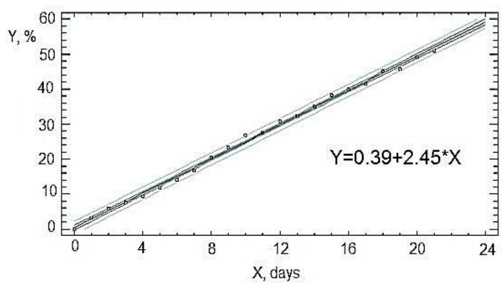

Figure 9. Ratio of loss of clarified liquid to activated sludge Y depending on time X, %.

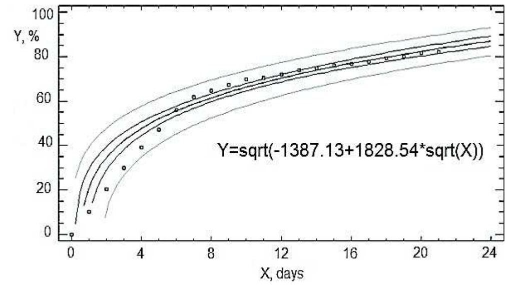

Figure 10. Share of total nitrogen in the liquid that is being purified (clarified liquid and activated sludge) Y depending on time X, %.

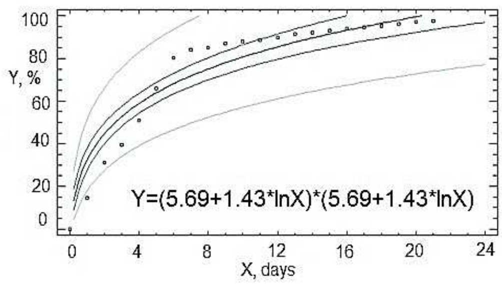

Figure 11. Share of total phosphorus in the liquid that is being purified (clarified liquid and activated sludge) Y depending on time X, %.

The aeration process was studied during 24 days period. 5 kg of activated sludge were placed in an aeration tank; the air supply was set at 30 l min^{-1} as measured by a rotameter. The air was supplied to the aeration tank according to performed calculations via the aeration system. It was found that 21 days were enough to achieve the minimal total nitrogen and total phosphorus content in the purified liquid.

Based on obtained theoretical and experimental data the coefficients were calculated, which were further used to create a mathematical model and an algorithm for selecting the proper technology of pig manure processing (Fig. 12).

The following six technologies were compared: 1) long term manure maturing in special facilities; 2) separation of manure into fractions with subsequent individual processing of solid and liquid fractions; 3) processing of pig manure in sedimentation tanks with stop logs and biological ponds; 4) processing of pig manure using flocculation and biological treatment facilities; 5) processing of pig manure using coagulators and biological treatment; 6) processing of pig manure using cyclic sedimentation tanks and biological treatment.

'Estimation of indicators with due account for farm conditions' block is used to assess the applicability of the technology in particular climatic zone, sufficient amount of arable land, etc.

'Calculation of indicators' block is used to calculate the criteria of technologies based on coefficients obtained from theoretical and experimental studies.

