**REPORT**

**LIP 1601-KS1441 Project "Introduction of the ecological system of agriculture is the basis for sustainable development of border rural area – EcoAgRAS"**

**Of South-East Finland – Russia Cross-Border Cooperation Programme 2014-2020**

**WP 1. Scientific justification of sustainability and environmental safety of production**

Saint Petersburg

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## Introduction

Intensification of agriculture increases the environmental pressures. Poor waste recycling infrastructure and the underuse of innovative technologies for livestock and poultry waste processing can adversely affect the environmental situation in the cross-border areas. The particular concern is the pollution of water bodies since this is the territory of the Baltic Sea catchment area falling under both the Russian environmental legislation and the Helsinki Convention with the focus on measures to reduce the nutrients input to water bodies from land-based sources, agriculture included. The territory of Priozerskij District is traditionally considered as an intersection of travelling routes from Russia to Finland, a place much visited by tourists that requires a special regime of economic activity, providing a healthy and safe environment.

The project goal is to improve the environmental safety and environmental quality of the rural territory by creating a system of design, technical, technological and managerial solutions and the infrastructure for utilisation of livestock and poultry farm waste.

The main project activities are in line with the Programme Priority 3 “Attractive, well-being environment and region”.

The aim of Work Package 1 is to identify the main environmental challenges of agriculture production in Leningrad Region and to elaborate the strategy to address them.

The tasks of WP1 are (1) scientific and expert analysis of the ecological status of livestock enterprises in Leningrad Region; (2) justification of Best Available Techniques (BATs) for manure utilisation; (3) development of BATs for manure utilisation.

## 1. Collection of environmental information on the negative impact of agricultural enterprises in Leningrad Region

Currently, under the decrees of the Russian Federation Government, the national agro-industrial complex is undergoing active development. This is directly related to the key provisions of the state’s economic strategy aiming at ensuring the country's food security.

Following specialization and concentration of production, as well as specific economic conditions, new livestock complexes are being built, and operating complexes are expanding their capacity. That way the labour productivity improves and the net cost of the products decreases. At the same time, the problems may arise with the use of animal/poultry manure produced in large quantities.

Leningrad Region is one of the leaders in the Russian Federation in livestock and poultry farming. The environmental risks associated with animal/poultry manure handling may occur in this region, since its entire territory is found within the Baltic Sea catchment area. Poultry factories, cattle farms and pig rearing complexes may find themselves in difficult environmental conditions, since the accumulated animal/poultry manure may become a source of environmental pollution if it is not used in the most feasible way.

Animal/poultry manure has always been considered as a valuable organic fertiliser, which allows increasing the soil fertility. However, if it is not applied an as organic fertiliser or the requirements of its processing technologies are not strictly observed, it loses its properties and is considered as a production waste with the ensuing consequences.

The studies conducted in the Institute for Engineering and Environmental Problems in Agricultural Production – branch of Federal State Budgetary Scientific Institution "Federal Scientific Agroengineering Center VIM" (IEEP – branch of FSAC VIM) over the past years have shown that in general Leningrad Region features the imbalance between the livestock/poultry and crop production sectors. Large-scale livestock and poultry complexes, for the most part, do not have a sufficient amount of their own agricultural land for applying all the organic fertiliser produced. At the same time, many crop-growing farms purchase the mineral fertilisers to improve soil fertility and to obtain the targeted yield. One way to address this problem may be to develop a well-functioning system to monitor the generation of nutrients on livestock/poultry complexes and the field nutrient requirements on the crop-growing farms.

### 1.1 Collection of initial data

The initial data on the status of livestock/poultry enterprises in Leningrad Region were collected in cooperation with Project Partner 1 – Committee for Agroindustry and Fishery Complex within the Leningrad Region Government. A special questionnaire was circulated to agricultural enterprises.

The following information was considered for the environmental assessment of agricultural enterprises in Leningrad Region:

- type of the enterprise (crop, livestock, poultry, mixed);
- profile of the enterprise (for pig farms - fattening, reproduction, combined breeding and feeding; for poultry factories - egg or broiler production; for cattle complexes – dairy or fattening);
- animal/poultry stock;
- area under agricultural crops (with a breakdown by cultivated crops), ha;
- use of mineral fertilisers, t / year;
- use of organic fertilisers, t / year;
- transfer of organic fertiliser to other enterprises, t / year.

To complete Task 1 of WP1 the data provided by Partner 1, the survey outcomes of typical agricultural enterprises and the remote sensing satellite data of Leningrad Region territories were used.

### 1.2 Data analysis

#### 1.2.1 Southern Finland data analysis

In Southern Finland the total number of farms is 22 200. Of all the farms 79 % are crop growing farms without any animal production. Dairy farms represent 7 % of the total number and 2.5 % are growing pigs, 4.5 % are growing beef cattle. Proportion of poultry farms is only 2 %. The average farm size in Southern Finland Regions varies between 40 - 60 ha cultivated lands per farm.

Agriculture and farms in Southern Finland (S-F) and totally in Finland in 2018 are shown in Tables 1 and 2.

Table 1.

Farms in Southern Finland (S-F) and totally in Finland in 2018

| Production | S-F (pcs) | Total (pcs) | Farms in S-F (%) |
|---|---|---|---|
| Crop production | 17564 | 35241 | 79.0 |
| Dairy | 1638 | 6854 | 7.4 |
| Pigs | 552 | 1080 | 2.5 |
| Beef | 986 | 3271 | 4.5 |
| Poultry | 334 | 514 | 1.5 |
| Other | 1080 | 2446 | 4.9 |

Table 2

Agriculture in Southern Finland (S-F) and totally in Finland in 2018

| Indicator | Value |
|---|---|
| Total number of farms in Finland, approximately | 49000 |
| Average farm size (cultivated field) | 48 ha |
| Number of farms, field more than 150 ha | 2258 |
| Number of farms, field more than 100 ha | 5589 |
| Average of heads per cattle and farm | 91 |
| Average of pigs per farm | 1887 |
| Average of animals per poultry company | 32506 |

Current number of dairy farms in Finland exceeds 6 200 farms (year 2018), of which 145 was organic farms. Only one third of all dairy farms are located in Southern Finland. During five last years, the total number of dairy farms has decreased 29 %. Size of dairy farms has wide variation, but farms with more than 100 cows, 453 farms totally, represent approximately 25 % of all the dairy farms. 55 % of all the dairy cows grow on farms with more than 50 cows. Total number of dairy cows in Finland is 263 600. Due to the totally different production structure and farm size it’s obvious that problems with manure and nutrient management somehow differ from those in Leningrad Region. Compared with the large and numerous cattle breeding companies in the Leningrad Region, Finnish production in every production sector is small-scale family farming.

Number of pig farms in Finland is near 1 000, and one-half of them are located in Southern Finland, in quite concentrated area in South-West Finland. The number of pig farms has decreased 7-

10 % annually during recent years. 50% of the growing pigs live on farms with more than 1 000 animals. Over 50 % of all the pigs grown for meat live on farms with more than 1 000 heads.

Number of poultry farms producing chicken meat in Finland is 171 totally, and number of turkey farms 54, respectively.

Total number of egg laying chicken in Finland is approximately 4 million, and young chicken 607 000 heads. 86 % of all egg-laying hens are growing on the 133 farms with more than 10 000 animals, but almost 2/3 of the chicken farms have less the 50 animals.

Estimation of nutrient load to water bodies tells that 60 % of the total annual phosphorus load in Finland comes from agriculture and animal husbandry, but less than 50 % of nitrogen load, respectively. As fertilizer, 9 kg total P per hectare is used annually in manure, plus 6 kg P in chemical fertilizers, respectively.

The proportion of nutrient load from agriculture around the Archipelago area and Southern coastal area is clearly higher than in average. 90% of the total nutrient load happens outside the growing season. The changing climate, including growing precipitation in autumn and wintertime causes more and more erosion and nutrient load, especially phosphorus. Concentration of animal farms and production to certain areas easily will cause overload of manure on field fertilizer use regionally or locally, compared with the actual needs of crops in Finland as well. Phosphorus is the main problem. The total amount of manure produced in Finland is 15.5 million tons annually. 230 000 tons chemical fertilizers are used annually as well. Of the total fertilization with N, manure and slurry from wastewater treatment represents 40 %, the rest comes in chemical fertilizers. Fertilization with phosphorus is 33 000 tons annually, of which 60 % comes in manure and slurry. N fertilization is in average 70 kg/ha, P fertilization 6 kg/ha respectively.

Quality of water around coastal areas is good or excellent only in 25% of water bodies and areas. In other parts of Finland situation is much better. The goals in better water quality in the Baltic Sea and Gulf of Finland, set by The Finnish Government, have not yet been achieved. Growing farm size and concentrated animal production are the main reasons for this in agriculture. Transportation of manure is expensive. Of the total manure produced, 75 % is produced in slurry or other liquid form. 40 % of the liquid manure is injected in soil, and the rest is used as diffuse distribution on the soil cover. Nitrogen used in manure in average represents the amount that of crops need, but the average amount of Phosphorus exceeds estimated plant needs.

### 1.2.2 Leningrad Region data analysis

Leningrad Region is divided into 17 municipal districts, where 142 agricultural organisations are located – 94 cattle complexes, 8 pig rearing complexes, 12 poultry factories, 2 mixed-type enterprises (cattle and pig rearing) and 26 crop-growing farms (Fig. 1). One district – Podporozhskij – does not have any agricultural enterprises. That is why it was not considered in the study.

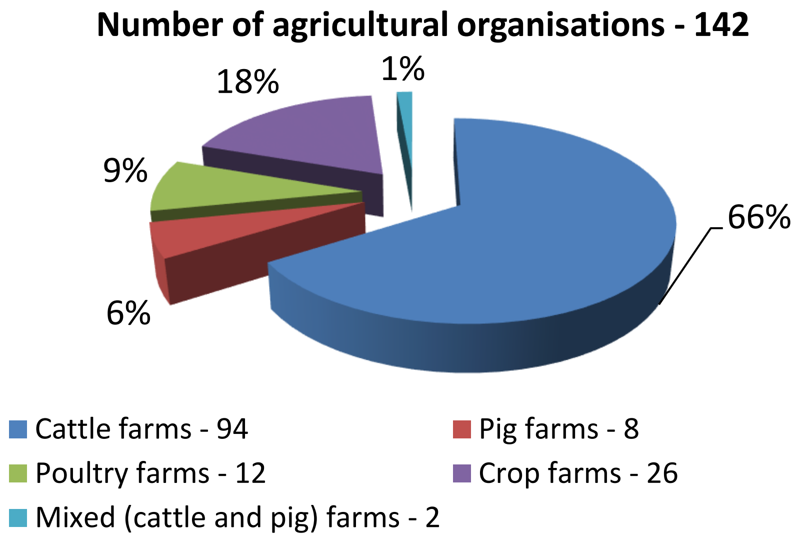


Fig. 1. Agricultural organisations in Leningrad Region

Leningrad Region has 116 livestock and poultry enterprises with the stock exceeding 29 million head of farm animals/poultry: 159,783 head of cattle, 184,867 head of pigs and 28,970 thousand head of poultry.

**Cattle farming**

There are 96 agricultural enterprises in Leningrad Region, which are engaged in cattle rearing: 94 – cattle only, 2 – mixed-type (pigs and cattle). The most widespread specialization of cattle farms is dairy production (92). The cattle farming in Leningrad Region may be characterised as intensive – above 70% of cattle complexes have the animal stock over 1000 head (one-time housing). (Fig. 2)

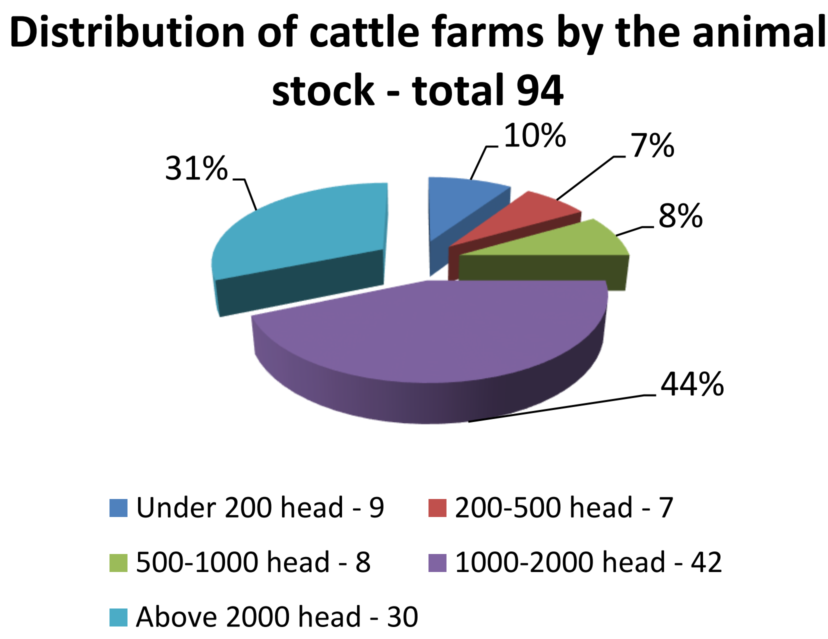


Fig. 2. Distribution of cattle farms by the animal stock in Leningrad Region

Forty-two farms have the cattle stock from 1000 to 2000 head and 30 farms have the cattle stock over 2000 head (one-time housing).

**Pig farming**

In Leningrad Region there are 10 agricultural enterprises engaged in pig rearing (8 pig rearing complexes and 2 mixed-type (pigs and cattle) farms. The pig stock in Leningrad Region is distributed unevenly – above 65% of the total or 120577 head are housed in Tosnenskij District on two pig complexes – “Idavang Agro” and “Agroholding Pulkovskij”. Only one pig complex has the animal stock below 5000 head (one-time housing); four pig complexes have the stock from 5,000 to 10,000 head (one-time housing). All the rest pig complexes have the stock over 10,000 head (one-time housing).

**Farm poultry farming**

By the results of 2018, Leningrad Region is the top egg producer in the Russian Federation (3,166.7 mln. pieces); it ranks second in the farm poultry stock (30.17 million head) and places fifth in the poultry meat production (314.1 thousand tons). This fact indicates the intensive character of poultry farming in this region.

There are 12 poultry enterprise in Leningrad Region, of which five are the leaders with the poultry stock over 500,000 head (one-time housing). The overall farm poultry stock in Leningrad Region is 28,970 thousand head (as of July 2019), with 66% or 18,937,000 head being housed in Kirovskij District.

## Crop farming

The main crops cultivated in Leningrad Region are perennial and annual grasses and legumes. The area of arable land (as of the end of 2017) is 387.9 thousand ha, i.e. 13.1% of that in the North-West Federal District of the Russian Federation [1].

Fig. 3 shows the distribution of agricultural land in the districts of Leningrad Region. Boksitogorskij Municipal District has less than 1% of regional agricultural land.

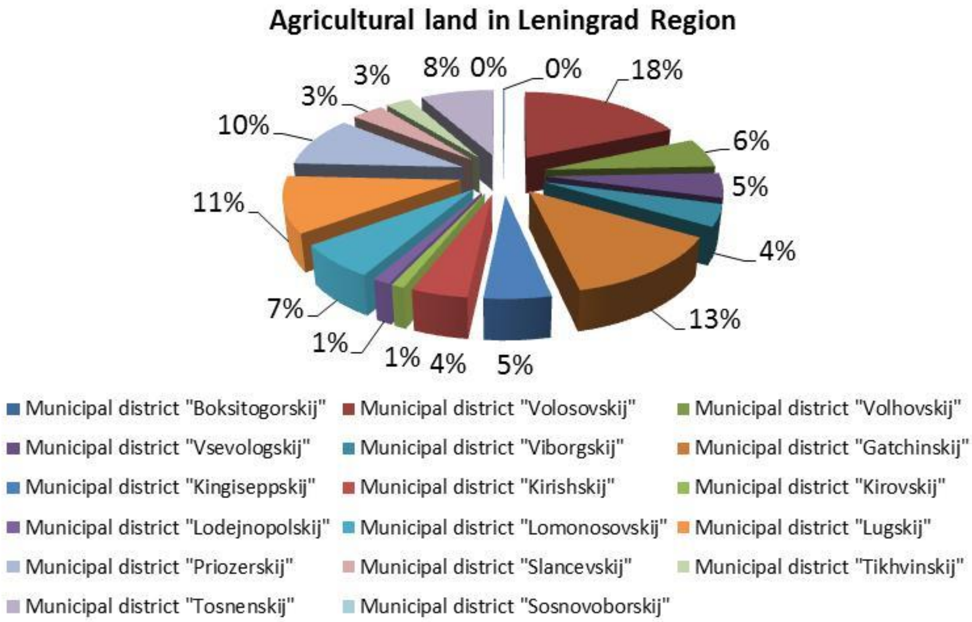


Fig. 3. Areas of agricultural land in the districts of Leningrad Region

As seen in Fig.3, the biggest area of agricultural land is found in Volosovskij District – 36,547 hectares. Gatchinskij District occupies the second place in terms of agricultural land area – 26,299 hectares.

The agricultural land soils of Leningrad Region are described in detail based on the soil survey outcomes and the land valuation data of agricultural enterprises and districts in the region. They are represented by above 300 variants combined into eight agro-genetic groups (Table 3) [31].

Table 3

The soil-cover structure of agricultural land in Leningrad Region

| Group number | Soil | Percentage to total, % |
|---|---|---|
| 1 | Sod-podzolic | 28 |
| 2 | Sod-podzolic, slightly gleyic | 19 |
| 3 | Sod-podzolic gleyic | 17 |
| 4 | Sod-podzolic gleyed | 5 |

| | | |
|---|---|---|
| 5 | Sod-carbonate | 18 |
| 6 | Peaty-podzolic | 2 |
| 7 | Lowland peaty | 6 |
| 8 | Alluvial | 5 |

The sod-podzolic automorphic soils (No. 1) are found on the largest area of agricultural land in the region. However, the soils with the different degrees of excessive moisture content (No. 2, 3, 4, 6, 7, and 8), which require the water regime control, are found on above half of agricultural land. About a sixth of the agricultural land has sod-carbonate soils, which, unlike all others, do not need liming.

The average values of the main properties of the arable (humus) horizon of the above soil groups were calculated by the mathematical processing of the relevant indicators for the soil assessment groups established during the 4th round of land assessment in Leningrad Region (Table 4).

Table 4

Average values of the properties of arable (humus) horizon by soil groups (numerator), variation of average values by assessment groups (denominator), soil quality scores and land quality grades

| № | Soils | Properties | | | Quality scores | Land quality grades |
|---|---|---|---|---|---|---|
| | | Humus, % | pH | Total absorbed bases S, mmol/ 100 g soil | | |
| 1 | Sod-podzolic | 2.4<br>1.7–3.1 | 5.2<br>4.5–5.8 | 8.0<br>2.2–12.8 | 61.0–75.0 | 2.0 |
| 2 | Sod-podzolic, slightly gleyic | 3.3<br>2.1–3.7 | 5.2<br>5.0–5.4 | 9.8<br>5.9–12.2 | 54.0–62.0 | 2.0–3.0 |
| 3 | Sod-podzolic gleyic | 4.5<br>3.6–4.7 | 5.4<br>5.1–5.8 | 14.1<br>9.5–15.9 | 44.0–54.0 | 3.0 |
| 4 | Sod-podzolic gleyed | 4.9<br>4.2–6.0 | 4.9<br>4.7–5.1 | 11.3<br>9.3–13.0 | 30.0–35.0 | 4.0 |
| 5 | Sod-carbonate | 3.6<br>2.6–5.8 | 6.6<br>6.3–6.9 | 22.7<br>12.1–36.0 | 67.0–88.0 | 1.0–2.0 |
| 6 | Peaty-podzolic | — | 5.6<br>4.6–6.6 | 13.7<br>7.5–20.0 | 11.0–28.0 | 4.0–5.0 |
| 7 | Lowland peaty | — | 5.9<br>5.3–6.5 | 35.6<br>33.0–38.3 | 20.0–26.0 | 5.0 |
| 8 | Alluvial | 3.5<br>1.4–6.0 | 5.4<br>5.2–5.6 | 13.9<br>7.7–20.6 | 15.0–67.0 | 2.0–5.0 |

Based on the studies [31], the main agro-genetic groups of soils on the agricultural lands were defined and their resource potential was estimated. The agricultural land in Leningrad Region was systematized by the land quality grades based on the soil resource potential assessment.

The largest area of agricultural land is good quality land (Grade 2) – 38.7%, and medium-quality land (Grade 3) – 31%. These lands have mainly sod-podzolic soils. The excellent lands (Grade 1) have mainly sod-carbonate soils and partially sod-podzolic soils – 14.3% (Table 5).

Table 5

Classification of agricultural land by the land quality grades

| N | District | Average quality score of tilled land | Average quality score of agricul-tural land | Including those by land quality grades | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Excellent | Good | Medium | Below average | Poor |
| | | | | > 75.0 scores | 61.0–75.0 scores | 41.0–60.0 scores | 26.0–40.0 scores | < 25.0 scores |
| | | | | % | | | | |
| 1 | Boksitogorskij | 63.0 | 57.0 | 3.1 | 62.4 | 13.7 | 9.4 | 11.4 |
| 2 | Volosovskij | 73.0 | 73.0 | 59.3 | 25.8 | 12.9 | 0.6 | 1.4 |
| 3 | Volkhovskij | 65.0 | 52.0 | 3.5 | 39.9 | 35.1 | 7.9 | 13.7 |
| 4 | Vsevolozhskij | 57.0 | 53.0 | 0. | 41.5 | 41.7 | 8.1 | 8.7 |
| 5 | Vyborgskij | 57.0 | 46.0 | 0.0 | 14.1 | 50.8 | 20.7 | 14.4 |
| 6 | Gatchinskij | 68.0 | 61.0 | 24.5 | 28.4 | 32.4 | 4.7 | 10.0 |
| 7 | Kingiseppskij | 67.0 | 58.0 | 15.0 | 23.0 | 48.6 | 9.6 | 3.7 |
| 8 | Kirishskij | 63.0 | 57.0 | 0.0 | 51.1 | 37.1 | 6.8 | 5.0 |
| 9 | Kirovskij | 64.0 | 54.0 | 5.9 | 36.5 | 40.9 | 5.7 | 11.1 |
| 10 | Lodeinopolskij | 59.0 | 52.0 | 0.0 | 48.2 | 25.8 | 4.4 | 21.6 |
| 11 | Lomonosovskij | 69.0 | 63.0 | 27.5 | 33.7 | 28.0 | 6.9 | 4.0 |
| 12 | Luzhskij | 67.0 | 62.0 | 18.7 | 46.3 | 23.1 | 1.3 | 10.5 |
| 13 | Priozerskij | 56.0 | 51.0 | 0.0 | 36.2 | 41.9 | 10.4 | 11.5 |
| 14 | Slantsevskij | 66.0 | 61.0 | 7.4 | 58.2 | 20.3 | 6.3 | 7.9 |
| 15 | Tikhvinskij | 62.0 | 56.0 | 0.4 | 61.3 | 19.5 | 6.4 | 12.4 |
| 16 | Tosnenskij | 64.0 | 56.0 | 0.4 | 48.9 | 37.9 | 6.9 | 5.9 |
| Leningrad Region | | 65.0 | 58.0 | 14.3 | 38.7 | 31.0 | 7.1 | 9.0 |

All sod-podzolic soils had no significant differences in humus content. The pH value was maximum in the case of sod-carbonate soils, and minimal – in podzolic-gleyed soils; the exchange acidity of these soils significantly differed from those of other soil variants.

The bonitet (quality) score was maximum in the case of sod-carbonate soils, and minimal – in the case of podzolic-gleyed soils. With an increase in the gleization of sod-podzolic soils, the score significantly decreased. The exceptions were sod-podzolic and sod-podzolic slightly gleyed soils – no significant differences were found between the quality scores in these soils.

The quality grade of the sod-carbonate and sod-podzolic soils was the same; and in other soils this indicator significantly increased with an increase in the gleization of sod-podzolic soils.

The problem of utilising a large amount of livestock and poultry waste can impede the normal functioning of farms and constitute a serious obstacle to the development of the agro-industrial complex in Leningrad Region. At the same time, there is another environmental and economic problem – the lack of nutrients in the fields in Leningrad Region. Modern methods of animal/poultry manure processing provide the production of high-quality organic fertilisers, which will contribute to improving the soil texture.

### 1.3 Analysis of organic waste generation

For environmental assessment of agricultural enterprises, production and accumulation of animal/poultry manure in each district of Leningrad Region were considered and the feasibility of its application as an organic fertiliser to the agricultural land in this district (Table 1).

Table 6

Amount of animal/poultry manure produced and agricultural land area in the districts of Leningrad Region (as of end 2018)

| № | District | Amount of animal/poultry manure produced, t/year | Available agricultural land, ha |
|---|---|---|---|
| 1 | Boksitogorskij District | 8160.0 | 350.0 |
| 2 | Volosovskij District | 405004.0 | 36547.0 |
| 3 | Volkhovskij District | 259843.5 | 11584.0 |
| 4 | Vsevolozhskij District | 269202.1 | 9513.0 |
| 5 | Vyborgskij District | 483185.6 | 8374.0 |
| 6 | Gatchinskij District | 489406.8 | 26299.0 |
| 7 | Kingiseppskij District | 144248.0 | 10263.0 |
| 8 | Kirishskij District | 101689.0 | 8678.0 |
| 9 | Kirovskij District | 917175.7 | 2016.0 |
| 10 | Lodeinopolskij District | 48946.5 | 2683.0 |
| 11 | Lomonosovskij District | 203272.2 | 13010.0 |
| 12 | Luzhskij District | 665322.0 | 21571.0 |
| 13 | Priozerskij District | 468083.3 | 19690.0 |
| 14 | Slantsevskij District | 81796.5 | 6948.0 |
| 15 | Tikhvinskij District | 85008.5 | 5478.0 |
| 16 | Tosnenskij District | 568249.1 | 16105.0 |

96 cattle rearing complexes in Leningrad Region produce above 3 million tons of manure per year; 8 pig rearing complexes produce above 604 thousand tons of manure per year; 12 poultry factories produce above 1.3 million tons of poultry manure (Fig.4)

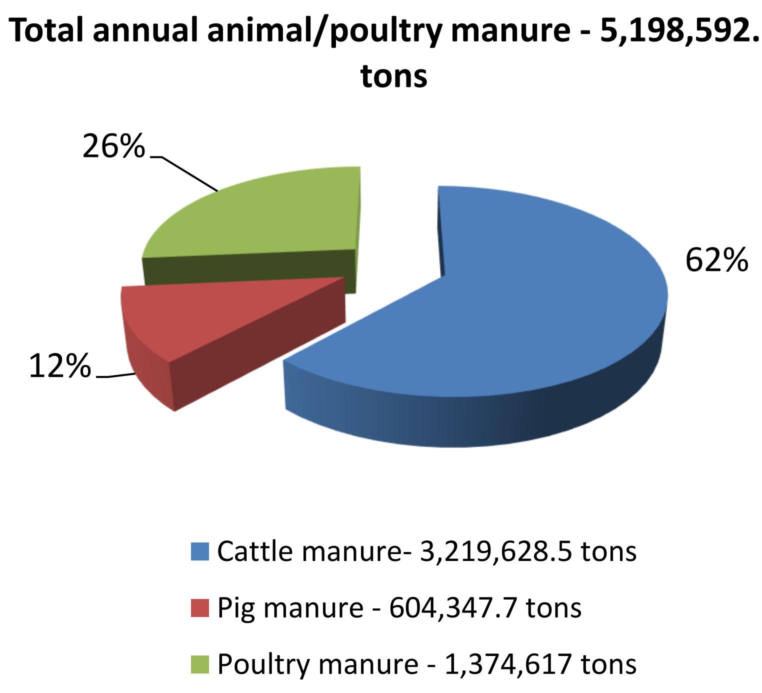


Fig. 4. Amount of animal/poultry manure produced

The nutrient content in the excrement of different farm animals/poultry is shown in Table 7.

Table 7.

The nutrient content in the excrement of different farm animals/poultry

| | |
|---|---|
| Content in the dry matter of cattle excrement, % | |
| Total nitrogen (N) | 3.2 |
| Phosphorous ($P_2O_5$) | 1.8 |
| Potassium, ($K_2O$) | 5.0 |
| Content in the dry matter of pig excrement, % | |
| Total nitrogen (N) | 6 |
| Phosphorous ($P_2O_5$) | 3.2 |
| Potassium, ($K_2O$) | 2.5 |
| Content in the dry matter of poultry excrement with bedding, % | |
| Total nitrogen (N) | 3.6 |
| Phosphorous ($P_2O_5$) | 3.4 |
| Potassium, ($K_2O$) | 2.0 |
| Content in the dry matter of poultry excrement without bedding, % | |
| Total nitrogen (N) | 6.2 |
| Phosphorous ($P_2O_5$) | 3.5 |
| Potassium, ($K_2O$) | 2.1 |

All the animal/poultry manure produced contains 31900 t of nitrogen and 6800 t of phosphorous (on the primary nutrient basis). Above 190,000 hectares of agricultural land may be fertilized with this amount of nutrients.

## 2. Analysis of the environmental risks and identification of their sources

### 2.1 Environmental risks

#### 2.1.1 Environmental risks associated with the nutrient load

To identify the risks associated with the nutrient load from livestock and poultry complexes, the mass of nitrogen in the organic fertiliser was calculated for each district.

Using HELCOM Recommendations [2, 3] (170 kg/ha of nitrogen) and Management Directive for Agro-Industrial Complex “Recommended Practice for Engineering Designing of Systems for Animal and Poultry Manure Removal and Pre-application Treatment” the maximum application rate for each type of organic fertilizer, produced from cattle, pig or poultry manure, was calculated. With received application rates (t/ha), the known total area of agricultural land in each district and the cultivated crops, the potential for the complete use of animal/poultry manure in the districts of Leningrad Region was determined (Table 8).

Table 8

Potential for the complete use of animal/poultry manure in the districts of Leningrad Region

| № | District | Agricultural land area, ha | Estimated nitrogen, which could be applied on available agricultural land, t/year | Nitrogen generated in the fertilizer produced, t/year | Balance (Estimated additional nitrogen, which could be applied on available agricultural land, t/ha) |
|---|---|---|---|---|---|
| 1 | Boksitogorskij District | 350.0 | 59.5 | 29.8 | +29.7 |
| 2 | Volosovskij District | 36547.0 | 6213 | 1458.1 | +4755 |
| 3 | Volkhovskij District | 11584.0 | 1969.3 | 907.9 | +1061.4 |
| 4 | Vsevolozhskij District | 9513.0 | 1617.2 | 935.9 | +681.3 |
| **5** | **Vyborgskij District** | **8374.0** | **1423.7** | **3596.6** | **-2172.9** |
| 6 | Gatchinskij District | 26299.0 | 4471.0 | 2587.9 | +1883.1 |
| 7 | Kingiseppskij District | 10263.0 | 1744.7 | 519.3 | +1225.4 |
| 8 | Kirishskij District | 8678.0 | 1475.3 | 366.0 | +1109.3 |
| **9** | **Kirovskij District** | **2016.0** | **342,9** | **8776,1** | **-8433,2** |
| 10 | Lodeinopolskij District | 2683.0 | 456.1 | 137.0 | +319.1 |
| 11 | Lomonosovskij District | 13010.0 | 2211.7 | 872.1 | +1339.6 |
| 12 | Luzhskij District | 21571.0 | 3667.3 | 1339.2 | +2328.1 |
| 13 | Priozerskij District | 19690.0 | 3347.2 | 1529.2 | +1818.0 |
| 14 | Slantsevskij District | 6948.0 | 1181.2 | 294.5 | +886.7 |
| 15 | Tikhvinskij District | 5478.0 | 931.3 | 306.0 | +625.3 |

| | | | | | |
|---|---|---|---|---|---|
| 16 | Tosnenskij District | 16105.0 | 2738.0 | 1689.2 | +1048.8 |
| | **Total in Leningrad Region** | | | | **+8508.1** |

The nitrogen mass in the organic fertiliser has been adjusted compared to the nitrogen mass in the raw manure by the nitrogen loss during the manure processing into an organic fertiliser.