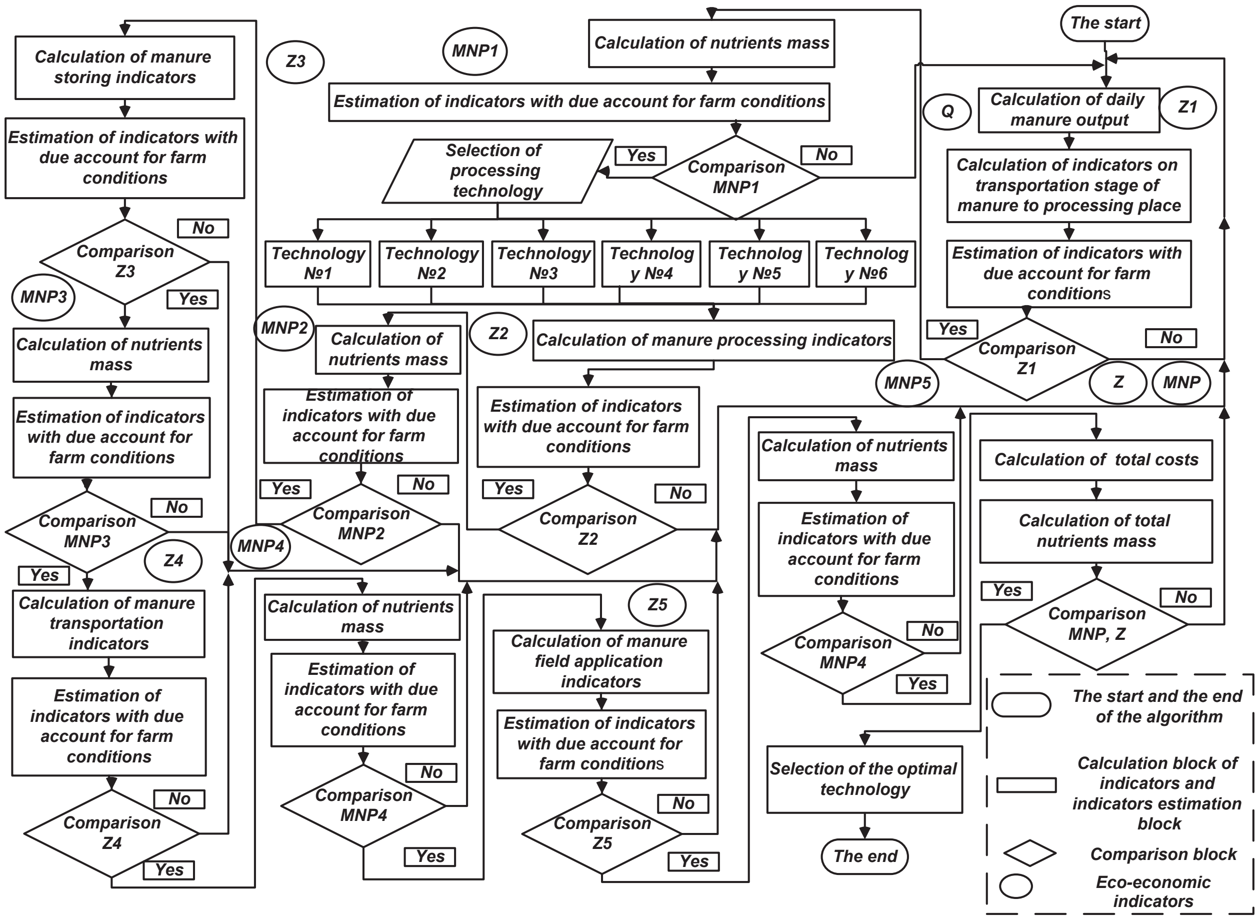

Figure 12. An algorithm to select the proper pig manure processing technology.

For automated selection of pig manure processing technology a web based computer program was created using PHP and MySQL (State Registration Certificate of Computer Program No. 2016611106; http://eco.sznii.ru/test/pigs1.html).

The designed algorithm was tested using the initial data from a pig complex in Leningrad Region with manure output of 150 t per day (with 93.4% moisture content) and no own farmland for organic fertilizer application. The compared technologies (No. 1–No. 6) were assessed for the conditions of this complex (Table 1, Table 2). The program selected the technology of pig manure processing using cyclic sedimentation tanks and biological treatment (No. 6). Currently the technology of long-term manure maturing in special facilities (No. 1) and subsequent application of liquid organic fertilizers on the fields rented from other farms is in place, with the transportation distance being up to 50 km.

Table 1. Comparison of pig manure processing technologies

Title/Number of technology	Units	Extremum direction	1	2	3	4	5	6
Economic criterion Z	thousand roubles t^{-1}	min	4.12	4.44	4.96	4.42	4.54	4.11
Ecological criterion M_{NP}	t	max	278.9	270.6	178.4	256.9	232	336.4

Table 2. Annual economic and ecological indicators

Indicator	Technology in place (No. 1)	Selected technology (No. 6)
Capital costs, thousand roubles	198,195	210,240
Specific capital costs, thousand roubles t^{-1}	3.63	3.84
Labour inputs, man – hour t^{-1}	6	1,8
Energy inputs, roubles per ton	10	96
Fuel inputs, thousand roubles per ton	0.11	0.08
Operating costs, thousand roubles	26,828	14,783
Specific operating costs, thousand roubles per ton	0.49	0.27
Ecological effect from improved soil fertility, roubles per ton	970	1,030
Reduced costs, thousand roubles per ton	4.12	4.11
Ecological indicator, t	278.9	336.4

The above values prove the eco-economic effectiveness of the technology of multi-stage processing of pig manure. It features lower operating costs, fuel and labour inputs as well as higher ecological effect owing to improved soil fertility.

The designed method for selection of pig manure processing technology was applied when rendering consulting services to above 10 pig rearing complexes in Kaliningrad, Leningrad, Kursk and Tver Regions. Recommended technologies were included in the on-farm document 'Technological Regulations. Proprietary Standard for Manure Processing and Application'.

The obtained results are in line with the previous investigations (Arkhipchenko et al., 1987).

CONCLUSIONS

The result of presented study is the algorithm for selecting the best-suited technology of pig manure processing. The algorithm demonstrates that:

– in case the farm does not have its own land for application of produced organic fertiliser, the multi-stage processing is a feasible option of pig manure utilisation. Such technologies produce solid concentrated organic fertilizers (40–50% from the initial mass of manure) and clarified liquid (40–50% from the initial mass of manure), which can be discharged on filtration fields;
– in case the farm has sufficient amount of cultivated land, the long- term manure maturing is used.

The developed algorithm is formalized in a mathematical model, based on two criteria: economic and ecological (mass of retained nutrients in produced organic fertilizer). The model is implemented in a web based computer programme (using PHP and MySQL). Simulation results demonstrated 90% accurate choice of technology.

The designed model was tested for the conditions of a pig complex in Leningrad Region with the manure output of 150 t per day and no own farmland. The programme selected a pig manure processing technology using cyclic sedimentation tanks and biological treatment. As compared with the practice in place this technology demonstrated 1.8 times lower operating costs per one ton of produced organic fertilizer, 1.4 times lower fuel inputs and 3.3 times lower labour inputs. It also featured higher ecological safety coefficient. Estimated ecological and economic effect of introduction of this technology amounted to 5936 thousand roubles per year.

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