Calculations regarding Leningrad Region show that the nutrient load on the environment in the districts is different. Most of the districts have the potential to apply additional nitrogen with organic fertilisers on the available agricultural land. Only two districts – Vyborgskij and Kirovskij Districts, have a shortage of land to apply the produced 2172.9 and 8433.2 t N/year, respectively, that leads to the possible environmental risks. However, the nutrient load in these two districts can be relieved by applying the produced organic fertilisers to the agricultural land in the neighbouring districts, as the total potential of nitrogen application in Leningrad Region is positive: +8769.2 tons of nitrogen per year. The data obtained are also shown on the map of Leningrad Region (Fig. 5).

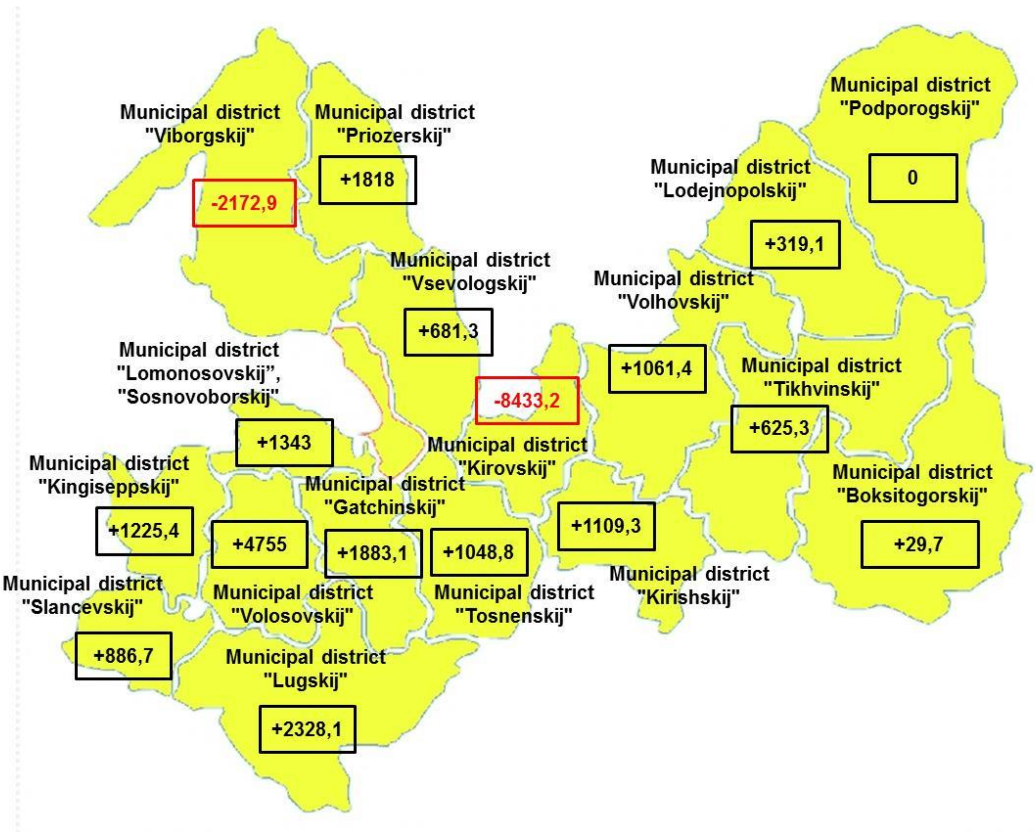


Fig. 5. The potential of the use of organic fertiliser nitrogen, t N/year

The map in Fig.5 demonstrates that in general Leningrad Region has certain reserve of agricultural land for applying the organic fertilisers and this contributes to the development of animal husbandry in the region. Only two districts feature a risk of having too many livestock complexes on their territory. Therefore, it is not advisable to increase the number of any animal species here, or else the increase in the farm animal stock should be accompanied by the introduction of BATs of organic waste processing and the expansion of crop farming.

### 2.1.2 Environmental risks associated with intensive production

Intensification of production results in animal/poultry stock increase on particular production sites.

In the Baltic countries, the animal density of 1.5 LSU/ha of the agricultural area was adopted as a conditionally safe value [4, 5]. Exceeding the range of values of 1.5 - 1.7 LSU/ha can bring about the risk of accumulation of excessive amounts of nutrients in the soil and a significant increase in pollutant emissions into the atmosphere.

The case study showed that the average density of farm animals and poultry per unit of the cultivated land in Leningrad Region is 2.2 LSU / ha. It means that Leningrad Region exceeds the recommended value. (Fig. 6)

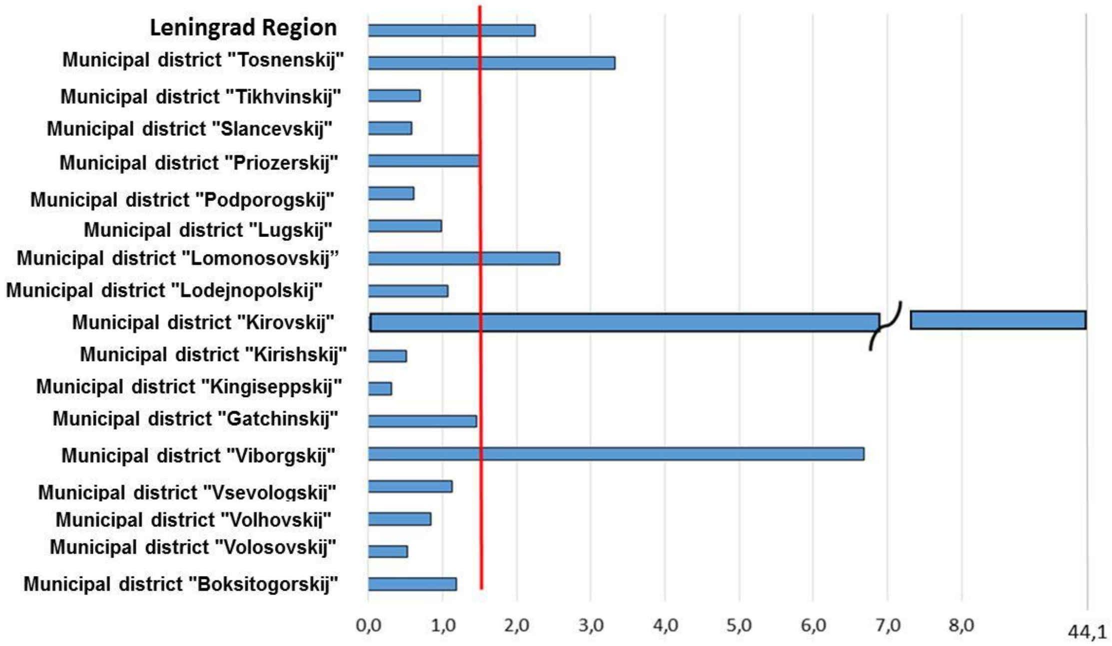


Fig. 6. The average animal/poultry density in Leningrad Region

The highest environmental risks may occur in Kirovskij District, with the animal/poultry density being 44.1 LSU/ha.

In general three districts in Leningrad Region feature the high environmental risks, with the animal/poultry density being above 3.1 LSU/ha and 13 districts have low environmental risks in case of further intensification of livestock and poultry farming.

### 2.1.3 Environmental risks associated with diffuse loads

To calculate the diffuse load on water bodies, the estimation method of the diffuse load from agricultural activities developed at IEEP was used [6]. An increase in the diffuse load can lead to the potential risk of leaching and migration of nutrients from the fields located in the catchment area of water bodies.

The actual diffuse load of nitrogen and phosphorus on the catchment area from agricultural activities throughout Leningrad Region was found to be 20.67 kg/ha for nitrogen and 1.24 kg/ha for phosphorus. At the same time, the recommended normative value, which does not generate environmental risks, for this region is N = 8.5-19.3 kg/ha, P = 0.07-2.03 kg/ha, depending on the soil type.

Expanding the existing enterprises and the construction of new complexes of intensive livestock and poultry farming may lead to the risk of excessive input of nitrogen and phosphorus into the water bodies from the catchment areas.

## 2.2 Identification of environment risk sources

### 2.2.1 Status of available manure storages

The status of available animal/poultry manure storages on the agricultural enterprises in Leningrad Region was analysed. Fig. 7 shows the location of agricultural enterprises in Leningrad Region.

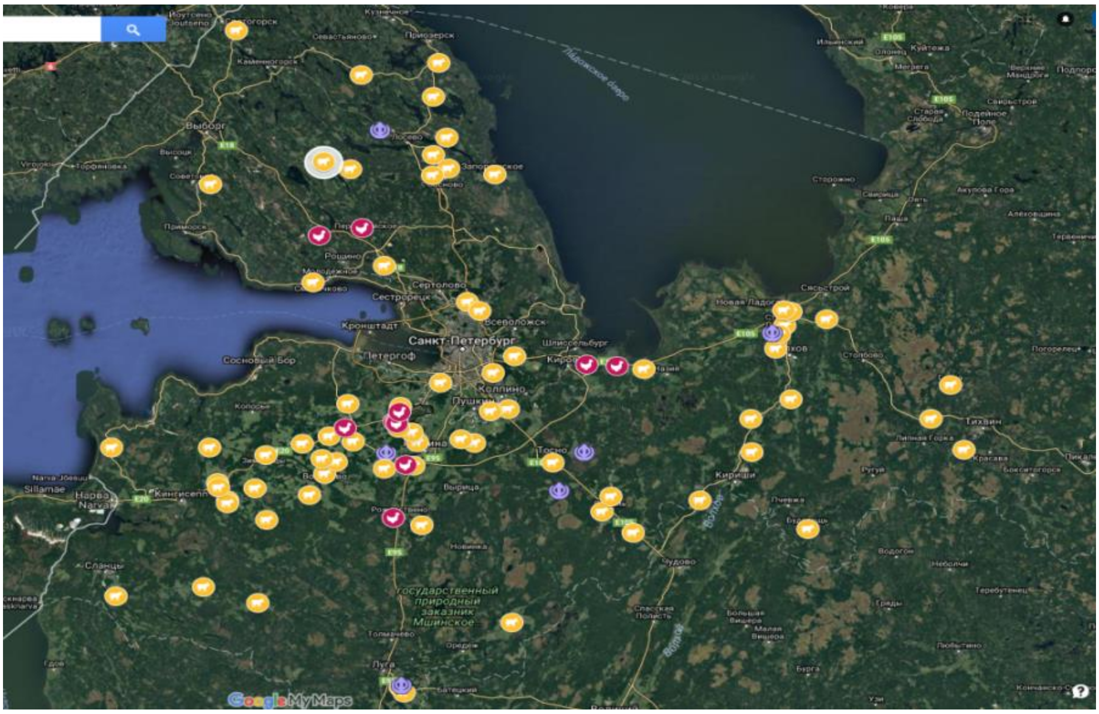


Fig. 7. Location of different types of agricultural enterprises in Leningrad Region

The capacity of available manure storage facilities (solid manure pads and storage facilities for semi-liquid and liquid manure and manure-bearing wastewater) should be sufficient for processing of all produced animal/poultry manure into the organic fertiliser and its temporary accumulation. The volume of produced animal/poultry manure was compared with the capacity of existing manure storages/concrete pads to ensure the processing processes.

The design of pads and storage facilities were assessed for compliance with the related requirements – integrity (tightness), presence of a leak detection system, ensuring minimum emissions, etc.

Analysis of the status of available manure storage facilities in Leningrad Region showed that 34% of them are in the satisfactory condition, about 23% are estimated to have insufficient capacity, and 43% do not fully meet the requirements of the current legislation (Fig. 8).

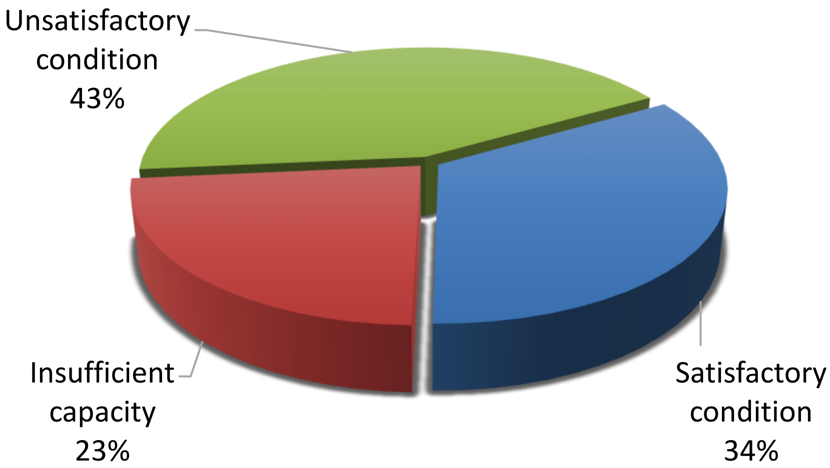


Fig. 8. The status of manure storages in Leningrad Region

The survey of agricultural enterprises in Leningrad Region revealed the moisture content of manure on some of them to exceed significantly the moisture content of natural animal excrement, increasing the volume of manure by 30–50%. Such an increase may lead to the potential risk that available manure storage capacity will not be enough to process the manure into the organic fertiliser following the established technological processes.

Above 50% of all manure storages are built without protection against possible unauthorized leaks, for example solid manure storages do not have the waterproof floor and walls; the storages for liquid manure and farm wastewater are not made of waterproof durable material, impervious to moisture and resistant to damage while handling the manure. Liquid manure storage facilities are not covered and protected in another way to reduce ammonia emissions. Currently, these design features comply with the environmental safety standards; however, under transition to BAT system, the manure storage facilities will require upgrading.

In cattle farming, 29% of manure storage facilities are found in the satisfactory condition; 20% are estimated to have the insufficient capacity and 51% do not meet the requirements of the current legislation fully (Fig. 9).

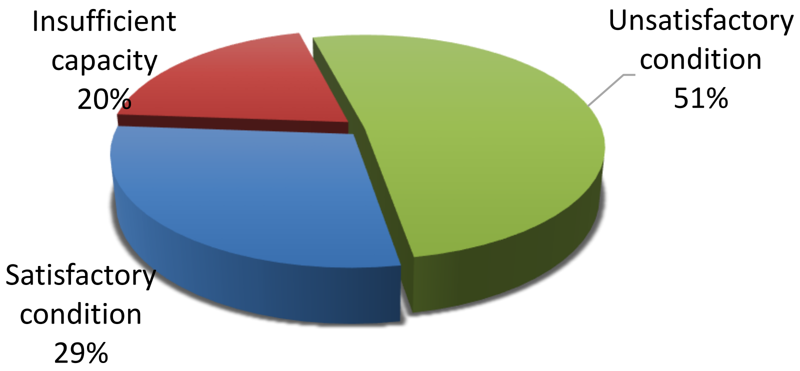


Fig. 9. The status of cattle manure storages in Leningrad Region

In intensive pig rearing, 87% of manure storage facilities are found in the satisfactory condition and about 13% are estimated to have the insufficient capacity (Fig. 10).

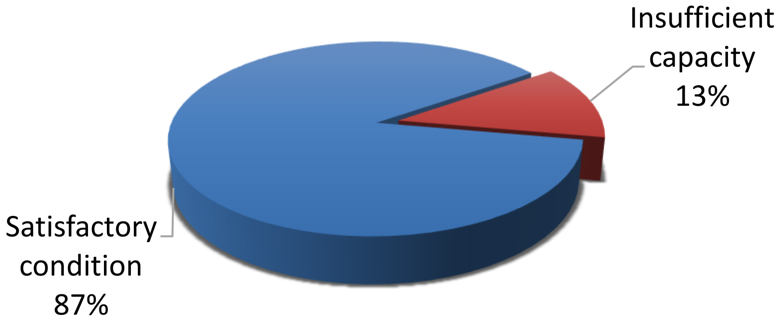


Fig. 10. The state of manure storages on pig complexes in Leningrad Region

In intensive poultry farming, 27% of poultry manure storages are found in the satisfactory condition; 55% are estimated to have the insufficient capacity and 18% do not meet the requirements of the current legislation fully (Fig. 11).

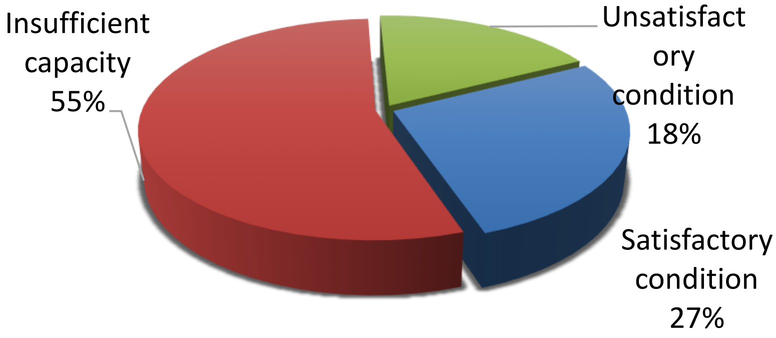


Fig.11. The status of poultry manure storages in Leningrad Region

To date, in Leningrad Region, there are many operating organizations, which are eager to upgrade completely the storage facilities within 5-7 years provided there is sufficient and timely funding.

The estimated cost of manure storages calculated per one cubic meter of capacity of different storage types [32]:

- uncovered film storage – starting with 800 RUR/$m^3$

- covered film storage - starting with 900 RUR/$m^3$

- uncovered concrete storage - starting with 1100 RUR/$m^3$

The general conclusion from the conducted analysis is that about 66% of the livestock/poultry enterprises in Leningrad Region need to upgrade the manure storage facilities.

### 2.2.2 Sufficient size and composition of machine and tractor fleet

When analysing the agricultural enterprises in Leningrad Region, special attention was paid to the machine and tractor fleet involved in the handling of animal/poultry manure and organic fertiliser produced.

The focus was on the following issues:

- availability of machinery units required for all technological operations of animal/poultry manure handling;
- service life of used machines and equipment;
- sufficient number and a load factor of used machines and equipment for transportation of animal/poultry manure from the animal/poultry houses to the place, where it will be processed into the organic fertiliser;
- sufficient number and a load factor of the used machines and equipment for processing of animal/poultry manure into the organic fertiliser, taking into account the observance of processing technology regimes;
- sufficient number and a load factor of used machines and equipment for transportation of produced organic fertiliser to the application fields, taking into account the agro-technical timescales;
- sufficient number and a load factor of used machines and equipment for field application of the produced organic fertilizer in the relevant agro-technical timescales.

Inadequate availability of machines and equipment for manure and organic fertiliser handling on any processing stage may lead to the risk of animal/poultry manure accumulation before the processing, disruption of the technological process and failure to observe the agro-technical timescales of organic fertiliser application.

Analysis of agricultural enterprises in Leningrad Region showed that large pig rearing complexes and poultry factories are forced to transport the produced organic fertiliser over a distance above 50 km that results in the significant workload of the machine and tractor fleet in the relevant agro-technical timescales and can lead to the risk of non-observance of these timescales.

For example, if the farm produces 36,400 tons of liquid organic fertilizer per year, the transportation distance is 50 km and the agro-technical application period is 120 days, the estimated costs, including the cost of fuel, depreciation, maintenance, and repair, will amount to 15.4 million roubles per year. Calculations show that for the environmentally sound transportation and application of produced organic fertiliser, the farm needs to have at least 7 application machines with the capacity of 11 tons each and 7 tractors of drawbar category 1.4, which could be coupled with these machines.

The elaboration of a plan for technological modernisation of an agricultural enterprise will help to eliminate the sources of environmental risks. It will ensure the adequacy of manure storage facilities taking into account the applied technological solutions and specify the composition and quantity of the machine and tractor fleet required for the environmentally safe and cost-effective handling of animal/poultry manure and organic fertiliser produced. This plan will describe each technological solution in terms of transition to BAT system and the selection procedure of these technological solutions.

Introduction of the monitoring and coordination system in organic fertiliser application will reduce the environmental risks of intensive livestock and poultry farming, lessen the environmental loading in the districts with high environmental risks and improve the soil fertility in the areas with nutrient deficiency on agricultural land. One of the elements of this monitoring system is the logistic apparatus for distributing the organic fertiliser produced on livestock/poultry complexes over the agricultural land, with due account for the crop requirements and the transportation distance.

To introduce a justified technological solution of the animal/poultry manure and organic fertilizer management, the Technological Regulations are developed for a particular farm. This document describes the entire technological chain of animal/poultry manure handling from the excrement formation to the application of ready organic fertiliser to agricultural land.

## 3. Elaboration of the proposals for improving the situation and enhancing the environmental safety of the region through technological and managerial decisions

Preliminary consideration of the relevant data of Leningrad Region showed that major environmental risks could arise during the organic waste utilisation. This may be explained by the inefficient use of nutrients (nitrogen and phosphorus) in the intensive machine-based technologies and the lack of established interaction between the livestock and crop production sectors. The main task in developing proposals how to remedy the environmental situation and to improve the ecological compliance of the region through the adequate technological and managerial decisions is to assess the agricultural enterprise as a whole and to identify the critically ineffective technological elements in place.

This task is fulfilled in the following steps:

- the cost-effective transportation distance of organic fertilisers for each supplying enterprise is determined both within its own district and to the surrounding districts;

- new technologies and technical solutions for animal/poultry manure processing and use allowing to enhance the nutrient saving are formed and scientifically grounded;

- logistics between the enterprises – producers of organic fertilisers, the livestock farms with the lower animal density and the crop-growing farms, are scientifically grounded and organised for the environmentally friendly use of fertilisers with due account for environmental and economic efficiency;

- the centralized complexes for the multi-stage processing of animal/poultry manure are created with the aim to concentrate the nutrients in smaller amounts of fertilisers for their subsequent rational application in more remote areas;

- continuous monitoring of machine-based technologies, which reduce the negative impact on the environment, is organized;

- a databank of technological solutions, machines, and equipment for animal/poultry manure handling is created to optimize their operation and to contribute to BAT system transition;

- the optimal combinations of machine-based technologies with the preliminary ranking of environmental, energy and economic indicators are identified;

- the scientifically grounded proposals for a real-time monitoring system of the environmental situation at agricultural enterprises are developed.

The main task of this monitoring system will be the collection and processing of incoming information on the amount of produced animal/poultry manure, the technologies for its processing, storage and further use of the resulting organic fertiliser with due account for the available agricultural land. The monitoring system will make it possible to control the entire process of manure handling in accordance with restrictive environmental standards.

### 3.1 Development of the action plan to improve the sustainability and environmental friendliness of rural areas

An agricultural enterprise as a source of adverse environmental effect is a very complex system with many interdependent indicators. The analysis of the on-farm production processes showed that the main pollution is associated with manure handling systems – removal from livestock houses, processing, storing, and field application [7, 8].

Nutrients (nitrogen and phosphorus) are the main indicators of the environmental impact.

Currently, the main way to improve the environmental compliance of industrial production and intensive farming is the transition to the best available techniques (BAT) system. This system aims to regulate the adverse environmental effect by introducing the state-of-the-art technologies and related monitoring systems and to make optimization decisions based on the monitoring results.

The step-by-step introduction of BAT for utilization of organic waste in agricultural production may be shown as a sequence of the following actions (Fig. 12).

As a part of the environmental legislation reforming in the Russian Federation, an algorithm for the phased transition to BAT is being currently developed. The stages of this algorithm are reflected in the relevant by-laws and orders.

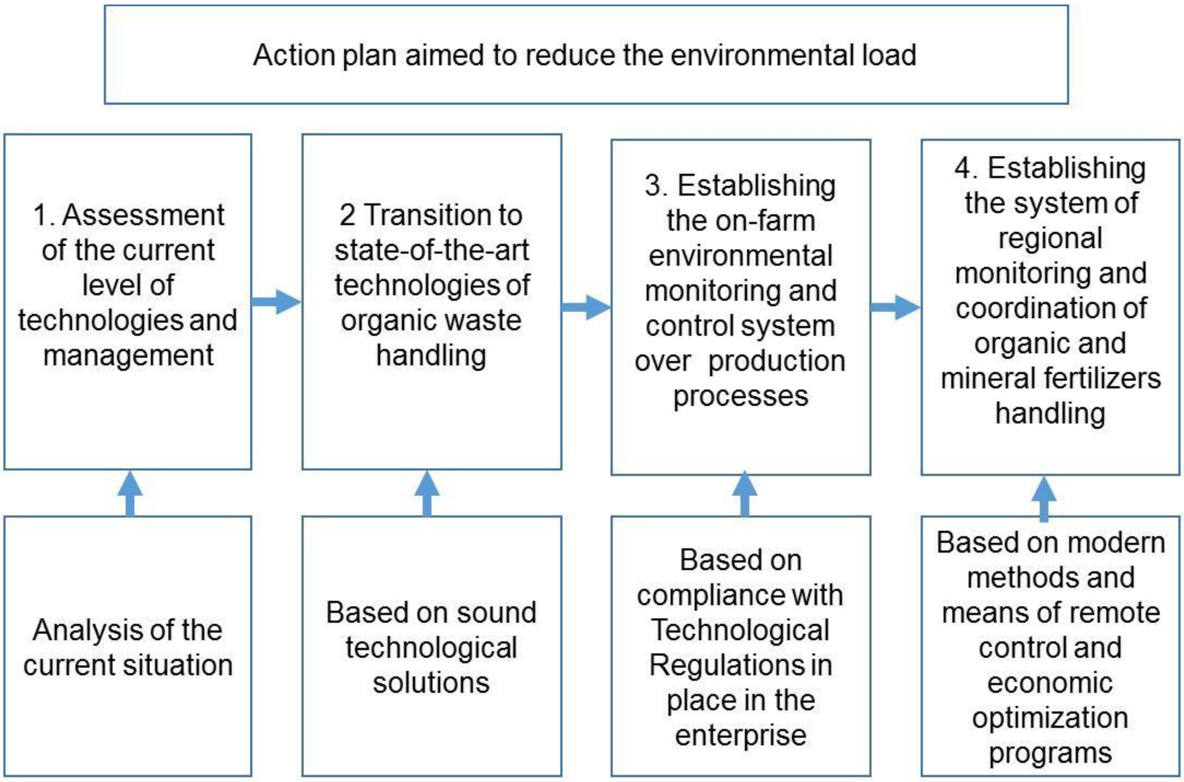


Fig. 12. The action plan aimed to reduce the environmental load

The first step "Assessment of the current level of technologies and management" evaluates the real technical condition of agricultural facilities and the quality of records associated with the organic waste handling operations. Based on the analysis and evaluation results, a technological modernization plan should be prepared with a reasonable list of recommended BAT and methods to monitor the functioning of technologies.

The second step "Transition to state-of-the-art technologies of organic waste handling" is the implementation of the technological modernization plan based on the list of recommended BATs.

Taking into account the high cost and duration of this work, the procedure of implementation should be prescribed providing for the priority in terms of the status and specialization of agricultural enterprises. The enterprises, which create the greatest risk of the diffuse pollution of water bodies, should be modernized in the first place.

The third step "Establishing the on-farm environmental monitoring and control system over the production processes" provides for the introduction of internal environmental control tools at agricultural enterprises, namely, Technological Regulations (Standard of Organisation).

The fourth step in the sequence of scenarios for BAT introduction is "Establishing the system of regional monitoring and coordination of organic and mineral fertilizers handling". This step is the most important for the subsequent assessment of the diffuse load from agriculture. This system allows for the on-line work with the updated information that improves the accuracy of the environmental load assessment, including the BAT effect.

### 3.2 The actions needed for managerial decision-making aimed to regulate the environmental load on rural areas

In order to ensure the environmental load reduction associated with agricultural production, the following tasks need be completed:

• to conduct a comprehensive analysis of the current situation on the functioning agricultural enterprises;

• to develop the technological modernization plan and to scientifically ground the list of recommended BAT;

• to introduce the operating procedure of livestock farms and poultry factories in compliance with the on-farm Technological Regulations for Animal/Poultry Manure Processing and Fertilising Use (Standard of Organisation);

• to introduce the system of remote monitoring and control over the animal/poultry manure handling (regular collection of information on manure production and organic fertiliser use; verification of the information received using the expert systems; managerial decision-making).

#### 3.2.1 A comprehensive analysis of the current situation on the functioning agricultural enterprises

According to Annex III "Criteria and Measures Concerning the Prevention of Pollution from Land-Based Sources" of the 1992 Helsinki Convention, Part II "Prevention of Pollution from Agriculture" the major measures, which may be used to analyse and assess the prevention of pollution from agricultural activities, are as follows:

1. Animal density

To ensure that the amount of animal/poultry manure does not exceed the comparable amount of arable land, a balance must be calculated between the number of animals on the farm and the land area, where the organic fertilizer is applied, expressed as animal density. The maximum number of animals should be determined considering the balance between the amount of NPK, primarily phosphorus and nitrogen, in animal/poultry manure and the requirements for mineral nutrition of crops. The Baltic Sea countries have adopted 1.5 LSU per one hectare of agricultural cultivated land as the averaged value of animal density. Regions with higher animal density are considered potentially hazardous in terms of the nutrient load on the water bodies.

2. Location of farm animal houses and livestock complexes

Farm animal houses and livestock complexes should be located and designed in such a way that the ground and surface water will not be polluted. The sanitation and hygiene regulations should be observed.

3. Construction of manure storages

Animal/poultry manure storages must be of such a quality that prevents/minimizes losses. Manure storages should be sufficiently large to store the entire amount of manure produced prior to being applied only when the plants actually require the nutrients. The storage volume must ensure the reception and storage of animal/poultry manure for at least 6 months and in accordance with the processing technology modes.

Following the environmental safety standards the processing and storage of animal/poultry manure in the Russian Federation are interrelated operations of a single process. As far as the liquid manure/organic fertilizer is concerned, the processing and storage is combined, the duration of 6 months is determined by the period of processing and accumulation before the soil application in the agro-technical timescales. As far as the solid organic fertilizer is concerned, the animal/poultry manure is processed on a watertight pad; the resulting solid organic fertilizer may be accumulated before the soil application in the agro-technical timescales on specially prepared field-edge sites close to the agricultural land.

Manure storage should be constructed to safeguard against unintentional spillages and be of such a quality that prevents nutrients loss. For all types of animal/poultry manure, the watertight storages/processing sites are required.

With regard to different types of manure, the following principles should be considered:

- solid manure should be stored in the storages with watertight floor and side walls
- liquid manure and farm waste should be stored in containers that are made of strong material impermeable to moisture and resistant to impacts of manure handling operations

The technologies applied should ensure the maximum efficiency of manure nutrients use by plants. The inter-farm cooperation in the processing and distribution of organic fertilizers has to be encouraged.

4. Agricultural wastewater and silage effluents

Wastewater from animal housing should be either stored in special tanks, liquid manure storages, or else be treated in some suitable manner to prevent environment pollution

5. Application of organic fertilisers

Organic fertilizers should be used in a highly effective manner. Organic fertilizers should be applied in such a way that minimizes the risk of nutrient loss. They should not be applied on frozen, water saturated or covered with snow soils. Organic fertilizers are recommended to be incorporated immediately after their soil application. The periods should be defined, when organic fertilizers should not be applied to the soil.

6. Application rates for nutrients

The rate of nutrients applied in the soil must be limited, based on the balance between the estimated crop nutrient requirements and the nutrient supply to the crops from the soil and fertilizers with due account for the need to meet the condition to reduce eutrophication.

National guidelines should be developed with fertilising recommendations, and they should take into account:

• soil properties, nutrient content, soil type and slope;
• climatic conditions and irrigation;
• land use patterns and agricultural practices, including crop rotation systems;
• all external potential nutrient sources.

The maximum amount of organic fertilizers applied to the land every year, including the farm animals excrement entering the soil during the grazing, is calculated in terms of nitrogen and phosphorus content and should not contain more than

• 170 kg/ha nitrogen
• 25 kg/ha phosphorus

with a view to avoiding the nutrient surplus, taking into account the soil characteristics, agricultural practices and crop types.

7. Winter crop cover

In relevant regions, the cultivated area should be sufficiently covered by crops in winter and autumn to effectively reduce the loss of plant nutrients.

8. Water protection measures

Special protection measures should be established to prevent nutrient losses to water bodies particularly as regards

- Surface water: buffer zones, riparian zones or sedimentation ponds should be established, if necessary.
- Groundwater: Groundwater protection zones should be established if necessary. Appropriate measures such as reduced fertilisation rates, zones where organic fertilizer application is prohibited and permanent grassland areas should be established.

The upgrading process on agricultural enterprises is already underway, although not at a very fast pace. New technological elements for manure processing and new storage facilities are commissioned annually. When designing the storage facilities, such a climatic aspect as the amount of precipitation, which affects the increase in the volume of processed animal/poultry manure, is taken into account. The measures to minimize ammonia and methane losses in the most effective way are also considered [33]: tight cover provides emission reduction by above 80%; plastic cover – by above 60%; floating cover – by above 40%; formation of a natural crust through minimum stirring and loading the slurry below the surface level – by 40%; manure bags – by 100%; replacing lagoons with covered tanks or high uncovered tanks with the depth above 3 m – by 30-60%.

9. Nutrient reduction areas

Wetland areas should be retained and where possible restored, to be able to reduce plant nutrient losses and to retain biological diversity.

10. Ammonia emissions on livestock farms

In order to reduce ammonia emissions in livestock farms, a surplus of nitrogen in the animal/poultry manure should be avoided by adjusting the composition of the diet to the requirements of individual animals/birds. In poultry farming, the ammonia emissions should be brought down by reducing the moisture content in the poultry manure or by removing the poultry manure from the poultry house to the storage outside as soon as possible. The programmes including strategies and measures for reducing ammonia volatilisation from the farms should be developed. Liquid and solid manure storage facilities should be covered or maintained in such a way as to efficiently eliminate ammonia emissions.

11. Plant protection products

Plant protection products shall only be handled and used according to a national risk reduction strategy, which shall be based on Best Environmental Practice (BEP). The strategy should be based on an inventory of the existing problems and define the suitable goals. It shall include the measures such as

- Plant protection products shall not be sold, imported or applied until registration and approval for such purposes has been granted by the national authorities

- Storage and handling of plant protection products shall be carried out so that their loss is prevented. Some crucial elements of a plant protection technology are transportation and filling and cleaning of equipment. Other dispersal of plant protection products outside the treated agricultural land area shall be prevented. Waste of plant protection products shall be disposed of according to national legislation .
- A license shall be required for commercial use of plant protection products. To obtain a license, suitable education and training on how to handle plant protection products with a minimum of impact on health and the environment shall be required. The users' knowledge regarding the handling and usage of plant protection products shall be updated regularly
- Application technology and practice should be designed to prevent unintentional drift or runoff of plant protection products. Establishment of protection zones along surface waters should be encouraged. Application by aircraft shall be forbidden; exceptional cases require authorization.
- Testing of spraying equipment at regular intervals shall be promoted to ensure a reliable result when spraying with plant protection products
- Development of alternative methods for plant protection control should be encouraged.

12. Environmental permits

Livestock farms above a specified size should require approval with regard to environmental aspects and impacts of the farms. Farms for the intensive rearing of poultry, pigs and cattle with more than 40,000 places for poultry, 2,000 places for fattening pigs (over 30 kg), 750 places for sows or 400 cattle units should obtain a permit fully coordinated by the relevant authorities. The permits must take into account the entire environmental performance of the enterprise, covering e.g. emissions to air, water, and land, generation of waste and prevention of environmental accidents. The permit conditions must be based on best available techniques (BAT). The competent authorities, in determining the permit conditions, should take into account the technical characteristics of the enterprise, its geographical location and the local environmental conditions.

13. Monitoring and evaluation

The national programmes of the Baltic Sea countries shall describe the implementation and monitoring of measures specified in HELCOM Recommendations. The countries shall develop projects to assess the effects of measures, specified in Recommendations, and the impacts of the agricultural sector on the environment

14. Education, information and extension service

The Baltic Sea countries shall promote the systems for education, information and extension (advisory service) on environmental issues in the agricultural sector.

#### 3.2.2 Development of the technological modernization plan and scientific substantiation of the list of recommended BAT

This activity involves laying the ground for the regional programme aimed to improve the application efficiency of organic and mineral fertilisers in order to preserve soil fertility and protect the environment. The list of technical and technological solutions, which provide the best performance indicators in the considered climatic and production conditions, should be scientifically substantiated. The sequence of a particular technology introduction should be determined, starting with the most environmentally sensitive objects and processes. The economic incentive measures associated with BAT transition should be provided.

##### 3.2.2.1 Estimation criteria for formation of the effective machine-based technologies for the animal/poultry manure utilisation (BAT)

In accordance with the Methodological recommendations approved by the Ministry of Industry and Trade of the Russian Federation, the economic efficiency of applying the environmental measures and technologies is the main criterion to identify a technology as the best available technology [9]:

$$E_{BAT} = \frac{Z_{oper}^{n+1}}{L^n - L^{n+1}} \;, \tag{1}$$

where $E_{BAT}$ – economic efficiency of BAT introduction, thousand roubles per ton per year;

$Z_{oper}^{n+1}$ – operating costs of the technology compared with the basic technology, thousand roubles per year;

$L^n$ – pollutant emissions under the basic technology, t /year;

$L^{n+1}$ – pollutant emissions under the technology compared with the basic technology, t /year.

The use of this criterion alone does not allow to analyse the technologies in detail, since it does not reflect the capital costs, as well as the environmental and economic effect of obtaining the additional output (organic fertilizers, electric and thermal energy, etc.).

For integrated assessment of technologies for animal/poultry manure utilisation the following criteria are suggested:

1) Generalised criterion $Z_K$, which shows specific capital and operational costs associated with nitrogen saving since exactly the nitrogen loss is the main indicator of the adverse environmental impact of animal/poultry manure utilisation technologies. It is calculated by the formula

$$Z_K = \frac{SCC + SOC}{K_{Nsaved}} \tag{2}$$

Where

$Z_K$ – utilisation costs of one ton of animal/poultry manure with account for nitrogen saved;

SCC, SOC – specific capital and operational costs per one ton of produced and spread organic fertilisers, roubles/t;

$K_{Nsaved}$ – nitrogen saving factor in animal/poultry manure processing technologies calculated as

$$K_{Nsaved} = \frac{Q^1{}_N}{Q_N} \tag{3}$$

Where

$Q^1{}_N$ –the amount of nitrogen applied with organic fertilisers, t;

$Q_N$ – the amount of nitrogen in the raw animal/poultry manure or initial mix prior to processing, t.

2) The criterion of eco-economic effect (benefits) $E_{eco\text{-}econ}$ from the introduction of animal/poultry manure utilisation technologies and the use of organic fertilisers. It is applied to assess the relevant technologies and to choose their rational options. It reflects the economic benefits from the lower negative impact on the environment and the additional income from the produced organic fertilisers and energy resources:

$$E_{eco-econ} = E_{yield} + E_{energy} + E_{envir} \tag{4}$$

Where $E_{yield}$ – sales income from the crop yield gain due to organic fertiliser application, roubles;

$E_{energy}$– sales income or economic benefit from the use of additional energy resources (ex. biogas), roubles;

$E_{envir}$ – environmental effect from the lower adverse impact on the environment, roubles.

The environmental effect due to the lower adverse impact on the environment is calculated as:

$$E_{envir} = I_{soil} + I_{water} + I_{air} \tag{5}$$

Where

$I_{soil}$ – reduction of the adverse impact on soils, roubles;

$I_{water}$ – reduction of the adverse impact on water bodies, roubles;

$I_{air}$ – reduction of the adverse impact on atmospheric air, roubles;

To determine the overall eco-economic benefits from the improved land productivity, the relationships between these benefits, the nitrogen saving factor and the crop yield gain were established for the organic fertilisers produced from cattle, pig and poultry manure, as shown in Fig. 13-15. The relationships were established on the basis of the obtained nitrogen saving data and the reference data on the crop yield gains under the application of various types of organic fertilisers. The sales income from the additional crop yield (potatoes in our case) was calculated with the wholesale price of 7500 roubles per ton.

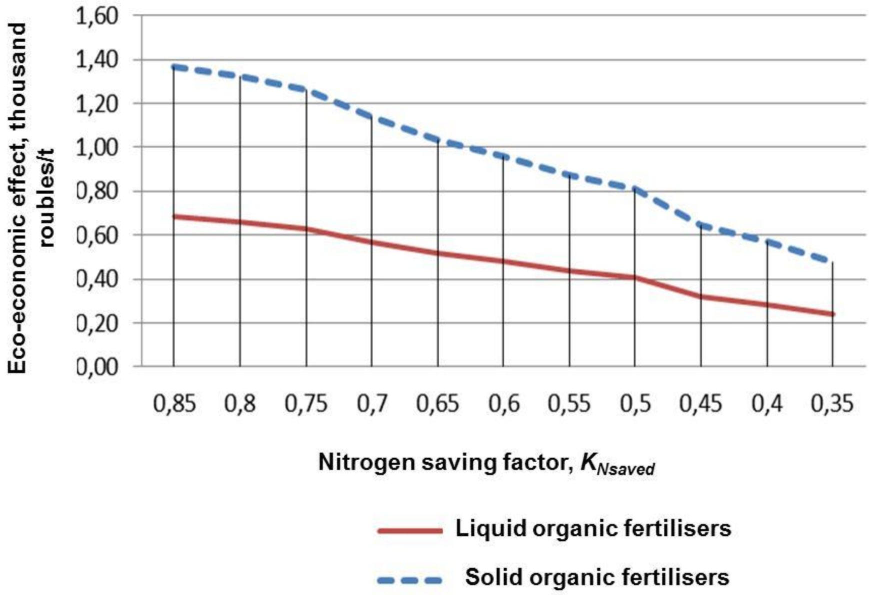


Fig. 13 Relationship between the eco-economic benefits and nitrogen saving factor for organic fertilisers produced from cattle manure

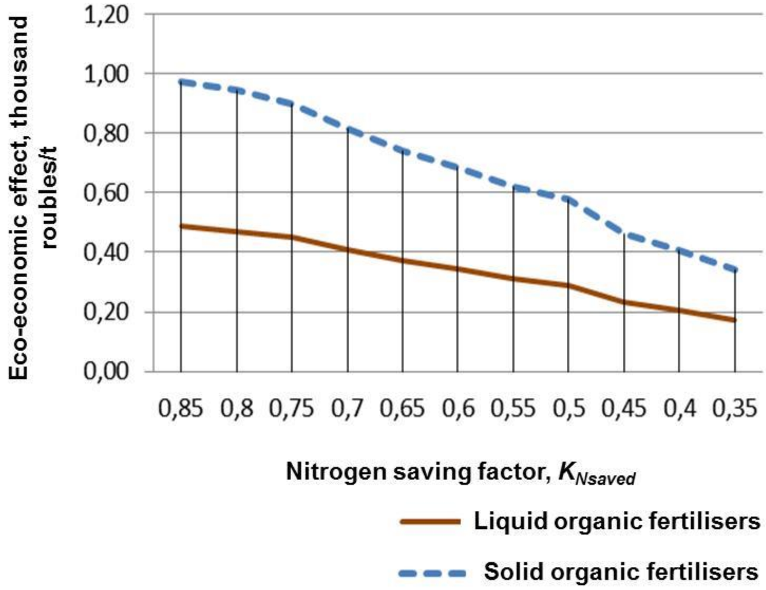


Fig. 14 Relationship between the eco-economic benefits and nitrogen saving factor for organic fertilisers produced from pig manure

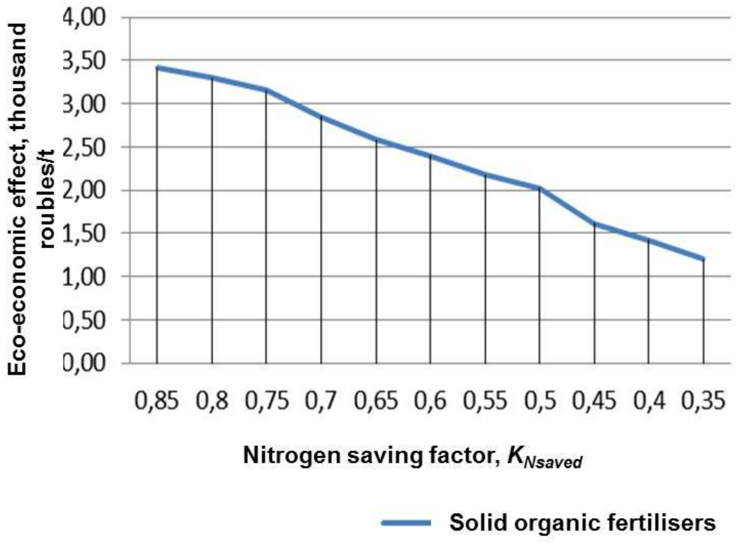


Fig. 15 Relationship between the eco-economic benefits and nitrogen saving factor for organic fertilisers produced from poultry manure

As follows from Fig. 13-15, the higher is the nitrogen saving factor, the higher are the eco-economic effect (benefits) [10-14].

The technologies are formed and the options are chosen by the above criteria in two stages:

1. The relevant recommended technologies are identified; their technical and technological characteristics and environmental and economic indicators are assessed; one technology is accepted to be adjusted to the particular enterprise conditions.

2. The possible options for combining the buildings, machines and equipment to implement the chosen technology are identified; the above criteria are calculated; the most effective solution is identified.

**3.2.2.2. Formation of the manure processing technology and selection of the most rational option: case study of a cattle farm**

The cattle manure processing technology was considered for a project pilot farm – Breeding Farm AO PZ Pervomajskij (Priozerskij District, Leningrad Region).

This cattle farm is typical for the Northwestern Federal District. It has a loose housing system with the total animal stock of 1,960 head, of which 1,000 are the cows with the milk yield of over 8,300 tons per year per cow. The average manure moisture content is 92%; the average transportation distance of organic fertilisers produced is 10 km.

The four most promising technologies for processing the cattle manure were identified by the survey results of the status of livestock farming in Leningrad Region and considered at the first stage:

1. Long-term storing (maturing) and application of the liquid organic fertiliser.
2. Manure separation into fractions with further composting of the solid fraction, long-term storing (maturing) of the liquid fraction and application of the liquid and solid organic fertilisers.
3. Manure separation into fractions with further biofermentation of the solid fraction, long-term storing (maturing) of the liquid fraction and application of the liquid and solid organic fertilisers.
4. Anaerobic manure processing with electrical and heat energy generation (biogas production) and application of the liquid and/or solid organic fertilisers.

When calculating the eco-economic effect (benefits) of the anaerobic digestion technology, the additional sales income of three MW of electricity at a price of five roubles/kW was taken into account.

The main technical, economic and environmental indicators of the listed technologies were determined. The graphic presentation of their comparative characteristics is found in Fig. 16 - 20.

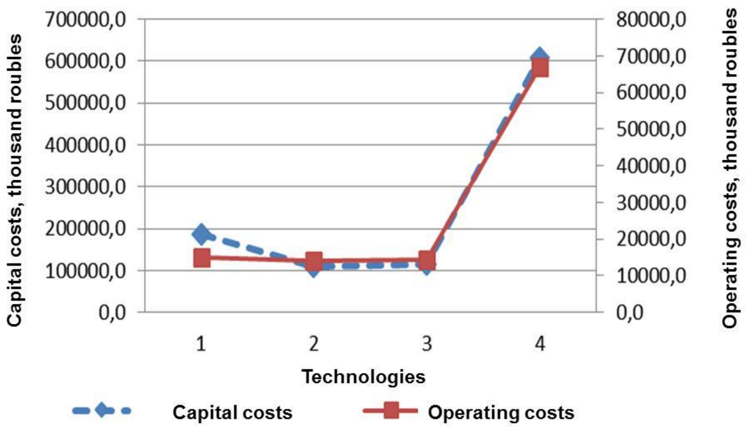


Fig. 16. Capital and operating costs for the considered technologies

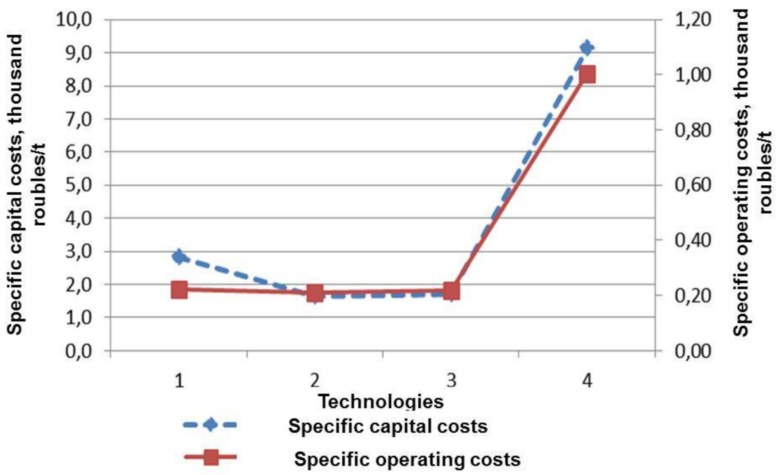

Fig. 17. Specific capital and operating costs for the considered technologies

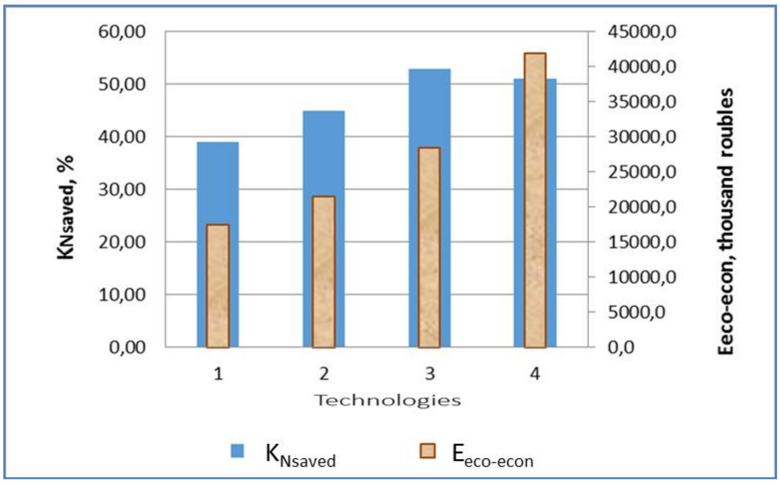


Fig. 18. Nitrogen saving factor and eco-economic effect (benefits) of considered technologies

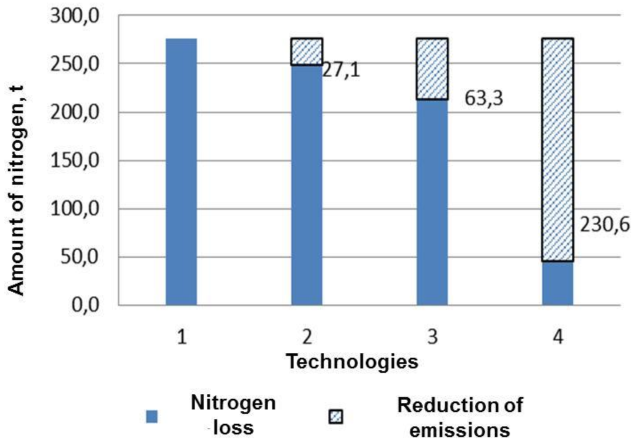


Fig. 19. Nitrogen loss and emissions reduction for the considered technologies

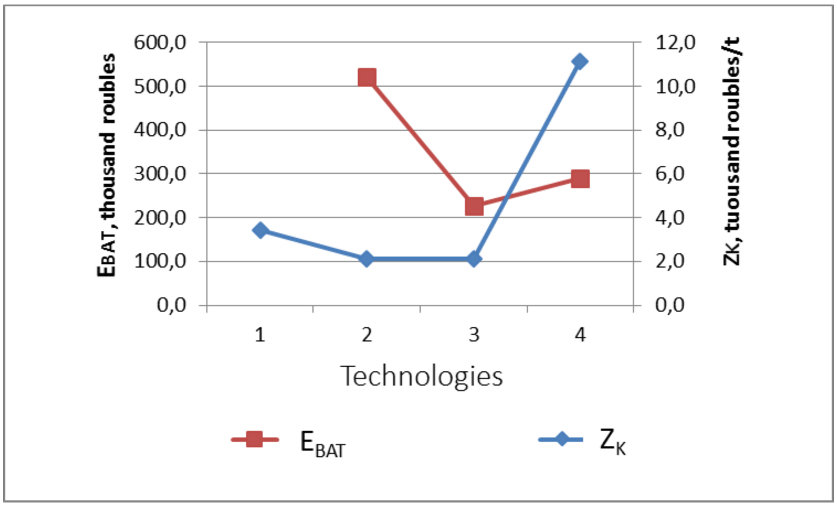

Fig. 20. Eco-economic efficiency and specific costs of manure utilisation with due account for nitrogen saving factor for the considered technologies

According to the obtained data analysis, the best indicators of specific capital and operating costs of manure processing under the considered farm conditions were demonstrated by:

- Technology 2 – manure separation into fractions with further composting of the solid fraction, long-term storing (maturing) of the liquid fraction and application of the liquid and solid organic fertilisers: specific capital costs of 1.6 thousand roubles/t and specific operating costs of 0.21 thousand roubles/t;

- Technology 3 – manure separation into fractions with further bio-fermentation of the solid fraction, long-term storing (maturing) of the liquid fraction and application of the liquid and solid organic fertilizers: specific capital costs of 1.7 thousand roubles/t and specific operating costs of 0.21 thousand roubles/t.

Moreover, these technologies had the equal values of the generalised criterion $Z_K$ = 2.1 thousand roubles (utilisation costs of one ton of animal/poultry manure with account for nitrogen saved).

Technology 4 – Anaerobic manure processing with electrical and heat energy generation (biogas production) and application of the liquid and/or solid organic fertilisers, had the best eco-economic effect (benefits) (Eco-econ) and economic efficiency of BAT introduction ($E_{BAT}$). This is because the anaerobic digestion has a minimal loss of nitrogen, which is partially transferred to biogas. At the same time, the sale of additional electricity generated brings in up to 15 million roubles/year. However, it is worth noting that the capital costs to introduce the anaerobic digestion technology are almost 5 times higher compared to those of Technologies 2 and 3 that makes the implementation of Technology 4 challenging. Of particular note is the small experience in the functioning of such technologies under the natural and climatic conditions of the Northwestern Federal District of the Russian Federation.

Based on the above considerations, Technology 3 – manure separation into fractions, followed the bio-fermentation of the solid fraction, the long-term storing (maturing) of the liquid fraction, and the subsequent application of produced solid and liquid organic fertilisers – was selected for further adjustment and introduction on the pilot farm.

According to this technology, the cows are housed in boxes on rubber mats and the bedding is used only for slight drying of the lying area. The resulting manure has the moisture content of 87-88% or about 92% together with the wastewater from the milking parlour. Such manure should be stored for at least 6 months for disinfection. Therefore, the following technological manure removal line is proposed to be installed in the animal houses in the framework of LIP 1601-KS 1441 Project. The manure is removed from manure feeding passages in the cow barns by scrapers. In each barn, the manure is pushed into the lateral canal under the slatted floor, from where it is transported to the buffer tank by screw conveyors. As manure accumulates in the buffer tank, it is automatically pumped via the pipelines, laid underground below the freezing depth, into the receiving tank of the intermediate pumping facility. The floor washing wastewater from the milking parlour is also pumped there. After the preliminary homogenization with a mechanical mixer, the collected liquid manure (manure-bearing wastewater) from all barns is pumped via the pipelines, laid underground below the freezing depth to manure separation department.

The line for collecting and pumping of liquid manure from the animal houses operates automatically by the pre-set mode.

In case of a short-duration failure of the pumps, the manure will be collected from the intermediate pumping facility directly by tractor-drawn slurry tankers.

The manure is separated into fractions on two screw press filters. The solid fraction in this process accounts for up to 15% of the input manure. The moisture content of the solid fraction is 65-70% so it may be loaded into trailers and transported to the composting pad. After separation, the liquid fraction has a moisture content of 96-98%; it practically does not have any left-over fodder or weed seeds and is much easier to pump through the pipes laid underground below the freezing depth into the accumulation tanks.

A part of the solid fraction is planned to be used to produce the soft and safe bedding material (meeting the veterinary, sanitary and hygienic requirements). For this purpose, a filtration and drying unit will be installed, which provides the accelerated aerobic composting, disinfection and slight drying of solid manure. A part of the manure-containing wastewater from the primary tank of the separation department is fed to this unit by a separate pump. After separation into fractions, the liquid fraction is discharged into the secondary tank of the separation department, and the solid fraction is fed into the drum-type fermenter. The resulting compost has the moisture content of about 55% and will be spread in the animals houses as a bedding material.

According to Technological Regulations for animal/poultry manure processing and fertilising use, developed for the pilot farm, the total annual output of the liquid fraction of manure will be 37,504 $m^3$. Following the requirements of Management Directive for Agro-Industrial Complex RD-APK 1.10.15.02-17, the volume of storages for the liquid fraction of manure is calculated for the storing period of at least 6 months, with due account for the atmospheric precipitation for this period. The total volume of manure storage facilities should be at least 20,000 $m^3$. The LIP 1601-KS 1441 Project provides for the construction of four steel tanks of 6,000 $m^3$ each.

### 3.2.3 Recommendation on organization of the on-farm environmental monitoring and control over the production processes

The basic document when organizing the system of manure handling and the on-farm environmental monitoring and control over the production processes is Technological Regulations of animal/poultry manure processing and fertilising use, tailored for each agricultural enterprise.

Technological Regulations include a list of organizational, technical and technological measures ensuring the safe removal of animal/poultry manure from the animal/poultry houses, processing and cost-effective use in the agricultural enterprise with the minimal negative impact on the environment.

According to the Federal Classificatory Catalogue of Wastes, the fresh animal/poultry manure is attributed to Classes III and IV of hazard depending of the animal and poultry type if it is not processed and applied as a fertiliser.

The Federal Law of 24.06.1998 No 89-FZ (revised edition of 25.12.2018, with amendments of 19.07.2019) “On the Management of Production and Consumption Waste” introduced the concept of waste accumulation as the temporary storage of waste for a period of less than eleven months in places (pads) arranged in accordance with the requirements of environmental legislation and sanitary and epidemiological welfare legislation, with a view to their further utilisation, neutralisation, placement, and transportation.

On 23 May 2016, the Explanatory Statement of the Ministry of Natural Resources and Environment of the Russian Federation to the Federal Law №219-FZ was issued under the title “On registration of a license to collect, transport, process, dispose, neutralize, and place the waste of I - IV hazard class when handling manure”. This document considers the animal and poultry manure, generated in the process of economic activity, not a waste but a raw material. If the agricultural enterprise has in place and observes the relevant Technological Regulations (Standard of Organisation), the manure may be used for the own needs as a ready product, namely organic fertiliser. In this case, the legal requirements associated with the licenses for collecting, transporting, handling, disposing, neutralizing, and placing the waste of Classes I to IV of hazard, do not apply to animal and poultry manure.

The agricultural enterprise uses the animal/poultry manure in the own production processes, namely for production and application of organic fertilisers, according to Technological Regulations approved by the Director, based on the Federal Law “On Technical Regulating”.

Technological Regulations are the Standard of Organisation, a regulatory document developed and approved by the agricultural enterprise itself based on the requirement to apply standards for the purposes specified by the Federal legislation (Federal Law №184-FZ “On Technical Regulating” of 27.12.2002, and Federal Law №162-FZ “On Standartisation in the Russian Federation” of

29.06.2015). These purposes include improving the safety of life and health of citizens, animals and plants, and the level of environmental safety of production [15].

At the stage of waste accumulation, the farm processes (neutralizes) animal/poultry manure in accordance with the requirements of Management Directive for Agro-Industrial Complex RD-APK.1.10.15.02-17 “Recommended Practice for Engineering Designing of Systems for Animal and Poultry Manure Removal and Pre-application Treatment”, approved by the Ministry of Agriculture [16]. The resulting organic fertilisers must comply with the State Standard GOST R 53117-2008 “Organic fertilisers based on farm animal waste. Specifications” in effect from January 1, 2010, and be applied to the fields in order to obtain the targeted crop yields. Organic fertilizers can be transferred to other legal entities with the enclosed document issued by the veterinary service certifying the conformity of their quality and safety to the requirements of the above GOST [17].

The amount of produced and used waste, animal/poultry manure included, is recorded in accordance with the Accounting Procedure approved by the Order of the Ministry of Natural Resources and Ecology of September 1, 2011 No. 721 (revised version of 25.06.2014). Recorded data are summarized once in three months (as of April 1, July 1 and October 1 of the current year), as well as once a year (as of January 1 of the year following the accounting year) no later than the 10th day of the month following the specified period [18].

Technological Regulations describe the conditions and the flow of the technological process of animal/poultry manure processing into an organic fertiliser, which ensure the production of environmentally safe product with the quality indicators complying with the requirements of approved standards (specifications), labour safety and achievement of optimal technical and economic indicators of the particular agricultural enterprise [15].

In the context of transition to BAT system, Technological Regulations can ensure the timely obtaining of an integrated environmental permit.

Technological Regulations include the following main sections:

1) <u>Introduction</u>

The purpose and legal status of Technological Regulations are described.

2) <u>General characteristics of production process</u>

The basic initial data for Technical Regulations development are:

- number of animals houses (production sites) in the agricultural enterprise;
- type and stock of animals/poultry;
- type and amount of bedding used (water absorbing material);
- type animal/poultry hosing, manure removal system.

This information is submitted in the text form, summarized and tabulated.

General characteristics of the production process also include a description of the current system for processing and application of animal/poultry manure (how much is produced, how it is transported, processed, stored and applied). Information is provided on the availability of own land, cultivated crops, the use of mineral and organic fertilizers, availability of machines and equipment, and the agrochemical characteristics of soils.

3) Specifications of the raw material and ready products

The main raw material for the organic fertilizers production is animal/poultry manure. According to the State Standard GOST R 53042-2008 “Organic fertilizers. Terms and definitions”, the manure is a mixture of solid and liquid excrement of farm animals, with or without bedding, and with the water entering the manure removal system during the sanitary cleaning of premises and drinking water loss. Poultry/rabbit manure is the excrement of farm birds and rabbits with or without bedding.

When developing Technological Regulations, it is important to know the actual characteristics of the resulting animal/poultry manure (quantity and chemical composition), which are determined by sampling on each unloading place of animal/poultry manure, on accumulation (storage) places of manure and produced organic fertilizers.

The practice of developing Technological Regulations and the audits of livestock enterprises show that often the results of raw manure sample analyses demonstrate the significant deviations from the norms of technological designing. For example, increased moisture content of manure indicates an excessive water input, which leads to a significant variation in the total volume of manure produced. When the moisture content of manure increases from 88% to 94%, its volume increases twofold.

Depending on the animal/poultry manure processing technology adopted at the enterprise, dry, solid, semi-liquid or liquid organic fertilizers can be produced. The technological process of processing and general use of manure should comply with the Management Directive for Agro-Industrial Complex RD-APK.1.10.15.02-17 “Recommended Practice for Engineering Designing of Systems for Animal and Poultry Manure Removal and Pre-application Treatment”.

The resulting organic fertilizers must comply with the State Standard GOST R 53117-2008 “Organic fertilisers based on farm animal waste. Specifications”.

4) Description of the technological process of animal/poultry manure removal

The characteristics of the raw animal/poultry manure, the moisture content in particular, largely depend on the technology used to remove it from the animal house. This section describes the system for the animal/poultry removal and transportation to the processing place (type and number of machines and equipment), the operating modes and conditions in order to obtain the raw material with the constant quality and composition.

Manure removal system includes the intermediate pads or tanks, which have to be equipped in accordance with the Management Directive for Agro-Industrial Complex RD-APK.1.10.15.02-17.

Tanks for accumulation of liquid manure (slurry) have to comply with the requirements of State Standard GOST26074-84 “Liquid manure. Veterinary and sanitary requirements for treatment, storage, transportation and utilization” [19].

Manure should be removed and transported outside the livestock houses by mechanical (scraper, rod and screw conveyors, scraper units of reciprocating action, as well as various types of bulldozers) and hydraulic (gravity systems of continuous and periodic action) methods.

It is important that Technological Regulations show the frequency and unloading time of manure from the animal houses in order to facilitate the production control and coordinate the manure removal with the subsequent operation in the manure processing chain into an organic fertilizer.

5) <u>Description of the technological process of animal/poultry manure processing</u>

The main purpose of this section is to describe the technological process of animal/poultry manure processing into an organic fertilizer, as well as to specify the conditions for performing the technological operations.

6) <u>The norms of technological process</u>

This section contains all the necessary technological calculations to determine the quantitative characteristics of the raw material and the finished organic fertilizers. When calculating the total manure output, the water loss associated with the technological needs (drinking water leaks, washing of equipment, etc.).

7) <u>Field application of organic fertilisers</u>

This section of Technological Regulations specifies the rates and time limits for organic fertiliser application with the reference to the nutrients content, climatic and soil conditions, crop rotations in place on the farm, cropping pattern and the required level of crop productivity.

When calculating the application rates of organic fertilisers, the restrictions on their nutrient content specified in the international HELCOM recommendations were taken into account, namely the total amount of nitrogen applied should not exceed 170 kg / ha per year. Composts are spread mainly during the pre-sowing tillage and autumn ploughing. The liquid fraction of manure is recommended to be applied from April to the end of September. The time limits and methods of irrigation with liquid organic fertilisers are set in accordance with “Technological designing standards of irrigation systems which use the livestock waste water” 1.30.02-01-06 and “Veterinary and sanitary rules for the use of livestock waste for irrigation and fertilizing pastures” [20].

When calculating the application rates, it is important to consider the nutrient removal with the crop yield. The nutrient content in the finished organic fertilisers is determined as a part of the on-farm environmental monitoring and control over the production processes by the agrochemical analysis of the average (middle) sample [16].

It is important to note that only those organic fertilisers are subject to application, the characteristics of which correspond to State Standard GOST R 53117-2008.

An important point for observing the Technological Regulations, timely transportation and field application of organic fertilisers, in particular, is the availability of required machines and equipment. Therefore, this section develops a technological map of manure processing and organic fertilizers application [15].

8) On-farm environmental monitoring and control over the production process

The approval of Technological Regulations provides for the introduction of the on-farm environmental control of the production processes; therefore, this section presents a plan for organizing and conducting the monitoring for compliance with Technological Regulations associated with the use of manure as an organic fertiliser. The personnel responsible for observance of Technological Regulations keep the relevant records.

9) Ensuring occupational safety in organic fertiliser production

This section specifies the general occupational safety requirements in the production and application of organic fertilisers.

1. Organic fertilizers complying with the State Standard GOST R 53117-2008 are not toxic products. The State Standard GOST 12.1.007-76 “Occupational safety standards system. Noxious substances. Classification and general safety requirements” attributes them to Class IV of hazard in terms of their adverse health effect [21].

2. Storing pads for manure and compost should be provided on the sides with the boards and gutters for the run-off control. To collect and drain the run-offs and atmospheric precipitation special collectors should be provided. The watertight pads for solid manure processing are constructed with a slope of 0.002-0.003 (0.2-0.3%) towards the collectors.

3. The personnel engaged in the technological process of organic fertilizers production must follow the requirements of relevant state standards: State Standard GOST 12.2.002-91 “Occupational safety standards system. Agricultural machinery. Methods of safety evaluation” [22] and State Standard GOST 12.3.020-80 “Occupational safety standards system. Transporting process of loads in all fields of national economy. General safety requirements” [23].

4. In case of skin contact with the organic fertiliser, the contaminated skin should be washed with large amounts of soap and water; if necessary, a doctor is to be consulted.

5. In order to avoid emergencies and accidents when working on machine and transport units, the safety precautions and job descriptions must be observed

10) Environmental requirements

This section lists the necessary measures and requirements to ensure the environmental compliance of applied technologies:

1. General rules for environmental protection when using composts and organic fertilisers must comply with the requirements the State Standard GOST 26074-84 “Liquid manure. Veterinary and sanitary requirements for treatment, storage, transportation and utilization” and a number of Sanitary Regulations and Standards: 2.1.7.1287-2003, 1.2.1330-2003, 2.1.6.1032-2001, and 1.2.2584-10 [24-27].

2. Semi-liquid and liquid manure should be stored in reliably watertight facilities to avoid the infiltration of substances polluting the groundwater, soil, and plant products.

3. Solid manure and compost are allowed to be stored on special pads equipped on the sides with boards and gutters for the run-off control. The excess water and effluents are covered with sorbent materials (sawdust), which, after full saturation, are returned to the fertilizer production pad.

4. Application of fertilizers should not lead to excess accumulation in the soil of different elements and their compounds [28, 29].

Technological Regulations of animal/poultry manure processing and fertilising use are developed individually for each farm with the reference to the volumes and characteristics of the raw material, the availability and structure of agricultural land, the current crop rotation, and the availability and type of agricultural machinery.

When the developed Technological Regulation are introduced on the agricultural enterprise, the Director issues an order appointing the persons responsible for their observance and for organization of the constant monitoring of environmental compliance. Since the Director of the enterprise personally approves Technology Regulations, he is responsible to the state environmental supervision bodies for their implementation. With the strictly regulated process of animal/poultry manure utilisation in place, it is easier for the Director of the agricultural enterprise, as well as those responsible for the implementation of Technological Regulations, to control the process. As practice shows, introduction of Technological Regulations leads to 30%-plus reduction in nitrogen and phosphorus loss owing to the proper performance management.

The introduction of Technological Regulations allows the enterprise to switch to waste-free farming technology, as the output is not waste, but high-quality organic fertiliser.

The agricultural enterprise as a natural resource user is exempted from paying for the negative impact on the environment; it improves its environmental compliance and receives the additional profit in the form of the crop yield gain owing to improved soil fertility under the on-farm application of organic fertilisers and smaller purchases of mineral fertilizers.

**3.2.4 Recommendations on the introduction of the regional system for monitoring and coordination of organic and mineral fertilisers production and application**

The key objective of Recommendations is to propose a decision-making procedure for the executive authorities, who are responsible for agriculture development, when placing new livestock complexes and upgrading the existing ones in terms of their environmental impact from animal/poultry manure processing technologies and logistics of its use. The proposed methodological approach will allow to coordinate the activity aimed to improve the environmental compliance of agricultural production at the Federal subject level.

The block scheme of decision-making on environmentally sound location and operation of animal/poultry farms is shown on Fig. 21.

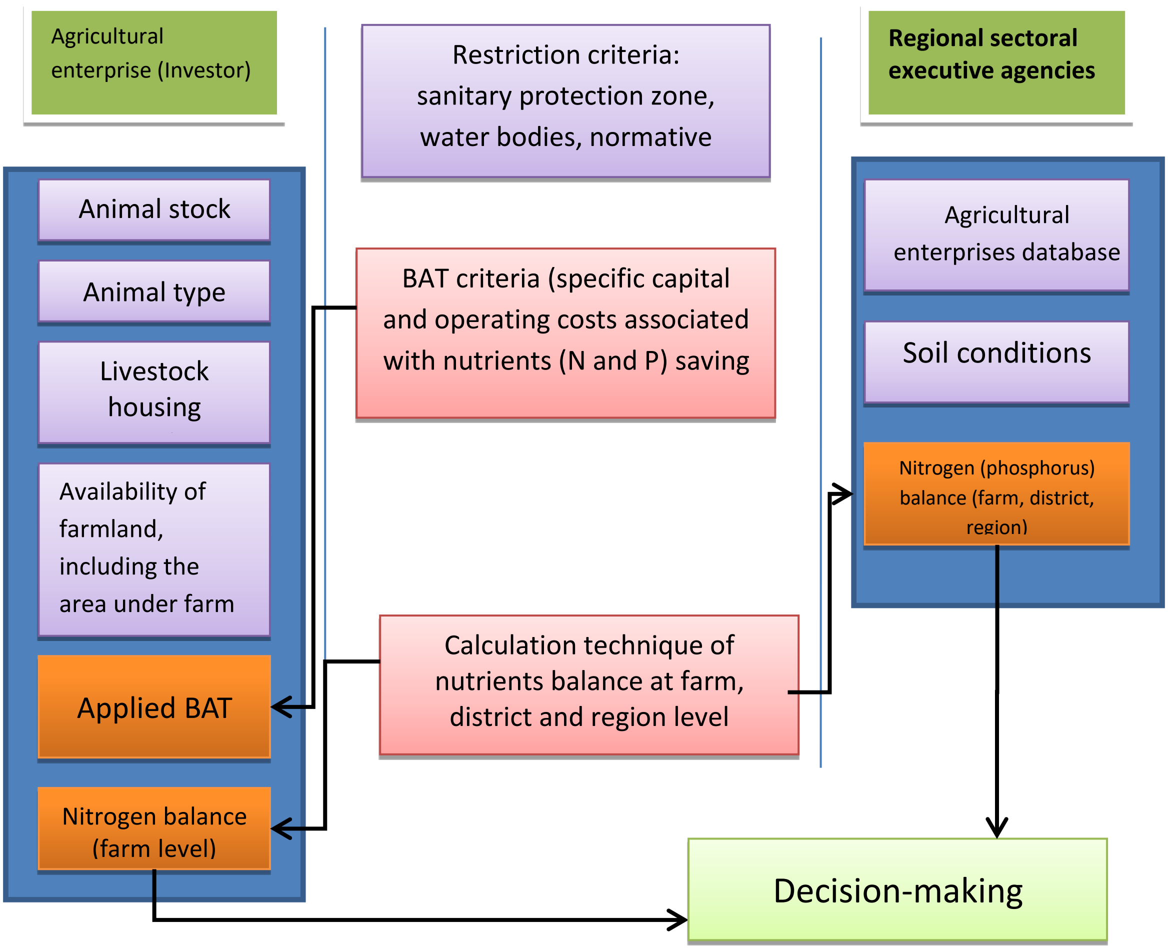


Fig.21. The block scheme of decision-making concerning the environmentally sound location and operation of animal/poultry farms

The offered scheme describes the interaction between the two stakeholders: an agricultural enterprise (investor) and the government agency, responsible for the agriculture development, in the following sequence:

1. Specification of farm profile and production capacity (the initial data source is the agricultural enterprise).

2. Choice and study of the site for construction (the initial data source is the agricultural enterprise and the government agency)

3. Detailed consideration of space-and-layout design and technical and technological options (the initial data source is the agricultural enterprise).

4. Checking the compliance with the restriction criteria, such as sanitary protection zone, water bodies, normative standards, etc. (the initial data source is the agricultural enterprise and the government agency)

5. Comparison of nutrients (N, P) balance in the designed/operating enterprise and N and P balance in the district selected for the new farm/operating farm location (the initial data source is the agricultural enterprise and the government agency)

6. Decision-making concerning the new farm location or production expansion. In case the N and/or P surplus is found in the designed/operating enterprise and if it is not economically viable at the district(s) level, the results of actions 1, 2, and 3 need to be revised.

#### 3.2.4.1 Organic and mineral fertiliser monitoring and management scheme

To monitor the production, processing and use of animal/poultry manure as an organic fertiliser, a database of agricultural enterprises needs to be created including the following indicators: amount of animal/poultry manure produced, N and P content in it, the area of agricultural land available for organic fertiliser application, amount of organic fertilisers used. For the meaningful monitoring and management, the executive authorities responsible for the agricultural sector have to be fully advised of these indicators. Potential suppliers and consumers of organic fertilizers are identified at district level.

Such a database was created during the survey of agricultural enterprises (livestock, poultry and crop farms). All information is in the Committee on Agro-Industrial Complex and Fishery of Leningrad Region. Our task is to create an algorithm for the effective work with this data.

Based on the created database of agricultural enterprises in Leningrad Region with the information on suppliers and consumers of organic fertilisers, an interactive tool for organic fertiliser management is being developed. The main purpose of the designed model of organic fertilisers transportation and distribution is to obtain an optimal logistic scheme for the distribution of organic fertilisers on the targeted territory with due account for the fertiliser nitrogen content and nitrogen requirements on individual agricultural enterprises.

The outcomes of many years of research conducted at IEEP as a part of state assignments and international projects implementation showed that the logistic model should take into account the following factors:

- the type and moisture content of produced organic fertiliser (solid, liquid);

- nutrient content (NPK) in the resulting organic fertiliser;

- requirements of agricultural land in solid and liquid organic fertilisers, taking into account the applied crop rotation and cultivated crops;

- agrochemical characteristics of agricultural land;

- targeted yields from the agricultural lands to be fertilised.

With these factors in mind, the preparation of scientifically grounded proposals on the logistics of using the organic fertilisers in the districts and the creation of an automated logistics system will improve the environmental safety of livestock / poultry complexes owing to:

- the solution of the logistic problem of decreasing the nutrient load on environment in the districts of Leningrad Region, where the agricultural land is not enough for application of all organic fertilisers produced;

- optimal choice of machines and equipment for transportation and application of organic fertilisers;

- calculation of the required machines and equipment and their load factor, depending on applied technological solutions.

Considering that many livestock and poultry complexes have their own land for produced organic fertiliser application, in the problem to be solved, the mass of total nitrogen in the obtained organic fertiliser was recalculated based on available agricultural land area.

An economic and mathematical model of the transport problem was applied. It was characterised by two groups of basic restrictions: the availability of production resources or the volume of capacities and the use of these resources or the satisfaction of resource demands. The target values were the volumes of resources on each livestock complex, which addressed the demands of each consumer.

The structured economic and mathematical model of the transport problem may be presented as follows:

$$z = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij} \rightarrow max\ (min); \qquad (6)$$

Under conditions:

$$\sum_{j=1}^{n} X_{ij} = A_i\ (i = 1,2, \dots, m); \qquad (7)$$

$$\sum_{i=1}^{m} X_{ij} = B_j\ (j = 1,2, \dots, n); \qquad (8)$$

$$\sum_{i=1}^{m} A_i = \sum_{j=1}^{n} B_j\ ; \qquad (9)$$

$$X_{ij} \leq D_{ij}\ (or\ with\ \geq, =) \qquad (10)$$

$$X_{ij} \geq 0, \qquad (11)$$

where

$m$ is the number of organic fertiliser suppliers;

$n$ is the number of organic fertiliser consumers;

$A_i$ is the mass of produced organic fertiliser in the $i$-th supplying complex;

$B_j$ is the mass of consumed organic fertiliser by the $j$-th consuming complex;

$C_{ij}$ is the distance, adjusted by the correction factor, taking into account the fertiliser nutrient content, from the $i$-th supplying complex to the $j$-th consuming complex;

$X_{ij}$ is the mass of organic fertiliser delivered from each supplier to each consumer.

$D_{ij}$ – volumes of additional restrictions.

To solve the problem of transportation and use of organic fertilizer with due account for the fertiliser nutrient content, the results of sample analysis from more than 70 agricultural enterprises in Leningrad Region  obtained at the institute laboratory during the previous research in 2014-2019 were used [30].

The total nitrogen content in the poultry manure-based fertiliser was found to be 7 kg/m3; in cattle manure-based fertiliser – 4.8 kg/m3; and in pig manure-based fertiliser – 2.4 kg/m3.

When creating the economic and mathematical model, the attention is paid to the dimension of all quantities included in it. All the row and column restrictions should have a single dimension. The variables should also have the same units of measure, and the coefficients of the objective function should be commensurate with its variables.

The scheme of the transport problem solution by the example of agricultural enterprises in Leningrad Region is shown on Fig. 22. Values on the map show nitrogen mass in transported organic fertilisers.

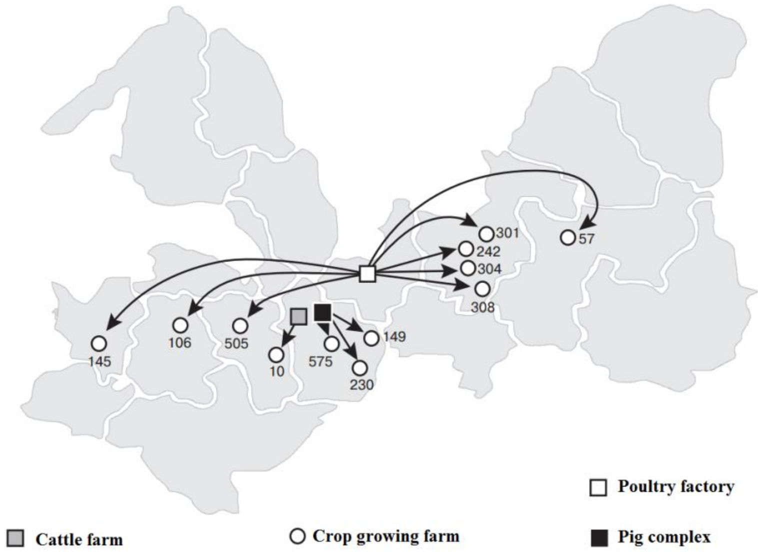


Fig. 22 - Visualisation of the transport problem solution by the example of agricultural enterprises in Leningrad Region

As a result, the user of this tool receives the recommendations on the distribution of organic fertilisers: logistics of transportation, the mass of transported organic fertilisers, transportation and organic fertiliser application technology.

There are some examples of private cooperation between the livestock and crop growing enterprises. Our task in the framework of the project is to make their interaction systemic and regulated under the assistance of the Committee on Agro-Industrial Complex and Fishery of Leningrad Region and the financial support. The coordinated systemic work is required.

#### 3.2.4.2 Environmental and economic criteria for substantiation of animal/poultry manure processing and application as an organic fertiliser

The environmental and economic feasibility of animal/poultry manure processing and application as an organic fertiliser is assessed by such indicators as specific capital costs, specific operating costs, the eco-economic effect (benefits) from organic fertilisers use and the cost-effective transportation distance of organic fertilisers.

The cost-effective transportation distance meets the condition that the received additional (net) profit (eco-economic effect from organic fertilizers use) exceeds the manure processing and fertiliser transportation costs.

The net profit from the organic fertiliser use is determined as the extra crop yield cost minus related harvesting costs.

The economic efficiency of organic fertilisers use is limited by the cost-effective transportation distance to the application place. Transportation to a longer distance results in higher operating costs, in the negative economic effect from the organic fertiliser use, and, ultimately, in the increase in the final product cost. Survey of agricultural enterprises shows that the actual transportation distance of organic fertilisers in most cases exceeds the cost-effective one on all categories of farms (cattle and pig farms, and poultry factories). Consequently, animal/poultry manure processing and application as an organic fertiliser becomes non-profitable.

The main eco-economic effect from the use of organic fertilisers produced from animal/poultry manure is the improved quality indicators of farmland soils and crop yields. Therefore, it is necessary to consider the possibility of green-box farm subsidies related to the reimbursement of part of the costs associated with the package of agro-technological work, improving the environmental compliance of agricultural production and soil fertility and quality.

Livestock/poultry enterprises, which do not have enough land for organic fertiliser application, can sell the organic fertilisers in accordance with the State Standard GOST R 53117-2008 “Organic fertilisers based on farm animal waste. Specifications”, to crop-growing farms, thereby offsetting a part of the animal/poultry manure processing costs. It is advisable to fix the minimum price of one ton of organic fertilizers.

It was noted that the fertilizers used must comply with GOST R 53117-2008. This compliance is achieved by observing strictly the processing technology and conducting the on-farm environmental monitoring and control. For these purposes, the relevant Technological Regulations are to be introduced on all large-scale agricultural enterprises.

**3.2.4.3. Use of geographic information system**

Geographic information systems can be a visualization element of the developed systems. A database may be created on their basis with the persistence layers with the information about the agricultural enterprise, the soil cover and relief of the adjacent territory, the water bodies and the road network. For the most part, the data will be entered manually. The missing information is planned to be obtained through communication with the enterprise, as well as from open sources.

The information about the enterprise should include the following layers:

- location of animal houses;
- location of manure storages / processing sites;
- data on the agricultural land (location, actual use, cultivated crops, their target yields and previous yields, and the results of agrochemical surveys);
- application of mineral and organic fertilisers on each field (agrochemical contour).

The information layer on the soil cover should include:

- location of soil phases in the territory with the obligatory indication of the particle size distribution, thickness of the arable (humus) horizon, soil-forming and underlying rocks.

**Conclusions**

As part of Work Package 1, the status of agricultural enterprises in Leningrad Region was reviewed in terms of their environmental performance and proposals were prepared to improve the environmental compliance of agricultural production.

To achieve the aim of Work Package 1 – to identify the main environmental challenges of agriculture production in Leningrad Region and to elaborate the strategy to address them, at the first stage, a scientific and expert analysis of the ecological status of livestock enterprises in Leningrad Region was performed. For this purpose, questionnaires were elaborated and circulated to collect the initial data; the field trips were organized for the surveys of individual enterprises, and the satellite images of agricultural territories of Leningrad Region were studied. This way, the environmental information was collected, the analysis of which allowed to identify the possible risks of the negative environmental impact from agricultural enterprises in Leningrad region. The most significant of them are:

- ecological risks associated with intensification of production and increased nutrient load on the environment. Exceeding the safe range of farm animal density of 1.5 - 1.7 LSU/ha and production of more organic fertilisers in the districts than may be applied on the available agricultural land, leads to the risk of their accumulation and a significant increase in the application rate that, in turn, causes the nutrients surplus in the soil. Storing of non-applied organic fertilisers can lead to air pollution and higher diffuse loading on water sources due to the nutrients leaching with the storm runoffs;

- ecological risks associated with the diffuse loading. An increase in the diffuse load can lead to the risk of leaching and migration of nutrients from the fields located in the catchment area of the water bodies;

- insufficient capacity of manure storage facilities to accumulate all the animal/poultry manure produced and the lack of well-established logistics for the distribution of organic fertilisers between the livestock/poultry complexes and agricultural land of other farms increases the risk of organic fertilisers being applied on the fields in winter.

The following closely linked actions may contribute to reducing the risks of negative environmental impact from agricultural enterprises:

1) Development and control over the fulfilment of recommendations on the introduction of the on-farm environmental monitoring and control system over the production processes. This system implies the approval and observance of local regulatory acts, such as Technological Regulations. Technological Regulations are the main tool in establishing the on-farm system of animal/poultry manure handling, which should be taken into consideration under transition to BAT system.

2) Development of recommendations on the introduction of the regional system for monitoring and coordination of organic and mineral fertilisers production and application. These recommendations can be used by the authorities to assess the environmental situation, to establish relationships between agricultural enterprises regarding the effective use of organic fertilisers when forecasting the development and operation of agricultural production.

3) Creation of a demonstration site at the pilot farm with modern and BAT complying technological solutions of organic waste management. The demonstration site will launch a working facility, where the specialists of all agricultural enterprises can be trained to improve their environmental literacy and to further introduce the state-of-the-art technological solutions.

**References**

1. Performance assessment of the agro-industrial complex of Leningrad region. Available at: old.agroprom.lenobl.ru/Files/file/6_17_04_2017_leningradskaya_oblast_doklad_chekmareva_p_a__(pravlennui)_(1).pdf

2. Convention on the protection of the marine environment of the Baltic sea area, 1992 (Helsinki Convention). Available at: www.helcom.fi/documents/about%20us/convention%20and%20commitments/helsinki%20convention/1992_convention_1108.pdf

3. Measures aimed at the reduction of emissions and discharges from agriculture. HELCOM recommendation 24/3. Adopted 25 June 2003 having regard to Article 20, Paragraph 1 b) of the Helsinki Convention www.helcom.fi/Recommendations/Rec%2024-3.pdf

4. Stocking Rates of Land Capability for Agriculture Classes https://www.hutton.ac.uk/sites/default/files/files/ladss/Stocking-Rates-LCA.pdf

5. Climate Change and Agricultural Development: Adapting Polish Agriculture to Reduce Future Nutrient Loads in a Coastal Watershed https://link.springer.com/article/10.1007/s13280-013-0461-z

6. Briukhanov A., Alexeev L., Oblomkova N., Subbotin I. Results of field studies on nitrogen and phosphorus input from agricultural production to selected water bodies in western Dvina. Proceedings of 17th International Scientific Conference "Engineering for Rural Development". 2018. pp. 285-291.

7. Maximov D.A., Briukhanov A.Y. Strategy of environmental load reduction under intensification of agricultural production. *Tekhnologii i tekhnicheskie sredstva mekhanizirovannogo proizvodstva produkcii rastenievodstva i zhivotnovodstva*. [Technologies, machines and equipment for mechanised crop and livestock production].2013.No. 84. pp 207-212. (In Russian)

8. Uvarov R.A. Survey of cattle manure bioconversion technologies most adapted to the conditions of North-West Russia. *Innovatsii v sel'skom khozyaistve* [Innovations in Agriculture]. 2015. No.2(12). pp 207-212 (In Russian)

9. Decree of the Ministry of Industry and Trade of the Russian Federation No.3134 of 23 August 2019 "On approval of the Methodological recommendations for identifying a technology as the best available technology". Available at: http://docs.cntd.ru/document/420295635 , accessed 09.09.2019

10. Eskov A.I., Novikov M.N. et al. Spravochnaya kniga po proizvodstvu I primeneniyu organicheskikh udobrenii [Reference book on the production and use of organic fertilizers].Vladimir: VNIPTIOU. 2001. 495 p. (In Russian)

11. Arkhipchenko I.A., Rulkens V. Mikrobnye udobreniya dlya zemledeliya I uluchsheniya okruzhayushchei sredy [Microbial fertilizers for arable farming and improving the environment]. *Ekologiya I promyshlennost' Rossii* [Ecology and industry of Russia]. 2006. No 3. pp 4-7. (In Russian)

12. Orlova O.V., Afanasev V.N., Arkhipchenko I.A. Tekhnologiya proizvodstva effektivnykh bioudobrenii iz ptich'ego pometa s pomoshch'yu mikrobnykh inokulyumov [The technology for the production of effective biological fertilizers from poultry manure using microbial inoculums]. *Ekologiya I promyshlennost' Rossii* [Ecology and industry of Russia]. 2009. No. 11 pp 6-13. (In Russian)

13. Eskov A.I., Lukin S.M., Anisimova T.Yu. et al. Resursy organicheskikh udobrenii v sel'skom khozyaistve Rossii [Organic Fertilizer Resources in Russian Agriculture]. Information and analytical reference book. Vladimir: VNIPTIOU.2006. 213 p. (In Russian)

14. PetrovaV.I., KonovalovS.N., ArkhipchenkoI.A. Effektivnost' bioorganicheskogo udobreniya omug v sadu yabloni [Efficiency of OMUG fertilizer in the apple orchard]. *Plodovodstvo I yagodovodstvo Rossii* [Pomiculture and Small Fruit Culture in Russia]. 2014. vol. XXXVIII. No. 2. pp 34-40. (In Russian)

15. Briukhanov A.Yu., Maximov D.A, Huhta Harri, Vasiliev E.V., Minin V.B., Subbotin I.A., Recommendations on arrangement of full-scale ecological monitoring and control of animal and poultry manure processing and application systems. The order of development of Technological Regulations. (Ed. Briukhanov A.Yu.). Saint Petersburg: SZNIIMESH Publishers. 2012. 56 p.

16. Management Directive for Agro-Industrial Complex 1.10.15.02-17.Recommended Practice for Engineering Designing of Systems for Animal and Poultry Manure Removal and Pre-application Treatment. Moscow: Rosinformagrotekh, 2017. 173 p. (In Russian)

17. State Standard GOST R 53117-2008 “Organic fertilisers based on farm animal waste. Specifications”. 2010. 15 p. (In Russian)

18. Order of the Ministry of Natural Resources of the Russian Federation No 721 of 01.09.2011. Available at: http://www.consultant.ru/document/cons_doc_LAW_120572/ (In Russian)

19. State Standard GOST 26074-84. “Liquid manure. Veterinary and sanitary requirements for treatment, storage, transportation and utilization”. Available at: http://docs.cntd.ru/document/gost-26074-84 (In Russian)

20. Technological designing standards of irrigation systems which use the livestock waste water” 1.30.02-01-06. Available at: http://docs.cntd.ru/document/1200065582 (In Russian)

21. State Standard GOST 12.1.007-76 “Occupational safety standards system. Noxious substances. Classification and general safety requirements”. Available at: http://docs.cntd.ru/document/5200233 (In Russian)

22. State Standard GOST 12.2.002-91 “Occupational safety standards system. Agricultural machinery. Methods of safety evaluation”. Available at: http://docs.cntd.ru/document/1200018537 (In Russian)

23. State Standard GOST 12.3.020-80 "Occupational safety standards system. Transporting process of loads in all fields of national economy. General safety requirements". Available at: http://docs.cntd.ru/document/1200000300 (In Russian)

24. Sanitary Regulations and Standards 2.1.7.1287-03. "Sanitary and epidemiological requirements for soil quality" (with amendments of 25 April 2007). Available at: http://docs.cntd.ru/document/901859456 (In Russian)

25. Sanitary Regulations and Standards 1.2.1330-03 "Hygienic requirements for the production of pesticides and agrochemicals". Available at: http://docs.cntd.ru/document/901865555 (In Russian)

26. Sanitary Regulations and Standards 2.1.6.1032-01. "Sanitary Requirements to Quality Assurance of Community Air". Approved by Chief Sanitary Officer of the Russian Federation on 17 May, 2001. Available at: http://docs.cntd.ru/document/901787814 (In Russian)

27. Sanitary Regulations and Standards 1.2.2584-10 Hygienic requirements for the safety of testing, storage, transportation, sale, use, disinfection and disposal of pesticides and agrochemicals (with amendments of 10 June 2016). Available at: http://docs.cntd.ru/document/902204851 (In Russian)

28. Hygienic standards 2.1.7.2041-2006 Maximum permissible concentration (MPC) of chemicals in the soil. Available at: http://docs.cntd.ru/document/901966754 (In Russian)

29. Hygienic standards 2.1.7.2511-09. Approximate permissible concentrations of chemicals in soil. Available at: http://docs.cntd.ru/document/902163355 (In Russian)

30. Briukhanov A.Y., Vasilev E.V., Shalavina E.V., Kucheruk O.N. Engineering Solutions of Environmental Problems in Organic Waste Handling. *IOP Conference Series: Earth and Environmental Science.* Available at: http://iopscience.iop.org/article/10.1088/1755-1315/87/4/042001/pdf.

31. Sukhanov P.A. Scientific basis for the assessment and management of the agro-resource potential of the region (on the example of the Leningrad Region). DSc (Engineering) Thesis. Saint Petersburg. 2013. Available at: www.agrophys.ru/Media/Default/Page/Dissertation%20board/Avtoreferat_SukhanovPA.pdf (In Russian)

32. Construction systems. Available at: https://pvh-membrannaya-krovlya.ru/laguny-i-navozohranilishha/ (In Russian)

33. Bittman, S., Dedina, M., Howard C.M., Oenema, O., Sutton, M.A., (eds), 2014, Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen, Centre for Ecology and Hydrology, Edinburgh, UK. Available at: http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/AGD_final_file.pdf